ipcc

INTERGOVERNMENTAL PANEL ON climate change

Chapter 2

Bioenergy

Chapter:	2				
Title:	Bioenergy				
(Sub)Section:	All				
Author(s):	CLAs:	Faaij, P.C. Andre; Moreira, Jose Roberto			
	LAs:	Berndes, Göran; Dhamija, Parveen; Dong, Hongmin; Gabrielle, Benoît X; Goss Eng, Alison M; Lucht, Wolfgang; Mapako, Maxwell; Masera Cerutti, Omar; McIntyre, Terry Charles; Minowa, Tomoaki; Pingoud, Kim			
	CAs:	Chum, Helena; Yang, Joyce C.			
Remarks:	First Order Draft				
Version:	01				
File name:	SRREN_Draft1_Ch02.doc				
Date:	22-Dec-09 19:30	Time-zone:	CET	Template Version:	13

COMMENTS ON TEXT BY TSU TO REVIEWER

Yellow highlighted – original chapter text to which comments are referenced

Turquoise highlighted – inserted comment text from Authors or TSU i.e. [AUTHORS/TSU: ….]

Chapter 02 has been allocated a total of 102 pages in the SRREN. The actual chapter length (excluding references & cover page) is 107 pages: a total of 5 pages over target.

Expert reviewers are kindly asked to indicate where the Chapter could be shortened in terms of text and/or figures and tables.

In addition, all monetary values provided in this document will need to be adjusted for inflation/deflation and then converted to USD for the base year 2005. For conversion tables see http://www.ipcc-wg3.de/internal/srren/fod

Chapter 2: Bioenergy

CONTENTS

EXECUTIVE SUMMARY

Bioenergy today

Chapter 2 discusses biomass, a primary source of fiber, food, fodder and energy. Since the dawn of society Biomass is the most important renewable energy source, providing about 10% (46 EJ) of the annual global primary energy demand. A major part of this biomass use (37 EJ) is non-commercial and relates to charcoal, wood and manure used for cooking and space heating, generally by the poorer part of the population in developing countries. Modern bioenergy use (for industry, power generation, or transport fuels) is making already a significant contribution of 9 EJ, and this share is growing.

Currently, modern bioenergy chains involve a wide range of feedstocks, conversion processes and end-uses. Feedstock types include dedicated crops or trees, residues from agriculture and forestry and related transformation industries, and various organic waste streams. Their economics and yields vary widely across world regions and feedstock type/conversion processes, with costs ranging from 5 to 80 US$/GJ biofuels, from 5 to 20 US$/GJ for electricity, and from 1 to 5 US$/GJ for heat from solid fuels or waste.There are several important bioenergy systems today, most notably sugar cane based ethanol production and heat and power generation from residual and waste biomass that can be deployed competitively. Depending on energy prices and specific market conditions, also smaller scale applications (for power heat and biofuels) can compete, such as jathropha oil production in rural settings.

Future potential

The expected deployment of biomass for energy on medium to longer term differs considerably between various studies. Large scale biomass deployment is largely conditional: deployment will strongly depend on sustainable development of the resource base and governance of land-use, development of infrastructure and on cost reduction of key technologies. Based on the current state-of-the-art analyses, the upper bound of the biomass resource potential halfway this century can amount over 400 EJ. This could be roughly in line with the conditions sketched in the IPCC SRES A1 and B1 storylines, assuming sustainability and policy frameworks to secure good governance of land-use and improvements in agricultural and livestock management are secured.

If the right policy frameworks are not introduced, further expansion of biomass use can lead to significant conflicts in different regions with respect to food supplies, water resources and biodiversity. The supply potential may then be constrained to a share of the biomass residues and organic wastes, some cultivation of bioenergy crops on marginal and degraded lands and some regions where biomass is evidently a cheaper energy supply option compared to the main reference options (which is the case for sugar cane based ethanol production). Biomass supplies may then remain limited to an estimated 100 EJ in 2050.

Impacts

Bioenergy production interacts in complex ways with society and the environment, including feedbacks among climate change, biomass production and land use. The impacts of bioenergy on social and environmental issues – ranging from health and poverty to biodiversity and water quality – may be positive or negative depending upon local conditions, how criteria and how actual projects are designed and implemented. Many conflicts can also be avoided and synergies with better management of natural resources (e.g. soil carbon enhancement and restoration, water retention functions) and contributing to rural development are possible. Optimal use and performance of biomass production and use is regionally specific. Policies therefore need to take regionally specific conditions into account and need to incorporate the agricultural and livestock sector as part of good governance of land-use and rural development interlinked with developing bioenergy.

Future options and cost trends

There is clear evidence that further improvements in power generation technologies, supply systems of biomass and production of perennial cropping systems can bring the costs of power (and heat) generation from biomass down to attractive cost levels in many regions, especially when competing with natural gas. In case carbon taxes of some 20-30 U$/tonne would be deployed (or when CCS would be deployed), biomass can also be competitive with coal based power generation.

There is clear evidence that technological learning and related cost reductions do occur with comparable progress ratio's as for other renewable energy technologies. This is true for cropping systems (following progress in agricultural management when annual crops are concerned), supply systems and logistics (as clearly observed in Scandinavia, as well as international logistics) and in conversion (ethanol production, power generation, biogas and biodiesel).

With respect to second generation biofuels, recent analyses have indicated that the improvement potential is large enough to make them compete with oil prices of 60-70 U$/barrel. Currently available scenario analyses indicate that if R&D and market support on shorter term is strong, technological progress could allow for this around 2020.

Several short term options can deliver and provide important synergy with longer term options, such as co-firing, CHP and heat production and sugar cane based ethanol production. Development of working bioenergy markets and facilitation of international bioenergy trade is another important facilitating factor to achieve such synergies.

Data availability is limited for production of biomaterials and biochemicals, bio-CCS concepts and algae. Recent scenario analyses indicate that advanced biomaterials (and cascaded use of biomass) as well as bio-CCS may become very attractive mitigation options on medium term. Algae may have a potential to produce liquid or gaseous fuels with minimal land-use, but their deployment is uncertain and may not be significant before 2030

GHG & Climate change impacts

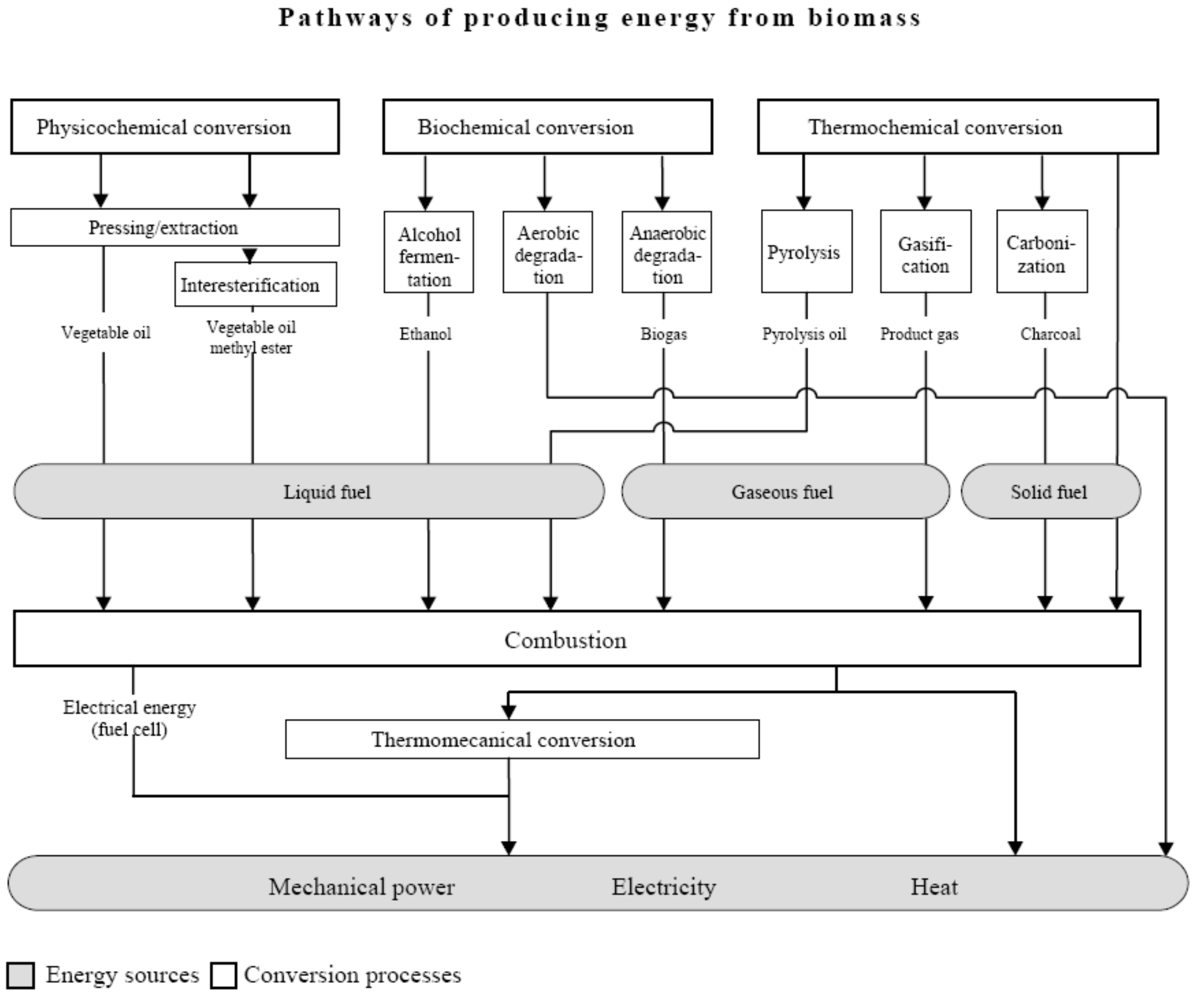
Bioenergy at large has a significant GHG mitigation potential, provided resources are developed sustainably and provided the right bioenergy systems are applied. Perennial cropping systems and biomass residues and wastes are in particular able to deliver good GHG performance in the range of 80-90% GHG reduction compared to the fossil energy baseline.

Biomass potentials are influenced by and interact with climate change impacts but the detailed impacts are still poorly understood; there will be strong regional differences in this respect. Climate change impacts on bioenergy feedstocks production are real but do not pose serious constraints if temperature raise is limited to 2°C. Bioenergy and new (perennial) cropping systems also offer opportunities to combine adaptation measures (e.g. soil protection, water retention and modernization of agriculture) with production of biomass resources.

The recently and rapidly changed policy context in many countries, in particular the development of sustainability criteria and frameworks and the support for advanced biorefinery and second generation biofuel options does drive bioenergy to more sustainable directions. There is consensus on the critical importance of biomass management in global carbon cycles, and on the need for reliable and detailed data and scientific approaches to facilitate more sustainable land use in all sectors.

2.1 Introduction Current Pattern of Bioenergy Use and Trends

Biomass continues to be the world's major source of food, fodder and fibre as well as a renewable resource of hydrocarbons for use as a source of heat, electricity, liquid fuels and chemicals. Biomass sources include forest, agricultural and livestock residues, short-rotation forest plantations, dedicated herbaceous energy crops, the organic component of municipal solid waste (MSW), and other organic waste streams. These are used as feedstocks, which through a variety of chemical and physical process, produce energy carriers in the form of solid fuels (chips, pellets, briquettes, logs), liquid fuels (methanol, ethanol, butanol, biodiesel), and gaseous fuels (synthesis gas, biogas, hydrogen). These fuels can then be used to produce mechanical power, electricity and heat as shown in Figure 2.1.1.



SRU/SG 2007-2/Fig. 2-2; data source: KALTSCHMITT and HARTMANN 2001

Figure 2.1.1: Pathways of producing energy from biomass TSU: improve readability of graph

Sustainably produced and managed, bioenergy can provide a substantial contribution to climate change mitigation and at the same time provide large co-benefits in terms of local employment and regional economic development. Bioenergy options may help increase biospheric carbon stocks (for example through plantations on degraded lands), or reduce carbon emissions from unsustainable forest use (for instance through the dissemination of more efficient cookstoves). Additionally, bioenergy systems may reduce emissions from fossil fuel-based systems by replacing them in the generation of heat and power (for example by gasifying biomass in CHP TSU: definition missing systems), or in the provision of liquid biofuels such as ethanol instead of gasoline. Advanced bioenergy systems and end-use technologies, can also substantially reduce the emission of black carbon and other short-lived GHGs such as methane and carbon monoxide, which are related to the burning of biomass in traditional open fires and kilns. Not properly designed or implemented, the large-scale expansion of bioenergy systems is likely to also have negative consequences for climate and sustainability such as inducing direct and indirect land use changes that can alter surface albedo, release carbon from soils and vegetation or negatively impact local populations in terms of land tenure or reduced food security. In all these cases a life-cycle analysis must be conducted to assure that the net effect of bioenergy options is positive.

According to available IEA energy statistics, bioenergy provides about 10 percent of the world's current total primary energy supply (47.2 EJ of bioenergy out of a total of 479 EJ in 2005, i.e. 9.85 percent) (IEA-ETE, 2007a). Most of this is for use in the residential sector (for heating and cooking) and is produced locally. In 2005 bioenergy represented 78 percent of all global renewable energy produced. A full 97 percent of biofuels are made of solid biomass, 71 percent of which is used in the residential sector, as biomass provides fuel for the cooking needs of 2.4 billion people. Biomass is also used to generate gaseous and liquid fuels, and growth in demand for the latter has been significant over the last ten years (GBEP, 2008). Residues from industrialized farming, plantation forests, and food and fibre-processing operations that are currently collected worldwide and used in modern bioenergy conversion plants are difficult to quantify but probably supply approximately 6 EJ/yr. Current combustion of over 130 Mt of MSW TSU: definition missing provides more than 1 EJ/yr though this includes plastics, etc. Landfill gas also contributes to biomass supply at over 0.2 EJ/yr (IPCC, 2007).

Biomass can be used as a source of many forms of useful energy as is shown in Figure 2.1.1 but up to now provides a relatively small amount of the total primary energy supply (TPES) of the largest industrialized countries (grouped as G8 countries: United States, Canada, Germany, France, Japan, Italy, United Kingdom, and Russia) (1-4 percent). By contrast, bioenergy, mainly through the use of traditional forms (e.g. woodfuel and charcoal for cooking and heating) is a significant part of the energy supply in the largest developing countries representing from 5-27% of TPES (China, India, Mexico, Brazil, and South Africa) and more than 50% of TPES in the poorest countries. Worldwide, China with its 9000 PJ/yr is the largest user of biomass as a source of energy, followed by India (6000 PJ/yr), USA (2300 PJ/yr), and Brazil (2000 PJ/yr), while bioenergy's contribution in Canada, France and Germany is around 450 PJ/yr.

Global bioenergy use has been steadily growing worldwide in absolute terms in the last 40 years, with large differences among countries (see Fig 2.1.2 for the case of woodfuels). The bioenergy share in India, China and Mexico is decreasing, mostly as traditional biomass is substituted by kerosene and LPG within large cities, but consumption in absolute terms continues to grow. The latter is also true for most African countries, where demand has been driven by a steady increase in woodfuels, particularly in the use of charcoal in booming urban areas.

The use of solid biomass for electricity production is important, especially from pulp and paper plants and sugar mills. Bioenergy's share in total energy consumption is increasing in the G8 Countries through the use of modern forms (e.g. co-combustion for electricity generation, buildings heating with pellets) especially in Germany, Italy and the United Kingdom.

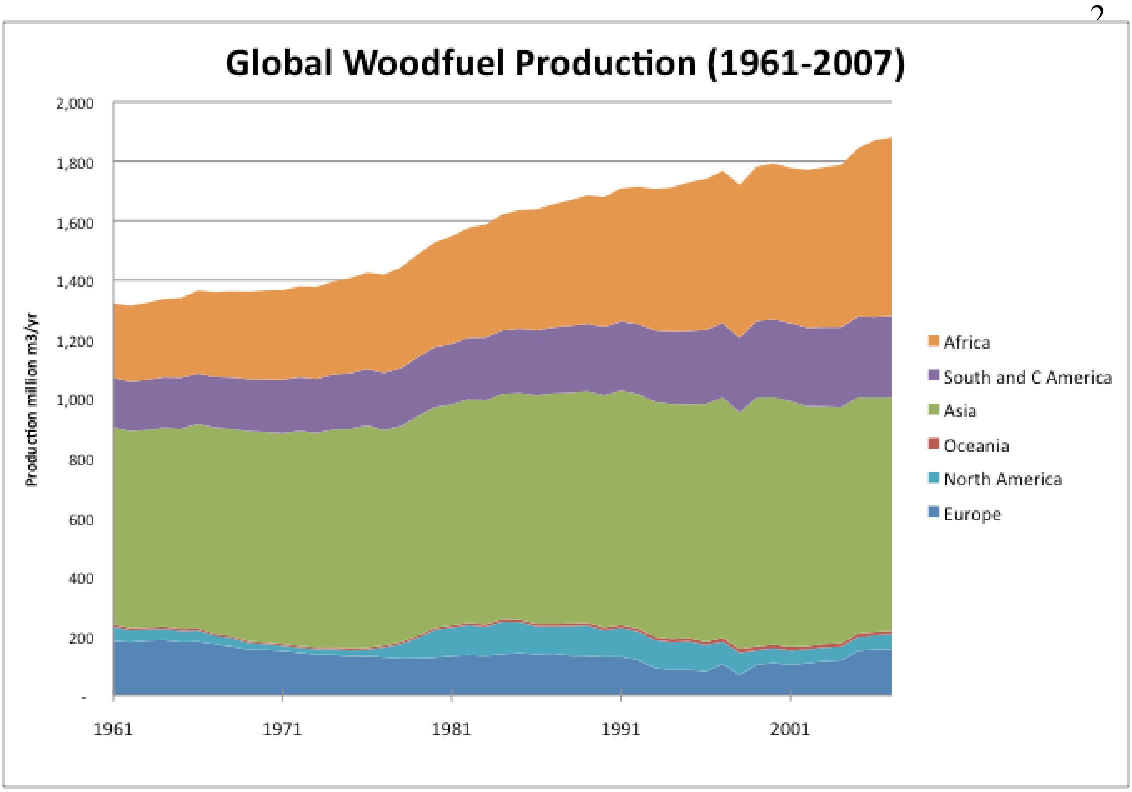


Figure 2.1.2. Global Fuelwood and Charcoal Production. Woody biomass is the main component of the solid biomass reported by IEA. According to the national statistics reported by FAO, in 2007 the total amount of wood used as fuelwood and for charcoal production reached 1,881 million m^3, 42% came from Asia, 32% from Africa, 15% from Latin America. The evolution of global fuelwood production in the period 1961-2007 is shown. World production increased from 1.3 billion m3/yr in1961 to 1.9 billion in 2007, which means an annual growth rate of 0.7%. It is interesting to note that outside of the periods with high oil prices (1977-82 and after 2004) the annual growth rates are smaller 0.3% in the period 1961-77 and 0.5% in the period 1984-2003. The bulk of fuelwood and charcoal demand is concentrated in developing countries, particularly within Africa and Asia. Their production has remained essentially constant in LA and Asia – with important differences among countries – while it has been growing significantly in Africa. Source: FAOSTAT, 2009.

While FAO statistics (Figure 2.1.2) represent an essential reference, they tend to underestimate woodfuel consumption. Until recent years biomass fuels were regarded as marginal products in both energy and forestry sectors (FAO, 2005a). In addition to such historical disregard, production and trade of biomass fuels are largely informal, thus excluded from the conventional sources of energy and forestry data. International forestry and energy data are the main reference sources for policy analyses but they are often in contradiction, when it comes to estimate biomass consumption for energy. Moreover, detailed analyses indicate quite firmly that national statistics systematically underestimate the consumption of woody biomass for energy (FAO, 2005b (Mexico); FAO, 2006a (Slovenia), FAO. 2007 (Italy), FAO, 2009a in press (Argentina), FAO, 2008a (Mozambique)).

2.1.1 Previous IPCC Assessments

Bioenergy has not been examined in detail in previous IPCC reports. In the most recent assessment (AR4) the analysis of GHG mitigation from bioenergy was scattered among 7 chapters making it difficult to obtain an integrated and cohesive picture of its potential, challenges and opportunities. The main conclusions from the AR4 report (IPCC, 2007) are as follows: i) the global sustainable potential for bioenergy was estimated at 250 EJ/yr (with a wide range on both sides); ii) The mitigation potential for electricity generation reaches 1,220 $MtCO_2$-eq for the year 2030, a substantial fraction of it at cost lower than 20 US$/t$CO_2$ TSU: use SI units, i.e.”t” not “tonne”!; iii) Within agriculture the report estimated an overall biomass supply for energy ranging from 22 EJ/yr in 2025 to more than 400 EJ/yr in 2050. From a top-down assessment estimate the economic mitigation potential of biomass energy supplied from agriculture to be 70–1260 MtCO_2-eq/yr at up to 20 US$/t CO_2-eq, and 560–2320 MtCO_2-eq/yr at up to 50 US$/t$CO_2$-eq. These potentials represent mitigation of 5–80% resp.20–90% of all other agricultural mitigation measures combined, at carbon prices of up to 20, and up to 50 US$/t$CO_2$-eq, respectively; iv) The energy potential for bioenergy coming from forest residues reaches 14-65 EJ/yr and the overall mitigation from the sector may reach 400 MtCO_2/yr up to 2030.

2.1.2 Structure of the chapter

Estimating the future mitigation potential of bioenergy presents unique analytical challenges in comparison to other renewable energy sources, given the multitude of existing and rapidly evolving bioenergy sources, complexities of physical, chemical, and biological conversion processes, variability in site specific environmental and socio-economic conditions and the many interlinkages between bioenergy and other land-based activities, such as food and fibre production, forest protection, and others, as well as particular political interests triggered by the rapid evolution in production and use of liquid biofuels.

In this chapter we seek to overcome these methodological and practical challenges by undertaking an integrated and comprehensive global review of the mitigation potential of bioenergy up to the year 2030. To reach this goal, we first examine the biomass resource potential, pointing out at the range of estimates from different sources as well as the opportunities and limitations from the potential competition for land, water and other resources. We then examine the main technology chains related to bioenergy production, from the feedstocks to the main end uses. Section 2.4 provides the global and regional status of market and industry development in bioenergy, while section 2.5 analyzes the environmental and socio-economic impacts of the current bioenergy systems. We pay particular attention to the recent developments in life-cycle analyses. Section 2.6 examines the emerging bioenergy technologies and integration systems. In section 2.7 we examine the cost trends for the major bioenergy systems and in section 2.8 we discuss the potential future deployment of bioenergy.

2.2 Resource Potential

2.2.1 Introduction

Different types of biomass can be used for energy:

- Primary residues from conventional food and fiber production in agriculture and forestry, such as cereal straw and logging residues;
- Secondary and tertiary residues in the form of organic food/ forest industry by-flows and retail/ post consumer waste;
- various plants produced for energy purposes including conventional food/feed/industrial crops, new types of agricultural plants and forest plants grown under varying rotation length.

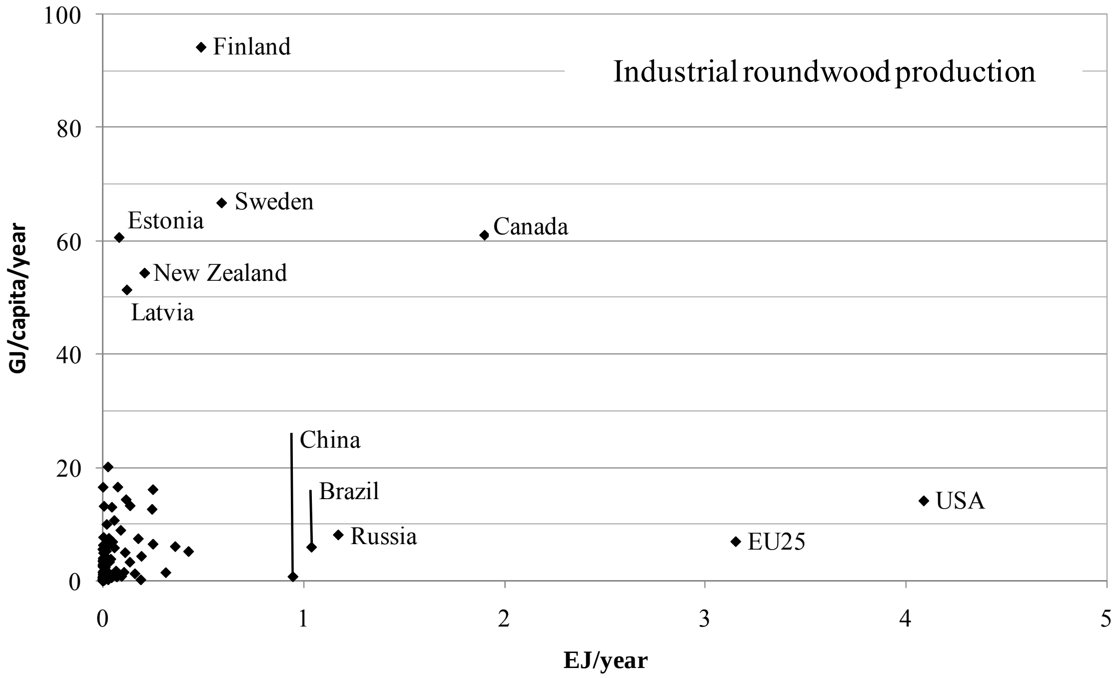
The quantification of current production of major crops and of industrial roundwood shown in Figure 2.2.1 offers a first perspective on the present human biomass production in relation to the size of the national and global energy systems. The present global industrial roundwood production amounts to 15-20 EJ (2-3 GJ/capita) of biomass per year and the global production of the major crops included in Figure 2.2.1 corresponds to about 60 EJ (10 GJ/capita) per year in total. For comparison, about 390 EJ (60 GJ/capita) of fossil fuels were commercially traded globally in 2005 (BP 2007).

The total biomass flows in agriculture and forestry – including also the flows considered to be potential bioenergy feedstocks – are substantially larger. Krausmann et al. (2008) estimate that residues make up 50-60% of the aboveground biomass on the world's cropland and that close to 40% of these residues are presently left on the fields after harvest. Wirsenius et al. (2004) estimate that the total global production of by-products and residues from the food and agriculture system (crop residues, manure, food industry residues, organic waste, etc.) amounted to about 140 EJ/yr in 1992/94. In forestry, felling losses are estimated to correspond to roughly one-third of the global wood removals, with substantially larger relative losses in tropical developing countries (Krausmann et al. 2008). In addition to this, large volumes of wood are cut during silvicultural thinning, which is an integrated part of forest management.

From this it can be concluded that:

- the present total global industrial forest biomass flow is much smaller than the present fossil fuel use. But a number of countries with large forest industries have significant per capita forest biomass flows and consequently have good prospects for making forest biomass an important part in the domestic energy supply (or export forest fuels to other countries);
- globally, agricultural biomass flows are larger than the forest sector flows and there are more countries than in the case of forestry that have a significant per capita production (e.g. above 20 GJ/capita/year). The agricultural biomass flows are rather limited compared to the energy system, but still in many countries residues could become a significant part of the energy supply.

This section focuses on the longer term biomass resource potential and how this has been estimated based on considering the Earth's biophysical resources and restrictions on their energetic use arising from competing requirements on these resources – including non-extractive requirements such as soil quality maintenance/improvement and biodiversity protection. More near term potentials are treated in Section 2.3 that discusses implementation potentials for bioenergy. The different bioenergy production systems are described in more detail in Section 2.3 and 2.6.



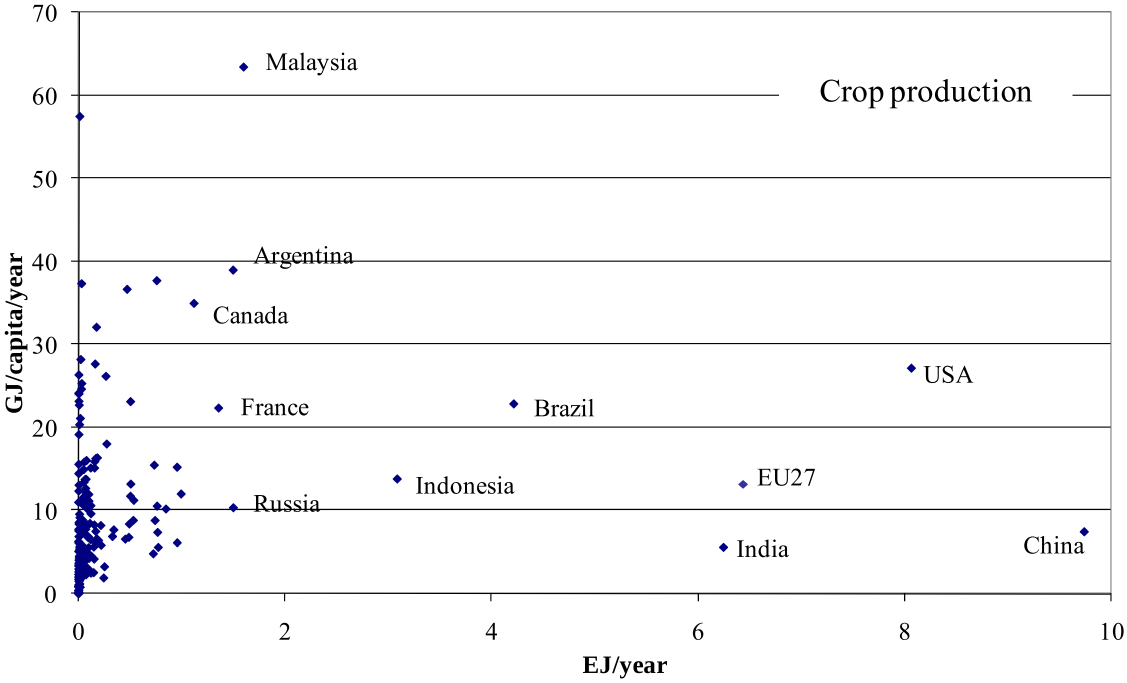


Figure 2.2.1. Production of major crop types (cereals, oil crops, sugar crops, roots & tubers and pulses) and industrial roundwood in the countries of the world: average for 2002-2006 (crops) and 2000-2003 (roundwood), converted to energy units. The figure shows the dominant crop and industrial wood producers in the world and the production per capita in different countries. Based on data provided by the UN Food and Agriculture Organization, FAO (FAOSTAT, 2008). Note that the two diagrams have different scales.

The biomass resource potential depends on the priority of bioenergy products vs. other products obtained from land – notably food and conventional forest products such as sawnwood and paper – and on how much biomass can be mobilized in total in agriculture and forestry. This in turn depends on natural conditions (climate, soils, topography) and on agronomic and forestry practices to produce the biomass, but also on how society understands and prioritizes nature conservation and soil/water/biodiversity protection and in turn how the production systems are shaped to reflect these priorities (Figure 2.2.2). Socio-economic conditions also influence the bioenergy potential by defining how – and how much – biomass can be produced without causing unacceptable socio-economic impacts. Socio-economic restrictions vary around the world, change as society develops, and – once again – depends on how societies prioritize bioenergy in relation to specific more or less compatible socio-economic objectives (see also Section 2.5 and Section 2.8).

Bioenergy production interacts with food and forestry production in complex ways. It can compete for land, water and other production factors but can also strengthen conventional food and forestry production by offering new markets for biomass flows that earlier were considered as waste products. Bioenergy demand can provide opportunities for cultivating new types of crops and integrate bioenergy production with food and forestry production in ways that improves the overall resource management, but it can also lead to overexploitation and degradation of resources, e.g., too extensive TSU: did you mean “intensive”? biomass extraction from the lands leading to soil degradation, or water diversion to energy plantations that impacts downstream water uses including for terrestrial and aquatic ecosystem maintenance.

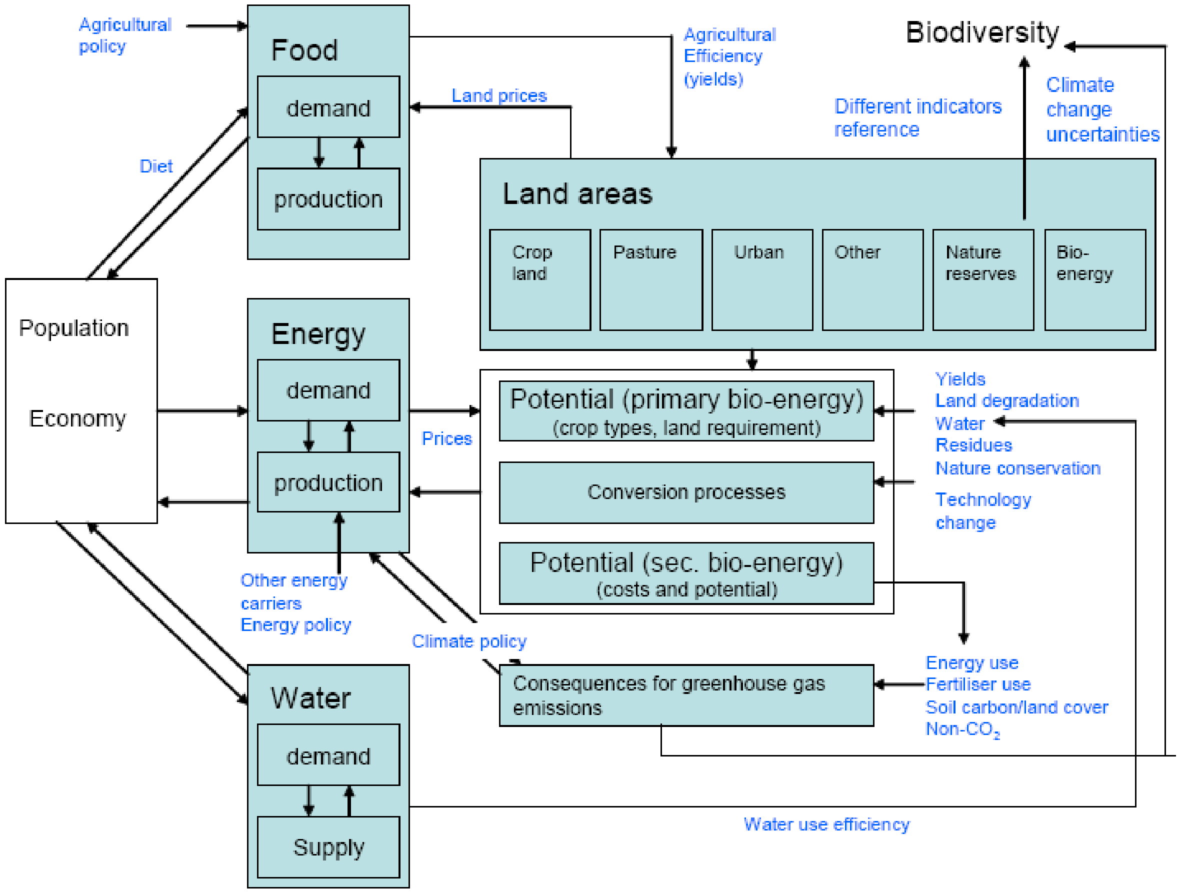


Figure 2.2.2. Overview of key relationships relevant to assessment of bioenergy potentials (Dornburg et al., 2008). Indirect land use issues and social issues are not displayed.

Studies quantifying the biomass resource potential have in various ways assessed the resource base while considering the influence of natural conditions (and how these can change in the future), socio-economic factors, the character and development of agriculture and forestry, and restrictions connected to nature conservation and soil/water/biodiversity preservation. A review of 17 available studies of future biomass availability carried out in 2002 revealed that no complete integrated assessment and scenario studies were available by then TSU suggests: “at that time” (Berndes et al., 2003). Since then, a number of studies have assessed the longer term (2050-2100) biomass supply potential for different regions and globally.

Most assessments of the biomass resource potential are based on a “food first” principle intending to ensure that the biomass resource potentials are quantified under the condition that global food requirements can be met (see e.g. WBGU, 2009). Assessments of the forest resource potential commonly employ a similar “fiber first” principle to ensure availability of resources for the production of conventional forest products such as sawnwood and paper.

Studies that start out from such principles should not be understood as providing guarantees that a certain level of biomass can be supplied for energy purposes without competing with food or fiber production. They quantify how much bioenergy that could be produced at a certain future year based on using resources not required for meeting food/fiber demands, given a specified development in the world or in a region. But they do not analyse how bioenergy expansion towards such a future level of production would – or should – interact with food and fiber production.

Studies using integrated energy/industry/land use cover models (Johansson and Azar, 2007; Leemans et al., 1996; Strengers et al., 2004; Müller et al., 2007; Van Vuuren et al., 2007; Melillo et al., 2009; Wise et al., 2009; Melillo et al., 2009; Lotze-Campen et al., 2009) can give insights into how an expanding bioenergy sector interacts with other sectors in society including land use and management of biospheric carbon stocks. Sector-focusing studies is another source of information on interactions with other biomass uses. Restricted scope (only selected biofuel/land uses and/or regions covered) or lack of sufficiently detailed empirical data can limit the confidence of results – especially in prospective studies. This is further discussed in Section 2.5 and Section 2.8.

2.2.2 Assessments of the biomass resource potential

Theoretical/physical/technical biomass resource potentials correspond to biomass production potentials that are limited only by the technology used and the natural conditions. Given that resource potential assessments quantify the availability of residue flows in the food and forest sectors – and as a rule are based on a food/fiber first principle – the definition of how these sectors develop is central for the outcome. Discussed further below, consideration of various types of restrictions connected to environmental and socio-economic factors as a rule limits the assessed potential to lower levels.

Table 2.2.1 shows ranges in the assessed biomass resource potential year 2050, explicit for various biomass categories. The ranges are obtained based on IEA Bioenergy (2009) and Lysen and van Egmond (2008), which reviewed a number of studies assessing the global and regional biomass supply potential, and on selected additional studies not included in these reviews (Field et al., 2008; Smeets and Faaij, 2007; Fischer and Schrattenholzer , 2001; Van Vuuren et al., 2009; Wirsenius et al., 2009). Diverging conclusions regarding the future biomass availability for energy can be explained by studies differing in scope, e.g., some studies are limited to assessing only selected biomass categories. But a major reason is that studies differ in their approach to considering different determining factors, which are in themselves uncertain: population, economic and technology development can go in different directions; biodiversity and nature conservation requirements set restrictions that are difficult to assess; and climate change as well as land use in itself can strongly influence the biophysical capacity of land. Biomass potentials can also not be determined exactly as long as uncertainty remains about decisions on tradeoffs that have to be made, e.g. with respect to the amount of acceptable additional biodiversity loss or acceptable intensification pressure in food production.

Although assessments employing improved data and modeling capacity have not succeeded in providing narrow distinct estimates of the biomass resource potential, they do indicate what the most influential parameters are that affect this potential. This is further discussed below, where approaches used in the assessments are treated in more detail.

Table 2.2.1. Overview of the assessed global biomass resource potential of land-based biomass supply over the long term for a number of categories (primary energy). For comparison, current global primary energy consumption is about 500 EJ per year and the present biomass use for energy is about 50 EJ per year.

Biomass category	Comment	Global biomass resource potential year 2050 (EJ/yr)
Energy crop production on surplus agricultural land	The potential biomass supply from agricultural land is usually assessed based on a “food first paradigm”: only land not required for food, fodder or other agricultural commodities production is assumed to be available for bioenergy. However, surplus – or abandoned – agriculture land need not imply that development is such that less total land is needed for agriculture: the lands may become excluded from agriculture use in modeling runs use due land degradation processes or climate change (see also “marginal lands” below). Large potential requires global development towards high-yielding agricultural production. Zero potential reflects that studies report that food sector development can be such that no surplus agricultural land will be available.	0 – >700
Energy crop production on marginal lands	Refers to biomass production on deforested or otherwise degraded or marginal land that is judged unsuitable for conventional agriculture but suitable for some bioenergy schemes, e.g., via reforestation. There is no globally established definition of degraded/marginal land and not all studies make a distinction between such land and other land judged as suitable for bioenergy. Zero potential reflects that studies report low potential for this category due to land requirements for e.g., extensive grazing management and/or subsistence agriculture, or poor economic performance of using the marginal lands for bioenergy.	0 – 110
Residues from agriculture	By-flows associated with food production and processing, both primary (e.g. cereal straw from harvesting) and secondary residues (e.g. rice husks from rice milling)	15 – 70
Forest residues	By-flows associated with forest wood production and processing, both primary (e.g. branches and twigs from logging) and secondary residues (sawdust and bark from the wood processing industry). Unexploited forest growth represents an additional resource. Forest growth on lands estimated as available for wood extraction that is not required for production of conventional forest products such as sawnwood and paper. Zero potential TSU: according to number in right column, zero potential is no possible indicates that studies report that demand from other sectors than the energy sector can become larger than the estimated forest supply capacity	30 – 150
Unexploited forest growth	Forest growth on lands estimated as available for wood extraction that is not required for production of conventional forest products such as sawnwood and paper. Zero potential indicates that studies report that demand from other sectors than the energy sector can become larger than the estimated forest supply capacity.	0 – 100
Dung	Animal manure	5 – 50
Organic wastes	Biomass associated with materials use, e.g. waste wood (producers), municipal solid waste	5 – >50
Total		<50 – >1000

2.2.2.1 The contribution from residues, processing by-flows and waste

Retail/post consumer waste and primary residues/processing by-flows in the agriculture and forestry sectors are judged to be important for near term bioenergy supplies since they can be extracted for energy uses as part of existing waste management and agriculture and forestry operations. As can be seen in Table 2.2.1 biomass resource assessments indicate that these biomass categories also have prospects for providing a substantial share of the total global biomass supply also on the longer term. Yet, the size of these biomass resources are ultimately determined by the demand for conventional agriculture and forestry products, and as was indicated by Figure 2.2.1 the present biomass flows in agriculture and forestry are rather limited compared to the global energy system (although these flows are clearly significant in some countries).

Assessments of the potential contribution from these sources to the future biomass supply combines data on future production of agriculture and forestry products obtained from food/forest sector scenarios with so-called residue factors that account for the amount of residues generated per unit of primary product produced. For example, harvest residue generation in agricultural crops cultivation is estimated based on harvest index data (i.e., ratio of harvested product to total aboveground biomass). The generation of logging residues in forestry, and of additional biomass flows such as thinning wood and process by-products, are estimated using similar residue factors.

The shares of the generated biomass flows that are available for energy – recoverability fractions – are then estimated based on considering competing uses, which can be related to soil conservation requirements or other extractive uses such as animal feeding and bedding in agriculture or fiber board production in the forest sector.

In addition to the forest biomass flows that are linked to industrial roundwood production and processing into conventional forest products, unexploited forest growth is considered in some studies. This biomass resource is quantified based on estimates of biomass increment in forests available for wood supply that is above the estimated level of forest biomass extraction for conventional industrial roundwood production – and sometimes for traditional bioenergy, notably heating and cooking. Smeets and Faaij (2007) provide illustrative quantifications showing how this “surplus forest growth” can vary from being a potentially major source of bioenergy to being practically zero as a consequence of competing demand as well as economic and ecological restrictions.

2.2.2.2 The contribution from energy plantations

From Table 2.2.1 it is clear that substantial supplies from energy plantations are required for reaching very high future bioenergy supply. Land availability (and suitability) for the production of dedicated energy crops, and the biomass yields that can be obtained on the available lands, are consequently two critical determinants of the biomass resource potential. Most earlier assessments of biomass resource potentials used rather simplistic approaches to estimating the contribution from energy plantations (Berndes et al. 2003), but the continuous development of modeling tools that combine databases containing biophysical information (soil, topography, climate) with analytical representations of relevant crops and agronomic systems has resulted in improvements over time (Fischer et al., 2008).

Figure 2.2.3 – representing one example (Fischer et al. 2009) – shows the modeled global land suitability for first generation biofuel feedstocks (sugarcane, maize, cassava, rapeseed, soybean, palm oil, jatropha). In this case a suitability index has been used in order to represent both yield potentials and suitability extent (see Caption to Figure 2.2.3). The map shows the case of rain-fed cultivation; including the possibility of irrigation would result in another picture. Land suitability also depends on which agronomic system that is assumed to be in use (e.g., degree of

mechanization, application of nutrients and chemical pest, disease and weed control) and this assumption also influence the biomass yield levels on the lands assessed as available for bioenergy plantations.

Based on overlaying information about the present global land cover – agriculture land, cities, roads and other human infrastructure, and distribution of forests and other natural/semi natural ecosystems – including protected areas – it is possible to quantify how much suitable land there is on different land cover types. For instance, almost 700 Mha, or about 20%, of currently unprotected grass- and woodlands is assessed suitable for soybean. About 580 and 470 Mha are assessed suitable for maize and jatropha while less than 50 Mha is assessed suitable for oil palm (note that these land suitability numbers cannot be added since areas overlap). Considering instead unprotected forest land, roughly ten times larger area (almost 500 Mha) is assessed as suitable for oil palm. However, converting large areas of forests with high carbon content into oil palm plantations would negatively impact biodiversity and also lead to large CO_2 emissions that can dramatically reduce the climate benefit of substituting fossil diesel with biodiesel from the palm oil produced (see Section 2.5).

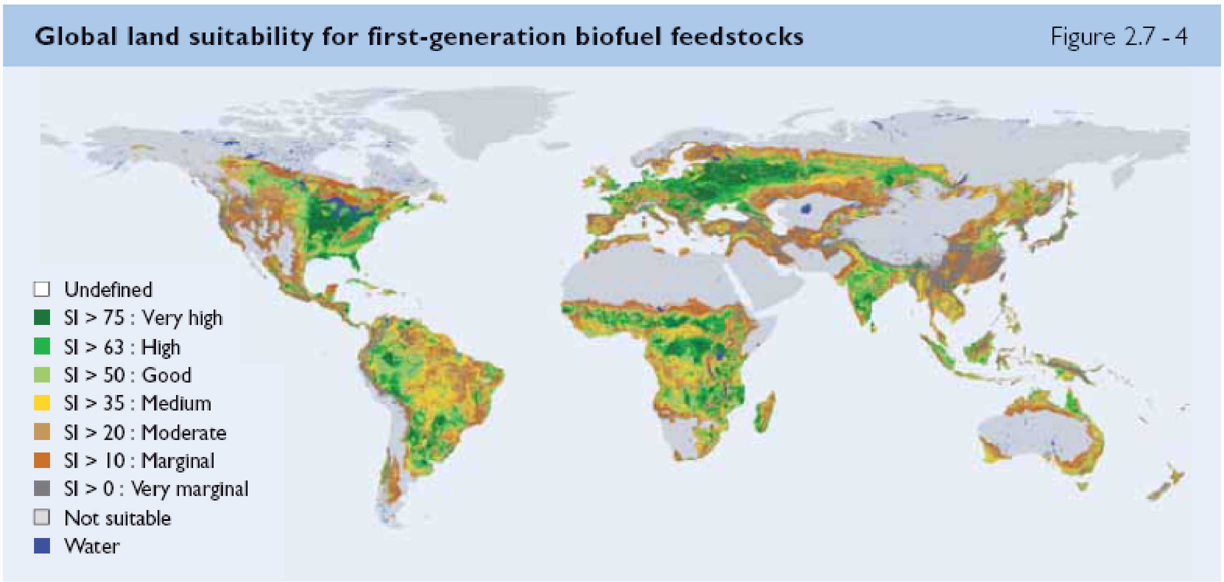


Figure 2.2.3. Suitability of land for production of selected agricultural crops that can be used as biofuel feedstocks. The suitability index SI used reflects the spatial suitability of each pixel and is calculated as SI=VS*0.9+S*0.7+MS*0.5+mS*0.3, where VS, S, MS, and mS correspond to yield levels at 80-100%, 60-80%, 40-60% and 20-40% of modelled maximum, respectively. Source: Fischer et al. 2009.

Supply potentials for energy crops can be calculated based on assessed land availability and corresponding yield levels. Table 2.2.2 shows the example of rain-fed lignocellulosic crops on unprotected grassland and woodland. In this case, lands with low productivity has been excluded and a rough land balance was made based on subtracting land estimated to be required for livestock feeding (Fischer et al. 2009). Note that Table 2.2.2 represents just one example corresponding to a specific set of assumptions regarding for example nature protection requirements, crop choice and agronomic practice determining attainable yield levels, and livestock production systems determining grazing requirements. Furthermore, it corresponds to the present situation concerning population, diets, climate, etc. and quantifications of future biomass resource potentials need to consider how such parameters change over time.

Table 2.2.2. Potential bionergy supply from rain-fed lignocellulosic crops on unprotected grassland and woodland where land requirements for livestock feeding have been considered. Calculated based on Fischer et al. (2009). TSU: all units in table if not otherwise stated are ha.

	Total grass- & woodland	**Of which**		**Balance available for bioenergy**	**Bioenergy potential**	
Regions		Protected areas	Unproductive or very low productive areas	Rough balance where areas req. for grazing has been excluded	Average yield[1] (GJ/ha)	Total bioenergy (EJ)
North America	659	103	391	110	165	18
Europe & Russia	902	76	618	110	140	15
Pacific OECD	515	7	332	110	175	19
Africa	1086	146	386	275	250	69
S&E Asia	556	92	335	14	235	3
Latin America	765	54	211	160	280	45
M East & N Afr.	107	2	93	1	125	0.2
World	**4605**	**481**	**2371**	**780**	**225**	**176**

[1] Calculated based on average yields for total grass- & woodland area given in Fischer (2009) and assuming energy content at 18 GJ/Mg dry matter. Rounded numbers.

Studies by Hoogwijk et al. (2003), Wolf et al. (2003) and Smeets et al. (2007) (from where Figure 2.2.3 is taken) are illustrative of the importance of energy crops for reaching higher global biomass resource potentials, and also of how different determining parameters are highly influential on the resource potential. Based on varying assumptions for critical aspects (e.g., population growth, level of improvements in agronomic technology, water supply and efficiency in use (rain-fed/irrigated), productivity of animal production system) Smeets et al. (2007) show that 0.7-3.5 billion hectares of surplus agricultural land – mainly pastures and with large areas in Latin America and sub-Saharan Africa – could potentially become available for bioenergy by 2050. If the suitable part of this land was used for lignocellulosic crops the total technical biomass resource potential – including also residues and forestry growth not required in the forest industry – would be above 1500 EJ (Figure 2.2.4).

Also pointing to the potential of pasture land conversion to bioenergy, Wirsenius et al. (2010) analyse the potential for land-minimized growth of world food supply through (i) faster growth in feed-to-food efficiency in animal food production; (ii) decreased food wastage; and (iii) dietary changes in favor of vegetable food and less land-demanding meat. They show that faster-yet-feasible livestock productivity growth combined with substitution of pork and/or poultry for 20% of ruminant meat can reduce land requirements by about 700 million hectares compared to a projection of global agriculture development up to 2030 presented by the Food and Agriculture Organization of the United Nations, FAO (Bruins, 2003).

In an analysis (WBGU, 2009) where current and near-future agricultural land is reserved for food and fibre production, thereby assuming mid-range future yield intensification, and where unmanaged lands are excluded from biomass production if carbon compensation from land conversion to plantation is slow (large standing biomass or carbon sink), the land is degraded, a wetland or environmentally protected, or where it is rich in biodiversity, global bioenergy potential from dedicated biomass plantations is estimated to vary between 34 and 120 EJ depending on the scenario (severity of the rules applied).

In a much less optimistic scenario for bioenergy – where agricultural productivity would remain at its current levels, population growth would continue at high rates and (biomass) trade and technology exchange would be severely limited – Smeets (2007) show that no land would be available for energy crops and the biomass resource potential be about 50 EJ consisting of municipal solid waste and some agricultural and forestry residues. Similarly, assuming a scenario of high population growth, high food demands and extensive agricultural production systems Wolf et al. (2003) arrive at zero potential for bioenergy.

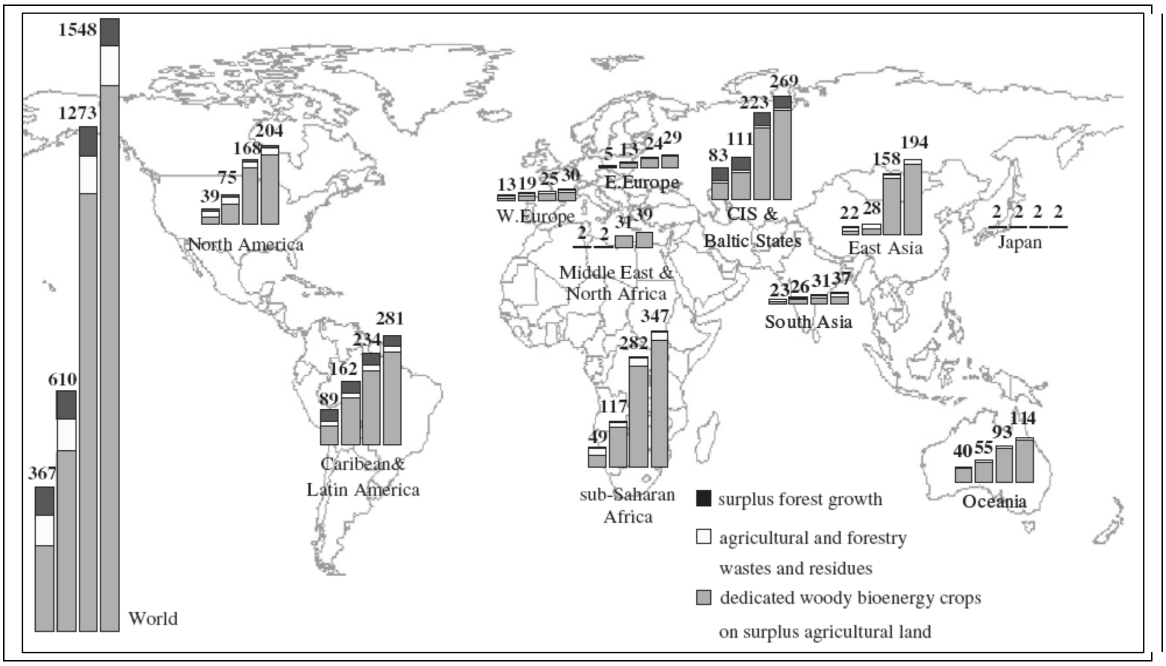


Figure 2.2.4. Illustration of the impact of different scenarios for agricultural productivity improvement on total technical bioenergy production potential in 2050, all other assumptions remaining equal (Smeets et al. 2007). All numbers in EJ.

2.2.3 Economic considerations in biomass resource assessments

Besides using restrictions based on minimum yield thresholds, assessments of the potential of energy plantations can include economic thresholds that exclude biomass resources judged as being too expensive to mobilize. For instance, land areas that are assessed as suitable for some types of bioenergy plantations can still be excluded when the estimated biomass production cost is considered too high. Alternatively, the potential of energy crops can be quantified based on combining land availability, yield levels and production costs to obtain crop- and region-specific cost-supply curves (Walsh 2000). These are based on projections or scenarios for the development of cost factors, including opportunity cost of land, and can be produced for different context and scale – ranging from feasibility studies of supplying individual bioenergy plants to describing the future global cost-supply curve. Figure 2.2.5 shows examples of global cost-supply curves for energy crops. A number of studies use this approach at different scales (Dornburg et al. 2007, Hoogwijk et al. 2008, de Wit et al. 2009, van Vuuren et al. 2009). Gallagher et al. (2003) exemplify the production of cost-supply curves for the case of crop harvest residues and Gerasimov and Karjalainen (2009) for the case of forest wood.

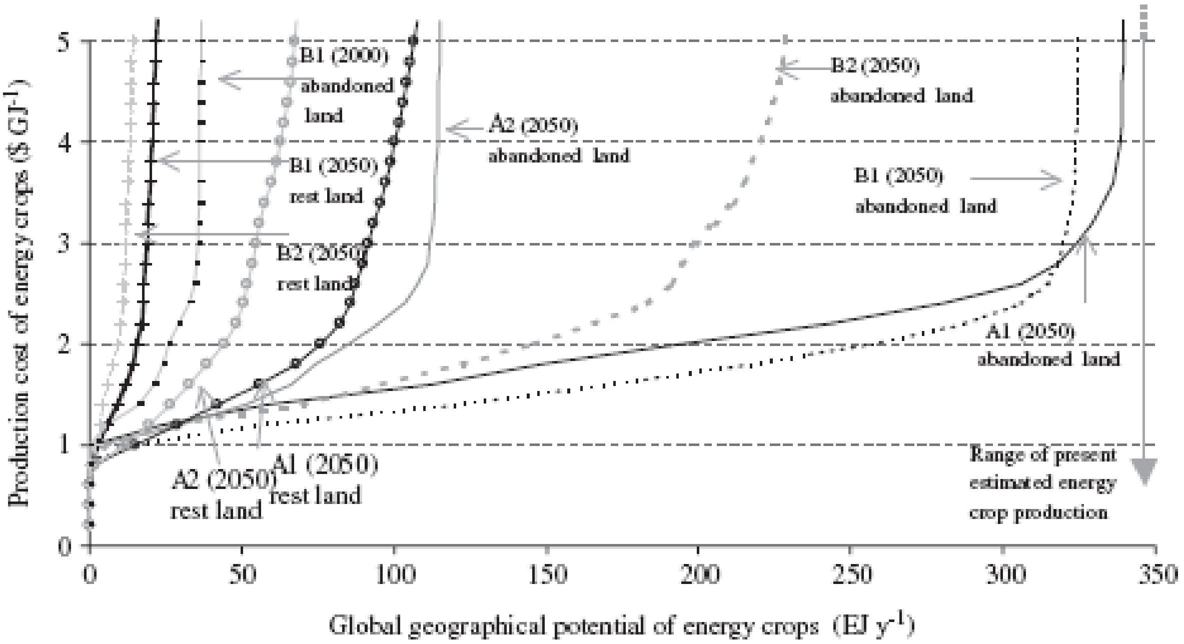


Figure 2.2.5. Global average cost-supply curve for the production of energy crops on the two land categories “abandoned land” (agriculture land not required for food) and “rest land” (TSU: add definition here), year 2050. The curves are generated based on IMAGE 2.2 modeling of four SRES scenarios (IMAGETeam 2001). The cost-supply curve at abandoned agriculture land year 2000 (SRES B1 scenario) is also shown. Source: Hoogwijk et al. 2008.

The biomass production costs can be combined with techno-economic data for related logistic systems and conversion technologies to derive economic potentials on the level of secondary energy carriers such as bioelectricity and biofuels for transport (see, e.g., Gan, 2007; Hoogwijk et al. 2008; van Dam et al. 2009). Using biomass cost and availability data as exogenously defined input parameters in scenario-based energy system modelling can provide information about implementation potentials in relation to a specific energy system context and possible climate and energy policy targets. This is further discussed in Section 2.7.

2.2.4 Constraints on biomass resource potentials

As described briefly above, many studies that quantify the biomass resource potential consider a range of constraints that restrict the potential to lower levels than those corresponding to unconstrained technical potentials. These constraints are connected to various impacts arising from the exploitation of the biomass resources, which are further discussed in Section 2.5. Below, important constraints are briefly discussed in relation to how they have been considered in studies assessing the biomass resource potentials.

2.2.4.1 Constraints on residue extraction rates

Soil conservation and biodiversity requirements set constraints on residue potentials for both agriculture and forestry. Organic matter at different stages of decay has an important ecological role to play in conserving soil quality as well as biodiversity in soils and above-ground. In forests, wood ash can be recirculated to forests to recycle nutrients taken from the forest and to mitigate negative effects of intensive harvesting. Yet, dying and dead trees, either standing or fallen and at different stages of decay, are valuable habitats (providing food, shelter and breeding conditions, etc.) for a large number of rare and threatened species (Grove and Hanula 2006). In agriculture, fertilizer inputs can compensate for nutrient removals connected to harvest and residue extraction, but maintenance or improvement of soil fertility, structural stability and water holding capacity requires recirculation of organic matter to the soil (Lal and Pimentel 2007, Wilhelm et al. 2007, Blanco-Canqui and Lal 2009). When ploughed under or left on the field/forest, primary residues may recycle valuable nutrients to the soil and help prevent erosion. Prevention of soil organic matter depletion and nutrient depletion are of importance to maintain site productivity for future crops. Overexploitation of harvest residues is one important cause to soil degradation in many places of the world.

However, thresholds for desirable amounts of dead wood at the forest stands are difficult to set and the most demanding species require amounts of dead wood that are difficult to reach in managed forests (Ranius and Fahrig 2006).

There are also large uncertainties linked to the possible future development of important determining factors. Population growth, economic development and dietary changes influence the demand for products from agriculture and forestry products and materials management strategies (including recycling and cascading use of material) influence how this demand translates into demand for basic food commodities and industrial roundwood.

Furthermore, changes in food and forestry sectors influences the residue/waste generation per unit product output which can go in both directions: crop breeding leads to improved harvest index (less residues); implementation of no-till/conservation agriculture requires that harvest residues are left on the fields to maintain soil cover and increase organic matter in soils (Lal, 2004); shift in livestock production to more confined and intensive systems can increase recoverability of dung but reduce overall dung production at a given level of livestock product output; increased occurrence of silvicultural treatments such as early thinning to improve stand growth will lead to increased availability of small roundwood suitable for energy uses and development of technologies for stump removal at harvest increases the generation of residues during logging (Näslund-Eriksson and Gustafson, 2008)

Consequently, the longer term biomass resource potentials connected to residue/waste flows will continue to be uncertain even if more comprehensive assessment approaches are used. It should be noted that it is not obvious that more comprehensive assessments of restrictions will lead to lower residue potentials; earlier studies may have used conservative residue recovery rates as a precaution in the face of uncertainties (see, e.g., Kim and Dale 2004).

2.2.4.2 Constraints on intensification in agriculture and forestry

The prospects for intensifying conventional long-rotation forestry to increase forest growth and total biomass output – for instance by fertilizing selected stands, introducing alien forest species and using shorter rotations – is not investigated in the assessed studies of biomass resource potentials. Intensification in forestry is instead related to shifts to higher reliance on fast-growing wood plantations that are in many instances identical to the bioenergy plantation systems assumed to become established on surplus agricultural land.

Intensification in agriculture is on the other hand a key aspect in essentially all of the assessed studies since it influences both land availability for energy crops (indirectly by determining the land requirements in the food sector) and the yield levels obtained for these crops (Lotze-Campen et al., 2009, provides an example). High assessed potentials for energy plantations rely on very efficient agricultural systems and optimal land use allocation beyond national borders, and the use of high-yielding bioenergy plantations on available lands. A notable example, Smeets et al. (2007) report a high-end bioenergy potential on surplus agricultural land at 1272 EJ/yr. However, as the authors also stress, this corresponds to a technical potential requiring productivity increases in agriculture that appear unrealistically high when comparing with other scenario studies of agriculture development (see, e.g., Koning 2008, IAASTF 2009, Alexandratos 2009).

Increasing yields on existing agricultural land is commonly proposed a key component for agriculture development (Ausubel, 2000; Tilman et al., 2002; Fischer et al. 2002, Cassman et al., 2003; Evans, 2003; Balmford et al., 2005; Green et al., 2005; Lee et al., 2006), Bruins, 2009 . Theoretical limits still appears to leave scope for further increasing the genetic yield potential (Fischer et al. 2009). But there can be limitations and negative aspects of further intensification of the use of cropland aiming at farm yield increases; high crop yields depend on large inputs of nutrients, fresh water, and pesticides, and contribute to negative ecosystem effects, such as eutrophication (Donner and Kucharik, 2008; see also Section 2.5).

Some observations indicate that it can be a challenge to maintain yield growth in several main producer countries, while other observations indicate that rates of gain obtained from breeding have increased in recent years and that yields may increase faster again as newer hybrids are adopted more widely (Edgerton 2009). Many infrastructural, institutional and technical constraints can reduce farm yields and prevent closing the gap between genetic yield potentials and farm yields for major crops. Even maintaining current yield potentials may prove to be difficult, as there are signs of intensification-induced declines of the yield potentials over time, related to subtle and complex forms of soil degradation (Cassman, 1999; Pingali and Heisey, 1999). Large areas of croplands and grazing land experience degradation and productivity loss as a consequence of improper land use (Fischer et al. 2002).

Biomass resource potential assessments that rely on established biophysical datasets and modelling tools run less risk of assuming developments towards biophysically unrealistic productivity levels. But databases still needs improvements (Sanchez et al. 2009) and assessment studies' modeling of agronomic advancement has a less solid basis leading to that the derived productivity growth rates could still prove to be too optimistic. Limits on intensification – connected to the effects of nutrient and chemical leaching causing eutrophication, and also to the risks that high-yielding alien species grown for bioenergy spread to surrounding natural ecosystems – are seldom treated explicitly as a constraint on intensification in biomass resource assessments but rather noted as a risk with the proposition that proper land management practice is critical for avoiding negative effects.

It should be noted that studies reaching high potentials for bioenergy plantations points primarily to tropical developing countries as major contributors. In these countries there are still substantial yield gaps to exploit and large opportunities for productivity growth – not the least in livestock production (Wirsenius et al. 2009, Edgerton 2009, Fischer et al. 2002).

2.2.4.3 Water related constraints

Water related constraints primarily influence the prospects for bioenergy plantations, including both intensification possibilities and the prospects for expansion of bioenergy plantations (Berndes 2008, Rost et al. 2009). To the extent that bioenergy is based on the utilization of residues and biomass processing by-products within the food and forestry sectors, water use would not increase significantly due to increasing bioenergy. The water that is used to produce the food and conventional forest products is the same water as that which will also produce the residues and by-products potentially available for bioenergy.

The impact of bioenergy plantations on water availability and use depends on site-specific conditions and prior land use/vegetation cover. To the extent that plantation establishment leads to higher site productivity and biomass accumulation it can be expected that the evapotranspiration increases, which can lead to falling groundwater levels and reduced downstream water availability in regions where water is scarce (Jackson et al. 2005, Zomer 2006). Impacts are further discussed in Section 2.5.

Water constraints are explicitly considered in some – but far from all – studies of the biomass resource potential. In studies that use biophysical datasets and modelling, water limitations can constrain the modelled land productivity to levels considered too low for meeting suitability criteria for bioenergy plantations. However, assumptions about productivity growth in agriculture may implicitly presume irrigation development that could lead to challenges in relation to regional water availability and use.

Illustrative of how water scarcity might constrain biomass resource potentials, Van Vuuren (2009) overlaid a water scarcity map for 2050 (Döll et al. 2003) and found that about 17% of the assessed bioenergy potential was in severe water-scarce areas and an additional 6% was in areas of modest water scarcity.

Studies that have investigated the link between large scale bioenergy supply and water have made impact assessments of a specified future bioenergy supply rather than assessed biomass resource potentials as determined by water availability (see, e.g., Berndes 2002, De Fraiture et al. 2008, De Fraiture and Berndes 2009). Thus, they add an important dimension but they do not give information about how much biomass that can be produced for energy within limits set by availability and competing use of water.

2.2.4.4 Biodiversity constraints on agriculture land expansion

Besides influencing possible residue extraction in agriculture and forestry, biodiversity can limit biomass resource potentials in many ways.

As noted above, biodiversity limits on intensification – connected to the effects of nutrient and chemical leaching, which can lead to changes in species composition in the surrounding ecosystems, and also to the risks that alien species grown for bioenergy spread to surrounding natural ecosystems – are not treated explicitly as a constraint on productivity growth. But some studies indirectly consider these constraints on productivity implicitly by assuming a certain expansion of alternative agriculture production that yields lower than conventional agriculture and therefore requires more land for food production (Fischer et al. 2009, EEA, 2007). Van Vuuren et al. (2009) illustrate the sensitivity to yield assumptions and show that yield increases for food crops in general have a more substantial impact on bioenergy potentials than yield increase for bioenergy crops specifically.

The common way of considering biodiversity requirements as a constraint is by including requirements on land reservation for biodiversity protection (e.g. WBGU, 2009). Biomass potential assessments commonly exclude nature conservation areas from being available for biomass production, but the focus is as a rule on forest ecosystems and takes the present level of protection as a basis. Other natural ecosystem also needs protection – not the least grassland ecosystems – and the present status of nature protection may not be sufficient for a certain target of biodiversity preservation.

Clearly, biodiversity impacts still may arise in the real world. Biodiversity loss may also occur indirectly, such as when productive land use displaced by energy crops is re-established by converting natural ecosystems into croplands or pastures elsewhere. Integrated energy system - land use/vegetation cover modelling have better prospects for analysing these risks. They are further discussed in Section 2.2.6 below. WBGU (2009) show that differences in the assumed severity of biodiversity protection between scenarios have a larger impact on bioenergy potential than either irrigation or climate change.

2.2.5 Summary conclusions on biomass resource assessments

As shown above, narrowing down the biomass resource potential to distinct numbers is not possible. But it is clear that several hundred EJ per year can be provided for energy in the future, given favourable developments. It can also be concluded that:

- Biomass use for energy can already today be strongly increased over current levels based on increased use of forestry and agricultural residues
- The short to medium term energy crop potential depends strongly on productivity increases that can be achieved in food production and environmental constraints that will restrict energy crop cultivation on different land types.
- The cultivation of suitable lignocellulosic crops can allow for higher potentials by making it possible to produce bioenergy on lands where conventional food crops are less suited – also due to that the cultivation of conventional crops would lead to large soil carbon emissions (further discussed in Section 2.5.2).
- Water constraints may limit production in regions experiencing water scarcity. But the use of suitable energy crops that are drought tolerant can also help adaptation in water scarce situations. Assessments of biomass resource potentials need to more carefully consider constrains and opportunities in relation to water availability and competing use.

While recent assessments employing improved data and modelling capacity have not succeeded in providing narrow distinct estimates of the biomass resource potential, they have advanced the understanding of how influential various parameters are on the potential. Some of the most important parameters are inherently uncertain and will continue to make long term biomass supply potentials unclear. However, the insights from the resource assessments can improve the prospects for bioenergy by pointing out the areas where development is most crucial. This is further discussed in Section 2.2.6 below where we also propose areas for further research.

2.2.6 Uncertainties and requirements for further research

There are several important but uncertain aspects that make assessments of future potentials for bioenergy plantations challenging but also important.

2.2.6.1 Water

Since many studies of the biomass resource potential have pointed out that plantation establishment on abandoned agricultural land and sparsely vegetated degraded land is one major option, the water use dimension of expanding bioenergy needs to be carefully investigated.

The impact of energy plantations on changes in hydrology needs to be researched in order to advance our understanding of how the changes in water and land management will affect downstream users and ecosystems. Such impacts can be both negative and positive. For example, local water harvesting and run-off collection upstream may reduce erosion and sedimentation loads in downstream rivers, while building resilience in the upstream farming communities. Also, a number of crops that are suitable for bioenergy production are drought tolerant and relatively water efficient crops that are grown under multi-year rotations. These crops provide an option to improve water productivity in agriculture and help alleviate competition for water as well as pressure on other land-use systems (Berndes 2008). They also offer a possibility to diversify land use and livelihood strategies and protect fragile environments.

Assessments of biomass resource potentials should preferably include the possibility of introducing bioenergy plantations into the agricultural landscape so as to improve water use efficiency. Rost et al. (2009) show how low-tech measures may alleviate water stress limitations to agricultural production.

2.2.6.2 Climate change impact on land use productivity and availability of land

The possible consequences of climate change for agriculture are not firmly established but indicate net global negative impact, where damages will be disproportionately concentrated in developing countries that will lose in agriculture production potential while developed countries might gain (Fischer et al. 2002, Cline 2007, Fischer 2009,).

Climate change is likely to change rainfall patterns while water transpiration and evaporation will be enhanced by increasing temperatures. Semi-arid and arid areas are particularly likely to be confronted with reduced water availability and problems in many river basins may be expected to increase. Generally, negative effects of climate change will outweigh the benefits for freshwater systems, thereby adversely influencing water availability in many regions and hence irrigation potentials.

Clearly, future assessments of biomass resource potentials need to reflect the most recent understanding of climate change impacts – including up-to-date databases. They should also reflect the understanding of how introduction of energy crop as a strategy for adaptation to climate change.

2.2.6.3 Plant breeding and genetic modification of crops

Advances in plant breeding and genetic modification of crops not only raises the genetic yield potential but also adapts crops for more challenging conditions (Fischer et al. 2009). Improved drought tolerance can improve average yields in drier areas and in rain-fed systems in general by reducing the effects of sporadic drought (Nelson et al., 2007; Castiglioni et al., 2008). It can also reduce water requirements in irrigated systems.

Dedicated energy crops have not been subject to the same breeding efforts as the major food crops. Selection of suitable crop species and genotypes for given locations to match specific soil types and climate is possible, but is at an early stage of understanding for some energy crops, and traditional plant breeding, selection and hybridization techniques are slow, particularly in woody crops but also in grasses. New biotechnological routes to produce both non-genetically modified (non-GM) and GM plants are possible. GM energy crop species may be more acceptable to the public than GM food crops, but there are concerns about the potential environmental impacts of such plants, including gene flow from non-native to native plant relatives. As a result, non-GM biotechnologies may remain particularly attractive. On the other hand, GMO food crops have already been widely accepted in many non-EU countries. One challenge will be to make advances in plant breeding become available for farmers in developing countries.

2.2.6.4 Intensified forest management

The prospects for intensifying conventional long-rotation forestry to increase total biomass output is not investigated in global/regional studies so far, but national level studies point to significant possibilities and also trade-offs to be managed.

2.2.6.5 New types of integrated land use systems

Assessments of biomass resource potentials have been done without sufficiently considering possibilities of new innovative agronomic practice involving integrated bioenergy/food/feed production. Integration can be realized at the feedstock production level – e.g., double-cropping systems (Heggenstaller 2008) and different types of agroforestry systems – and based on integrating feedstock production with conversion – typically producing animal feed that can replace cultivated feed such as soy and corn (Dale 2008) and also reduce grazing requirement (Sparovek et al., 2007)

Much attention has been directed to the possible negative consequences of land use change, such as biodiversity losses, greenhouse gas emissions and degradation of soils and water bodies, referring to well-documented effects of forest conversion and cropland expansion to uncultivated areas. However, most impact studies concern conventional food/feed crops and TSU suggests: whereas studies of environmental effects of lignocellulosic crops are less common (Dimitrou et al. 2009). Also, the production of biomass for energy can generate additional benefits. In agriculture, biomass can be cultivated in so-called multifunctional plantations that – through well chosen localization, design, management, and system integration – offer extra environmental services (including soil carbon increase and improved soil quality) that, in turn, create added value for the systems (Berndes et al. 2008) .

Many such plantations provide water related services, such as vegetation filters for the treatment of nutrient bearing water such as wastewater from households (Börjesson and Berndes 2006), collected runoff water from farmlands and leachate from landfills. Plantations can also be located in the landscape and managed for capturing the nutrients in passing runoff water. Sewage sludge from treatment plants can also be used as fertilizer in vegetation filters. Plantations can be located and managed for limiting wind and water erosion. For example perennial grasses are used by the US Conservation Reserve Programme to minimize soil erosion. Besides the onsite benefits of reduced soil losses, there are also offsite benefits such as reduced sediment load in reservoirs, rivers and irrigation channels. Plantations can also reduce shallow land slides and local ‘flash floods’.

Comprehensive assessments of the biomass resource potential linked to multifunctional bioenergy systems exists on national level (see, e.g., Berndes and Börjesson 2007) and for specific applications (e.g., Berndes et al. 2004), where plantation establishment for reclamation of degraded land is among the more diverse and numerous. Solid assessments require detailed comprehensive data making global comprehensive assessments based on uniform methodology challenging. However, an increased number of local/national assessments can give important information for implementation of strategies to capture the environmental benefits of expanding multifunctional biomass plantations.

2.2.6.6 Availability of degraded land

Future biomass potentials are co-determined also by whether degraded lands - of which productive capacity has declined temporarily or permanently - can be used for biomass production. At this moment the potential of the large area of degraded soils – classified as light and moderately degraded and covering about 10% of the total land area – to contribute to the production of biomass has not yet clearly assessed. Two possible drawbacks are the main reason: firstly the large efforts and long time period required for the reclamation of degraded land and secondly the low productivity levels of these soils. Analysis has been shown that using severely degraded land could increase biomass potentials from energy crops by about 30-45%. However, using severely degraded land for annual crop production might require large investments and many attempts for reclaiming degraded land for food production have failed.

2.2.6.7 Complementary methodological approaches

Studies using integrated energy/industry/land use/cover models produce a more dynamic description of the biomass resource potential, showing bioenergy development where bioenergy production and use is a modeling result rather than an input parameter. In such studies, land allocation to bioenergy as well as land/food/fiber prices give insights into the competitiveness of bioenergy in relation to other competing energy technologies, and in relation to other competing land uses. The outcome is among other things dependent on assumed policies influencing the demand for and competitiveness of bioenergy as well as other energy technologies.

In contrast to conventional assessments of biomass resource potentials where normative restrictions (e.g., with reference to food sector impacts and biodiversity considerations) limits the resource potential, this type of studies have the character of impact assessments and can show consequences of expanding bioenergy to scales beyond those defined by normative restrictions. Thus, instead of quantifying biomass resource potentials based on considering a range of sustainability constraints they provide an important basis for discussions of trade-offs between bioenergy supply and various socio-economic and/or environmental objectives.

An example of such studies, Melillo et al. (2009) developed two scenarios to analyse the environmental consequences of an aggressive global cellulosic biofuels program over the first half of the 21st century. They found that both could contribute substantially to future global-scale energy needs, but with significant unintended environmental consequences, either due to the clearing of large areas of natural forest, or due to the intensification of agricultural operations worldwide. Also, numerous biodiversity hotspots suffer from serious habitat loss. This further discussed in Section 2.5).

2.3 Technology

Bioenergy chains involve a wide range of feedstocks, conversion processes and end-uses (Figure 2.1.1). This section covers the existing and near-term technologies used in the various steps of these chains, and details the major systems which are currently deployed, while future technologies are presented in section 2.6.

2.3.1 Feedstock

2.3.1.1 Feedstock production or recovery

Feedstock types may be classified into dedicated crops or trees (i.e., plants grown specifically for energy purposes), primary residues from agriculture and forestry, secondary residues from agro and forest industries, and organic waste from livestock farming, urban, or industry origin.

Biomass production from dedicated plants includes the provision of seeds or seedlings, stand establishment and harvest, soil tillage, and various rates of irrigation, fertilizer and pesticide inputs. The latter depend on crop requirements, target yields, and local pedo-climatic conditions, and determine the intensity in the use of production factors (inputs, machinery, labor or land), which may vary across world regions for a similar species (Table 2.3.1). Within a given region, similar yield levels may be reached through a variety of cropping systems and production intensities. Strategies such as integrated pest management or organic farming may alleviate the need of synthetic inputs for a given output of biomass. Such distinction is beyond the scope of this section, but is a major avenue to improve the sustainability of biomass supply.

Wood for energy is obtained as fuelwood from the logging of natural or planted forests, and from trees and shrubs from agriculture fields surrounding villages and towns. Some of this is converted into charcoal. While natural forests are not managed toward production per se, problems arise if fuelwood extraction exceeds the regeneration capacity of the forests, which is the case in many parts of the world (Nabuurs et al., 2007). The management of planted forests involves silvicultural techniques similarly to those of cropping systems, from stand establishment to tree fellings. The use of synthetic fertilizers is considerably less intensive than on agricultural species.

Biomass may be harvested several times a year (for forage-type feedstocks such as hay or alfalfa), once a year (for annual species such as wheat or perennial grasses), or every 2 to 50 years or more (for short-rotation coppice and conventional forestry, respectively). Biomass is typically transported to a collection point on the farm or at the edge of the road before road transport to the bioenergy unit or an intermediate storage. It may be preconditioned and densified to make storage, transport and handling easier (section 2.3.2.).

Primary residues from agriculture consist of plant materials that remain on the farm after removal of the main crop produce, and include straw, stalks or leaves. They may be collected upon crop harvest. Primary residues from forest may be available from additional stemwood fellings or as residues (branches, stumps) from thinning salvage after natural disturbances, thinnings or final fellings. Typical values of residue recoverability are between 25 and 50 % of the logging residues and between 33 and 80% of processing residues (Nabuurs et al., 2007).

Secondary residues are by-products of post-harvest processing of crops, namely, cleaning, threshing, sawing, sieving, crushing, etc., and can be in the form of husk, dust, bagasse, cobs or straw, along with post-consumer recovered wood products having served their purpose e.g., pallets, construction wood, or furniture (Steierer et al., 2007). Examples include groundnut shells, rice husk, sugar cane bagasse or corn cobs (Dhingra, Mande, Kishore, et al.1996). They are stored and collected at the processing site. Although modes and volume of production of agricultural residues may differ by production area, the rates of production of residues relative to crop marketable yield are reported as 140% for rice, 130% for wheat, 100% for corn, and 40% for rhizomic crops (Hall et al. 1993).

A number of important factors have to be addressed when considering the use of residues for energy. First, there are many other alternative uses, for example, as animal feed, soil erosion control, animal bedding, and or fertilizers (manure). Second, they are seasonally available and their availability is difficult to predict. Availability is also conditioned by the amount of residue deemed essential for maintaining soil organic matter, which depends on pedo-climatic conditions and cultural practices (Wilhem et al., 2004), soil erosion control, efficiency in harvesting, and losses (Iyer et al., 2002). Although the availability of residues upon harvest makes collection easy for small-scale utilization, it creates storage problems if residues have to be saved for use during other months of the year, especially due to their low bulk density.

Organic waste utilizable for energy purposes includes animal residues such as cattle dung; poultry litter; MSW (municipal solid waste), including food and vegetable market waste, tree trimmings and lawn cuts; and industrial organic waste from food-processing industries, pulp and paper mills (black liquor). Sewage sludge from domestic and industrial water treatment plants is also a source of biomass for energy. Organic waste is usually stored on the production site in a tank or heap, prior to collection and transportation to the bioenergy unit in liquid or solid form. Organic waste contains many degradable organic materials and nutrients, and may be returned to soils as manure after conversion to energy. The organic waste that is buried into landfills is also a source of biomass, since it is digested by micro-organisms and evolved into biogas (landfill gas).

The species listed in Table 2.3.1 are not equivalent in terms of possible energy end-uses. Starch, oil and sugar crops are grown as feedstock for first-generation liquid biofuels (ethanol and bio-diesel), which only use a fraction of their total above-ground biomass, the rest being processed in the form of animal feed or lignocellulosic residues. Nevertheless, it is worthwhile to recognize that sugar cane bagasse and even sugar cane straw are being used as a source of bioelectricity in many sugar and ethanol producing countries (Dantas et al., 2009). On the other hand, lignocellulosic crops (such perennial grasses or short-rotation coppice) may be entirely converted to energy, and feature 2 to 5 times higher yields per ha than most of the other feedstock types, while requiring far less synthetic inputs when managed carefully (Hill, 2007). However, their plantation and harvest is more resource intensive than annual species, and their impact on soil organic matter after the removal of stands is poorly known (Anderson-Texeira et al., 2009). In addition, with the current status of technology lignocellulose can only provide heat and power whereas the harvest products of oil, sugar and starch crops may be readily converted to liquid biofuels and bioelectricity. Costs for dedicated plants vary widely according to the prices of inputs and machinery, labor and land-related costs (Ericsson et al., 2009). If energy plantations are to compete with land dedicated to food production, the opportunity cost of land (the price a farmer should be paid to switch to an energy crop) may become dominant and will scale with the demand of energy feedstock (Bureau et al., 2009). Cost-supply curves are needed to account for these effects in the economics of large-scale deployment scenarios.

Residues and waste streams are a coveted resource since their apparent costs only include collection, pre-conditioning and transport (Table 2.3.2). However, their export has to be carefully managed to avoid jeopardizing soil organic matter content and fertility in the long-run, which typically brings down their theoretical availability by 70% to 80% (EEA, 2006). Nutrient exports should also be compensated for, possibly by recycling residual ash, stillage or digestate from the bioenergy conversion process.

2.3.1.2 Interactions with the agriculture, food & forest sectors

Energy feedstock production may compete with the food, feed, and fibre and forest sectors either directly for land or for a particular stream of biomass (e.g., cereal straw for cattle bedding material vs. energy production). The outcome of these competition effects hinges on the economics of supply and demand for the various sectors and markets involved, at regional to global scales (see section 2.2). From a technology standpoint and at a local scale, synergistic effects may also emerge between these competing usages. Agroforestry makes it possible to use land for both food and energy purposes with mutual benefits for the associated species (Bradley et al., 2008). The associated land equivalent ratios may reach up to 1.5 (Dupraz and Liagre, 2008), meaning a 50% saving in land area when combining trees with arable crops respective to mono-cultures. Intercropping and mixed cropping are also interesting options to maximize the output of biomass per unit area farmed (WWI, 2006). Perennial species create positive externalities such as erosion control, improved fertilizer use efficiency, reduction in nitrate losses and water stress, and provision of habitat for biodiversity and biological control of pests (Openshaw, 2000; Semere and Slater, 2007). Perennial species such as switchgrass offer other benefits in terms of building and maintaining soil organic matter and improving soil structure (Paustian et al., 2006). Annual energy crops may be used as break crops in rotations involving cereals, to decrease the pressure of specific pathogens. Mixed cropping systems (e.g. a combination of legume and cereal crops, or a high diversity of grass species) result in increased yields compared to single crops, and may provide both food/feed and energy feedstock from the same field (Tilman et al., 2006; Jensen, 1996). Lastly, the revenues generated from growing bioenergy feedstock may provide access to technologies or inputs enhancing the yields of food crops, provided the benefits are distributed to local communities (Practical Action Consulting, 2009). The latter authors reviewed small-scale bioenergy projects in developing countries and concluded that they did not affect (and possibly improve) local staple food security, under those conditions.

Table 2.3.1. Typical characteristics of the production technologies for dedicated species and their primary residues.

Feedstock type	**Region**	**Yield (GJ/ha) / fraction**	**Management**			**Co-products**	**Costs USD/GJ**	**Refs.**
			N/P/K use	**Water needs**	**Pesticides**			
OIL CROPS		Oil						
Oilseed rape	Europe	42	+++	+	+++	Rape cake, straw	7.2	1,2
Soybean	N America Brazil	25 18,21	++ ++	+ +	+++ +++	Soy cake, straw	11.7	3,12
Palm oil	Asia Brazil	135-200 169	++ ++	+ +	+++ +++	Palm fronds, fruit bunches, press fibers	12.6	3
Jatropha	India Africa	21 45	+ +	+ +	+ +	Seed cake (toxic), wood, shells	2.9	3,4,5, 10,11
STARCH CROPS		As ethanol						
Wheat	Europe	54-58	+++	++	+++	Straw, DDGS	5.2	3
Maize	N America	72-79	+++	+++	+++	Corn stover, DDGS	10.9	3
Cassava	World	43	++	+	++	DDGS		3
SUGAR CROPS		As ethanol						
Sugar cane	Brazil India	116-149 95-112	++	+	+++	Bagasse, straw	1.0-2.0	3,20 3
Sugar beet	Europe	116-158	++	++	+++	Molasses, pulp	5.2	3,13
Sorghum (sweet)	Africa China	105-160	+++	+	++	Bagasse	12.8	3
LIGNOCELLULOSIC CROPS								
Micanthus	Europe	190-280	+/++	++	+		4.8-16	6,8
Switchgrass	Europe N America	120-225 103-150	++ ++	+ +	+ +		2.4-3.2 4.4	10,14
Short rotation Eucalyptus	S Europe S America	180 250	+ +	++ +	+ +	Tree bark	2.9-4 2.7	2,19
S.rotation Willow	Europe	140					4.4	3,7
Fuelwood (chopped) Fuelwood (from native forests)	Europe C America	110 80-150				Forest residues Forest residues, whole trees and branches	3.4-13.6 2-4	17
PRIMARY RESIDUES								
Wheat straw	Europe USA	60 7	+				1.9	2 14
Sugar cane straw	Brazil	90-126	+					21
Corn stover	N America India	15-155 22-30	+ +				0.9	9,14 21
Sorghum stover	World	85	+					9
Forest residues	Europe World	2-15					1-7.7	17

References: 1: EEA, 2006; 2: JRC, 2007; 3: Bessou et al., 2009; 4: Ndong et al., 2009; 5: Openshaw, 2000; 6: Clifton-Brown et al., 2004: 7: Ericsson et al., 2009; 8: Fargernäs et al., 2006;

9: Lal, 2005; 10: WWI, 2006; 11: Maes et al., 2009; 12: Gerbens-Leenes et al., 2009; 13: Berndes, 2008; 14: Perlack et al., 2005; 15: Yokoyama and Matsumura, 2008; 16: Kärhä, pers. com., 2009; 17: Karjalainen et al., 2004; 18: Nabuurs et al., 2007; 19: Scolforo, 2008; 20: Folha, 2005; 21: Guille, 2007.

Table 2.3.2: Typical characteristics of the production technologies for selected secondary residues and waste stream). Same references as Table 2.3.1.

Feedstock type	Region	Energy content	Cost USD/GJ	Ref.
Charcoal	Worldwide	29 GJ/odt	2	
Sugar cane bagasse	Brazil	15.5 GJ/odt	1.6-7.6	10,2
Rice husk	India	15 GJ/odt	2	21
Waste wood	Europe	18 GJ/odt	2.2	2
Wood pellets and briquettes	N Europe US/Canada	18 GJ/odt	8.8 5-5.3	16
MSW	USA	3.4 GJ/inhab.(organic)	May be negative	10
Cattle slurry	Asia N America	14-17/cattle head 14-32/cattle head		15
Black liquor	Europe	12 GJ/odt		
Waste cooking oil	Global	40 GJ/t		3

2.3.2 Logistics and supply chains

2.3.2.1 Preconditioning of biomass

Most non-woody biomass is available in loose form and has low bulk densities, which causes problems of handling, transportation and storage. Shredded biomass residues may be densified by briquetting or pelletizing, typically in screw or piston presses that compress and extrude the biomass (FAO, 2009c). The application of high pressure increases the temperature and lignin present in the biomass partially liquefies and acts as a binder. Briquettes and pellets can be good substitutes for coal, lignite and fuelwood as they are renewable, have consistent quality, size, better thermal efficiency, and higher density than loose biomass.

Briquettes are larger than pellets and are produced by compression and extrusion, with various compaction rates (Erikson and Prior, 1990). There are briquetting plants in operation in India and Thailand, using a range of secondary residues and with different capacities, but none as yet in other Asian countries. There have been numerous, mostly development agency-funded briquetting projects in Africa, and most have failed technically and/or commercially. The reasons for failure include deployment of new test units that are not proven, selection of very expensive machines that do not make economic sense, low local capacity to fabricate components and provide maintenance, and lack of markets for the briquettes due to uncompetitive cost and low acceptance (Erikson and Prior, 1990). There are indications that most of these obstacles are being overcome in efforts to protect the Virunga National Park in the Democratic Republic of Congo, a global biodiversity hotspot, by replacing illegal charcoal production by briquettes in the surrounding densely populated areas on the open market.

Wood pellets are made of wood waste such as sawdust and grinding dust. Pelletization produces somewhat lighter and smaller pellets of biomass compared to briquetting. Pelletization machines are based on fodder making technology. Pelletizing generally requires conditioning of biomass material by mixing with a binder or by raising its temperature through direct addition of steam or both (BEC, 2009). Wood pellet are easy to handle and burning is easy; shape and characteristics of fuel are uniform; transportation efficiency is high; energy density is high. Wood pellets are used as fuel in many countries for cooking and heating application (EREC, 2009).

Chips are mainly produced from plantations waste wood and wood residues (branches and nowadays even spruce stumps) as a by-product of conventional forestry. They require less processing and are cheaper than pellets. The handling of both chips and pellets is amenable to automation. Bark and wood are usually chipped separately because they have different properties. Depending on end use, chips may be produced on-site, or the wood may be transported to the chipper. For example in Durban, South Africa the chipper is located at the port and debarked logs are transported to the port by road and rail. The chips are pumped directly onto ships for export, in this case to Japan. Chips are commonly used in automated heating systems, and can be used directly in coal fired power stations or for combined heat and power production (Fargernäs et al., 2006).

Charcoal is a product obtained by heating woody biomass to high temperatures in the absence of oxygen, with a twice higher calorific value than the original feedstock. It burns without smoke and has a low bulk density which reduces transport costs. It has been in use in India and China since times immemorial. In many African countries charcoal is produced traditional kilns in rural areas with efficiencies as low as 10% (Adam, 2009), and typically sold to urban households while rural households use fuelwood. Hardwoods are the most suitable raw material for charcoal, since softwoods incur possibly high losses during handling/transport. Charcoal from granular materials like coffee shells, sawdust, and straw is in powder form and needs to be briquetted with or without binder. Charcoal is also used in large-scale industries as iron reducer, particularly in Brazil, and also increasingly as co-firing in oil-based electric power plants. Charcoal is produced in large-scale efficient kilns and fuelwood comes from high-yielding eucalyptus plantations (Scolforo, 2008). In Africa, frequently illegal charcoal production is seen as a primary threat to remaining wildlife habitats.

2.3.2.2 Logistics

The majority of households in the developing world depend on solid biomass fuels such as charcoal for cooking, and millions of small-industries (such as brick and pottery kilns) generate process heat from these fuels. Despite this pivotal role of biomass, the sector remains largely unregulated, poorly understood, and the supply chains are predominantly in the hands of the informal sector (GTZ, 2008). They are complicated by certain characteristics of the feedstocks, including high moisture content, low density, and seasonal availability patterns, necessitating specific handling, drying and voluminous storage. They may involve several intermediate steps between the supplier and the end-user and encompass wide geographical areas. A generic value chain showing elements and stakeholders is given on Table 2.3.3.

Table 2.3.3. A generic value chain showing elements and stakeholders (based on GTZ, 2008).

Production ⇨	Harvesting/ charcoal making ⇨	Transport ⇨	Wholesale ⇨	Retail ⇨	End use
Wood Producer	*Charcoal producer*	*Transporter*	*Wholesaler*	*Retailer*	*End user*

When fuelwood is marketed, trees are usually felled and cut into large pieces and transported to local storage facilities from where they are collected by merchants to wholesale and retail facilities, mainly in rural areas. Some of the wood is converted to charcoal in kilns and packed into large bags and transported by hand, animal drawn carts and small trucks to roadside sites from where they are collected by trucks to urban wholesale and retail sites. Thus charcoal making is an enterprise for rural populations to supply urban markets. Crop residues and dung are normally used by the owners as a seasonal supplement to fuelwood.

2.3.3 Conversion technologies

Different end use applications of biomass involve various conversion processes, which can be classified according to Table 2.3.4.

Table 2.3.4: Main routes for converting biomass to a range of possible end-uses.

Process	Type of Feedstock	Conversion Technology	End use
Thermo chemical conversion	Lignocellulosic crops, wood , primary and secondary residues	Combustion Pyrolysis Gasification Liquefaction Cogeneration	Cooking/heating/electricity/ cogeneration
Chemical	Oil crops, waste	Acid Hydrolysis/ Transesterification	Electricity /liquid biofuels
Biochemical	Starch, sugar, lignocellulosic crops, wood, residues, organic waste	Anaerobic digestion Ethanol Fermentation	Cooking/heating/ power /liquid biofuels in vehicles

2.3.3.1 Thermo-chemical Processes

Biomass combustion is a process where carbon and hydrogen in the fuel react with oxygen to form carbon dioxide and water with a release of heat. Direct burning of biomass is popular in rural areas for cooking. About 2.4 billion people in developing countries use firewood in inefficient traditional open fire cook stoves in poorly ventilated kitchens leading to major health problems in women and children (see section 2.5). Major efforts have been launched in the past decade on the development of more efficient and reliable cookstoves.

Grate combustion is the most commonly-used technology for small-scale industrial processes and heating systems. Combustion applications of fluidised bed technology were commercially developed in the 1970’s, with the advantages of more flexibility for fuels, and lower emissions of sulphur, nitrogen oxides and unburned components (Fargernäs et al., 2006). The technology for generating electricity from biomass is similar to the conventional coal-based power generation. The biomass is burnt in boilers to generate steam, which drives a turbo alternator for generation of electricity. The equipment required for these projects comprises mainly of boilers, turbines, and grid inter-phasing systems. Recent innovations include the use of air-cooled condensers to reduce consumptive use of water.

Charcoal as described earlier is produced through a process known as carbonization, which comprises three distinct phases: drying, pyrolysis and cooling. These may considerably overlap when the charcoal is made in large kilns. Selection of the charcoal making technology is based on:

the investment costs, duration of carbonization, yield and labour intensiveness. The Missouri kiln is widely used in developed countries (Massengale, 1985). Unlike the earth mounted traditional charcoal kiln, they consist of permanent structures made up of brick or concrete construction that can be used for several batches with minor maintenance.

Cogeneration is the process of using a single fuel to produce more than one form of energy in sequence. In normal electricity generation plants, up to 70% of heat in steam is rejected to the atmosphere. In cogeneration mode, however, this heat is not wasted and is instead used to meet process heating requirement. The overall efficiency of fuel utilization can thus be increased to 60% or even higher (over 90%) in some cases (Williams et al., 2009). The sugar industry across the world has traditionally used bagasse-based cogeneration for achieving self-sufficiency in steam and electricity as well as economy in operations. Technologies available for high-temperature/high-pressure steam generation using bagasse as a fuel make it possible for sugar mills to operate at higher levels of energy efficiency and generate more electricity than what they require. Similarly black liquor, an organic waste produced in paper and pulp industry is being burnt efficiently in boilers for producing energy that is used back as process heat (Faaij, 2006).

Biomass Gasification is the thermo-chemical conversion of solid biomass into a combustible gas mixture (synthesis gas, a mixture of CO and H_2) through a partial combustion route with air supply restricted to less than that theoretically required for full combustion. Synthesis gas can be used as a fuel in place of diesel in suitably designed/adopted internal combustion (IC) engines coupled with generators for electricity generation. It can replace conventional forms of energy such as oil in many heating applications in industry. The gasification process renders use of biomass relatively clean and acceptable in environmental terms. Most commonly available gasifiers use wood/woody biomass; some can use rice husk as well. Many other non-woody biomass materials can also be gasified, specially designed gasifiers to suit these materials (Yokoyama and Matsumura, 2008). Fuel is loaded into the reactor from the top, and is subjected to drying and pyrolysis as it moves down Air is injected into the reactor in the oxidation zone, and through the partial combustion of pyrolysis products and solid biomass, the temperature rises to 1100 °C, helping in breaking down heavier hydrocarbons and tars. As these products move downwards, they enter the reduction zone where synthesis gas is formed by the action of carbon dioxide and water vapour on red-hot charcoal. The hot and dirty gas is passed through a system of coolers, cleaners, and filters before it is sent to engines or turbines. It can also be upgraded to a liquid fuel using a catalyst (with e.g. the Fischer-Tropsch process) to produce a range synthetic liquid biofuels (synfuels). Biomass gasifier stoves are also being used in many rural industries for heating and drying (Yokoyama and Matsumura, 2008).

Biomass Liquefaction is the process of conversion of biomass materials to liquid fuels. This can be done by thermal and biochemical methods. Among the most common method in use is destructive distillation of wood to form charcoal and methanol. Destructive distillation was used in the past for generating methyl alcohol, which is used as a solvent and in many other applications.

2.3.3.2 Chemical Processes

Transesterification is the process where the alcohols reacts with triglycerides oils contained in vegetable oils or animal fats to form an alkyl ester of fatty acids, in the presence of a catalyst (acid or base; WWI, 2006). The production of this fuel referred to as bio-diesel thus involves extraction of vegetable oils from the seeds, usually with mechanical crushing or chemical solvents. The protein-rich by-product of oil (cake) is sold as animal feed or fertilizers, but may also be used to synthesize higher-value chemicals. Bio-diesel can also be made by hydrodeoxygenation of vegetable oil through processes which are currently already deployed (IEA Bioenergy, 2009), which is especially interesting for oils with low saturation such as palm oil.

2.3.3.3 Biochemical Processes

Fermentation of sugars by appropriate yeasts produces ethanol. The major feedstocks are sugarcane, sweet sorghum, sugar-beet and starch crops (such as corn, wheat or cassava). Ethanol from sugarcane or sugar-beets is generally available as a by-product of sugar mills, but it can also be directly produced from extraction juices and molasses. The fermentation either takes place in single-batch or continuous processes, the latter becoming widespread and being much more efficient since yeasts can be recycles. The ethanol content in the fermented liquor is about 10%, and is subsequently distilled to increase purity to about 95%. As the ethanol required for blending with gasoline should be anhydrous, the mixture has to be further dehydrated to reach a grade of 99.8%-99.9% (WWI, 2006).

Ethanol is viewed as a promising alternative to gasoline throughout much of the world. It is widely used in cars and buses in Brazil (WWI, 2006). Technological developments, improvements in feedstock and better management practices induced with adequate environment control have turned Brazil into a global benchmark in production of ethanol from sugarcane. In India, sugar cane molasses is the feedstock for ethanol production. India is one of the developing countries where ethanol is being used as a five percent ethanol-gasoline blend. Corn ethanol is popular in U.S.A where it is used as a blend with gasoline. However, it is considered less efficient than other types of ethanol (e.g., sugar cane) because only the grain is used and many petroleum-based products are used in its production. In Europe, most of the ethanol is refined to ethyl tertiary butyl ether (ETBE) in oil refineries before blending (WWI, 2006).

Anaerobic digestion involves the breakdown of organic matter in biomass such as animal dung, human excreta, leafy plant materials, and urban solid and liquid wastes by micro-organisms in the absence of oxygen to produce biogas, a mixture of methane (50-60%) and carbon dioxide with traces of hydrogen sulphide. In this process, the organic fraction of the waste is segregated and fed into a closed container (biogas digester). In the digester, the segregated waste undergoes biodegradation in presence of methanogenic bacteria under anaerobic conditions, producing methane-rich biogas and effluent. The biogas can be used either for cooking/heating applications or for generating motive power or electricity through dual-fuel or gas engines, low-pressure gas turbines, or steam turbines (IEA Bioenergy, 2009). The sludge from anaerobic digestion, after stabilization, can be used as an organic amendment. It can even be sold as manure depending upon its composition, which is determined mainly by the composition of the input waste. In recent years biogas systems have become an attractive option for decentralized rural development as it produces a cheap fuel and good quality, rich manure (Faaij, 2006). Many developing countries like India and China are making use of this technology extensively in rural areas. In Germany large size biogas plants have been set up for digesting grains, food waste to produce green power that can bring more returns to the farmers (Faaij, 2006).

2.3.4 Bioenergy Systems and Chains: Description of existing state of the art systems

Table 2.3.5 shows the most relevant bioenergy systems and chains in commercial and demonstration status (marked in the last column as NA TSU: please indicate what NA is abbreviation of) at global level presently. For each end-use biofuel there is information about the feedstock being used the technology required in the processing stage, the end-use sector, the country or region, the production cost, the market potential and the deployment potential. Some other information is also described in the column “Comments”. Liquid biofuels are mainly used in the transport sector and ethanol costs are usually lower than biodiesel for the systems which are already in commercial use (the ones based in rapeseed, soya and oil palm). It is relevant to note that conversion efficiency (from feedstock to end-use product) is modest, from a little over 50% to around 10%. Note that this efficiency is measured with respect to the feedstock listed, which usually is a fraction of total biomass grown. Thus, space for better use of the feedstock and, mainly the total biomass produced, is remarkable. Solid biomass, mostly used for heat, power and heat&power has usually lower production costs than liquid biofuels. Unprocessed solid biomass is less costly than pre-processed type (via densification), but for the final consumer the transportation and other logistic costs have to be added, which justify the existence of a market for both types of solid biomass. It is important to note that some of the bioenergy systems are under demonstration for small scale application due cost barriers imposed by economy of scale and consequently it is necessary to identify a different technology than the one used successfully for large scale applications (such as combustion for electricity generation).

Table 2.3.6 describes the characteristics of the existing state of the art of some bioenergy systems. The table lists the major end-use, the technical process on which its operation is based, the fuel efficiency, and capital cost. Some brief explanations are added in the column “Comments”. It is important that all these systems are being used commercially but some of them are cost competitive for the particular activity listed in the row “Type of use”.

Table 2.3.5. Table summarizing the state of the art of the main chains for production of end use biofuels.

End use biofuel	Major end use	Processing	Feedstock	Site	Comments	Production Cost by 2006 (EU$/GJ)	Market potential +low/+++ high	Present deployment +low/+++high	References
Ethanol	Transport	Fermentation	Sugar cane syrup	Brazil	Eff. = 0.38 only ethanol production; Mill size, advanced power generation and optimised energy efficiency and distillation can reduce costs further in the longer term/surplus electricity, 50kWh/t of sugar cane	8 to 12*	+++	+++	*IEA Bioenergy: ExCo,2007
		Fermentation	Molasses	India					
				Colombia					
				Thailand					
				Brazil	Mill size, advanced power generation and optimised energy efficiency and distillation can reduce costs further in the longer term/surplus electricity, 50kWh/t of sugar cane	8 to 12*	+++	+++	
	Transport	Fermentation	Corn grain	USA	Eff. = 0.56 wet milling and 0.55 dry milling *	25**	++	+++	*UK DFT, 2009; **Hamelinck, 2004; *** Tao, Aden, 2009;****Bain, 2007
				USA	Dry mill only	16***-17****			
				China	Price includes subsidy	4.5RMB/kgEtOH			
	Transport	Fermentation	Sugar beet	EU	Eff. = 0.12 *	20 to30**	+	+	*UK DFT, 2009;**IEA Bioenergy: ExCo,2007
	Transport	Fermentation	Wheat	EU	Eff. = 0.53 to 0.59* ** ***	29***	+	+	*Reith, 2002;**IEA, 2002;***UK DFT, 2009
	Transport	Fermentation	Cassava	Thailand			+	+	
	Transport	Hydrolysis/Fermentation	Lignocellulosic	USA	Eff. = 0.47 for wood and 0.40 for straw; includes integrated electricity production of unprocessed components*	12 to 17** 14-16*** (TC-BC) 10-13****(TC-BC) 17.6 (BC)*****	+++	NA	*Reith, 2002;**IEA Bioenergy: ExCo,2007; *** Tao, Ling, 2009;;****Bain, 2007;*****NRC, 2009
			corn stover***	USA	TC=thermochemical; BC=biochemical				

End use biofuel	Major end use	Processing	Feedstock	Site	Comments	Production Cost by 2006 (EU$/GJ)	Market potential +low/+++ high	Present deployment +low/+++high	References
				OECD		18 to 39*	+++	NA	*Sims et al., 2008
Liquids from biomass	Transport	Fischer-Tropsh	Lignocellulosic	USA	Via biomass gasification and subsequent syngas processing	12 to 17*	+++	NA	*Sims et al., 2008
						21**			** NRC, 2009
				OECD		18 to 39*	+++	NA	*Sims et al., 2008
Biodiesel	Transport	Transesterification	Rape seed	Germany	Eff. = 29%. For the total system it is assumed that surpluses of straw are used for power production*	25 to 40**	+++	++	*CSIRO, 2000; **IEA Bioenergy: ExCo,2007
				France					
	Transport	Transesterification	Soya	Brazil		24 to 34*	+++	+	*Agrolink, 2009
				USA		18**			**Tao, Aden, 2009
	Transport	Transesterification	Oil palm	Indonesia			+++	++	
	Transport	Transesterification	Jatropha	Tanzania	Large uncertain in yield/lack of data: assuming seed yields of 2.5 and 1 t/ha/yr in semi arid and arid regions can be obtained. With oil content of seeds of 34% and oil extraction of 90%, oil yields ranges from 0.8 to 0.3 t/ha/yr in these regions*	5.5*	+++	NA	*Wicke et al., 2009
	Transport	Transesterification	Vegetable oil	109 countries	Based in total lipids exported costs was evaluated for 109 countries. Neglects few countries with high production cost*	5.52 to 23.8*	+++	++	*Johnston and Holloway, 2007
	Transport	Transesterification	Microalgae	USA Experiment	Assuming biomass production capacity of 10,000 t/yr, cost of production per kg is $0.47 and $0.60 for photobioreactors and raceways, respectively. Assuming biomass contains 30% oil by weight, cost of biomass for providing a liter of oil would be $1.40 and $1.81, respectively. Oil recovered from the lower-cost biomass produced in photobioreactors costs $2.80/L.*. **Productivity =2.5 g/sqm/day; ***Productivity=10 g/aqm/day	80 or more* 140-180** 40-60***	+++	NA	*Chisti, 2007 *** Pienkos, Darzins, 2009
Renewable diesel	Transport	Hydrogenation	Soya	USA	LC Energy required 9.3 MJ/l assuming electricity efficiency conversion of 40%*	16**	+++	NA	*USEPA, 2008
									**Bain, 2007

End use biofuel	Major end use	Processing	Feedstock	Site	Comments	Production Cost by 2006 (EU$/GJ)	Market potential +low/+++ high	Present deployment +low/+++high	References
	Transport	Hydrogenation	Yelow grease	USA	LC Energy required 3.3 MJ/l assuming electricity efficiency conversion of 40%*	10**	+++	NA	*USEPA, 2008 **See note 2
	Transport	Hydrogenation	Rape seed	OECD		16*	+++	NA	*Hamelinck, 2004
Methanol	Transport	Gasification/Synthesis	Lignocellulosic	USA/EU	Combined fuel and power production possible	10 to 15*	+++	NA	*IEA Bioenergy: ExCo,2007
Butanol	Transport	Fermentation	Sugar/starch	USA		17.5*	+++	NA	* Tao, Aden, 2009
Liquid biofuels in general	Transport	Hydrolysis& Fermentation	Energy crops	EU	Price value calculated for the year 2000	12 to 16 *	+++	+++	*Hoogwijk, 2004
Hydrocarbons fuels (gasoline, diesel and jet fuel)	Transport	Biological synthesis from sugars or catalytic upgrading	Sugar, starch, or lignocellulosic	U.S. (and elsewhere)	Ongoing R&D with small pilots; insufficient public data for technoeconomic evaluation; dozens of companies developing intellectual property and starting commercialization*		+++	NA	NSF, 2008; DOE, 2009; Tang, Zhao, 2009; Biofuel Digest, 2008
briquettes	Electricity	Drying/Mechanical compression	Wood residues	EU/USA/ Canada	Large and continuously increasing co-combustion market	5.0*	+++	++	*Riegelhaupt et al., 2009
wood pellets	Heat	Drying/Mechanical compression	Wood residues	EU/USA/ Canada	Large and continuously increasing residential market	5.3*	+++	++	*Riegelhaupt et al., 2009
bagasse pellets	Heat	Drying/Mechanical compression	Sugar cane	Brazil	Large potential availability. No commercial use	3.1*	+++	NA	*Riegelhaupt et al., 2009
Solid biofuel	Electricity/Heat	Direct combustion	Forestry	EU		4*	+++	++	*Hoogwijk, 2004
	Heat (residential)	Pyrolysis	Wood	Developing countries	Use wood in large pieces or whole tree trunks. It is difficult to dry such large pieces before carbonising and the yield overall is lower but wood preparation costs are negligible*	2.1**	+++	+	*FAO, 2009; **Riegelhaupt et al., 2009
	Heat (industry)	Pyrolysis	Wood	Worldwide	Wood in smaller pieces is easier to dry in the air and hence the yield in carbonising is higher and is also required for the mechanised feeding systems used in most industrial type carbonising processes. Generally any industrial system adopted must face quite large wood preparation costs*	2.1**	+++	+	*FAO, 2009; **Riegelhaupt et al., 2009

End use biofuel	Major end use	Processing	Feedstock	Site	Comments	Production Cost by 2006 (EU$/GJ)	Market potential +low/+++ high	Present deployment +low/+++high	References
Fuelwood (small scale)	Heat (residential)	combustion	Fuelwood, biomass residues	Worldwide	Traditional devices are inefficient and generate indoor pollution. Improved cookstoves are available that reduce fuel use (up to 60%) and cut 70% indoor pollution	2.5*			See Note 1)
							´+++	+	
	Heat (small industries)	Combustion		Worldwide	Existing industries have low efficiency kilns that are also high polluting. Improved kilns are available that cut consumption in 50-60%	2.5*	´++	+	
Biomass gases									
(small scale)	Power & heat	Gasification	Wood residue	Worldwide	eff., 17%, India	2.5-3.5Rs/kWh	++	+	
		Gas engine	Agro residues		eff., 20%, Japan; Assumptions: 1) Biomass cost $3/GJ; Discount rate 10%; 2) Heat value $5/GJ.	7.5*			
									*IEA Energy, 2007
(large scale)	Power & heat	Gasification	Wood residue	Worldwide	IGCC; Assumptions: 1) Biomass cost $3/GJ; 2) Discount rate 10%	7 to 9*	+++	NA	
		Gas turbine	Agro residues						*IEA Energy, 2007
(large scale)	Synthetic diesel	Gasification	Wood residue	Worldwide		22	+++	NA	*Hamelinck, 2004
		Synthesis	Agro residues			21**			**NRC, 2009
Biogas									
Household biogas	Cooking, heat	Digestion	Manure	Worldwide	byproduct: liquid fertilizer		++	+	
			Human wastes		payback time	1-2 years			
Biogas (big scale)	Electricity	Digestion plus gas engine/ steam turbine	MSW	Worldwide	byproduct: liquid fertilizer		+++	+	
			Agro residues		eff., 15-20%				
			Industry waste		Widely applied for homogeneous wet organic waste streams and waste water*				*IEA Bioenergy: ExCo,2007
Biogas (medium scale)	transportation	Digestion plus gas clean up and compression	manures	US	By product credit not considered for fertilizers	14*	++	+	*Krich et al., 2005 Sustainable **Transportation Solutions, 2006
				UK	Developmental stage	13**			

End use biofuel	Major end use	Processing	Feedstock	Site	Comments	Production Cost by 2006 (EU$/GJ)	Market potential +low/+++ high	Present deployment +low/+++high	References
Biogas (small scale) includes landfill	Cooking, heat, electricity				Widely applied and, in general, part of waste treatment policies of many countries*		++	++	*IEA Bioenergy: ExCo,2007
					eff. 10-15%*				*IEA Bioenergy: ExCo,2007
Co-firing	Electricity	Combustion	MSW	Worldwide	eff., ~40%				
			Wood residue		Assumptions: 1) Biomass cost $3/GJ; 2) Discount rate 10%; 3) eff. 35-40%	0.05 US$/kWh*			*IEA Energy, 2007
Biomass pyrolysis	Fuel	Pyrolysis	Wood residue	OECD	Demonstration stage*		++(+)	NA	*Bauen et al., 2004
			Agro residues	USA	Commercial for specialty, demo for fuels	5.5**			**Bain, 2007
Biomass for direct combustion	Power & heat	Combustion	Wood	Worldwide	Processes are in demonstration for small-scale applications between 10 kW and 1 MWe. Steam turbine based systems 1-10 MWe are widely deployed throughout the world. Efficiency of conversion to electricity in the range of 30-35%*	Ect5-15 /kWh. High costs small scale power gen. with high-quality feedstock. Low costs for large-scale (i.e., >100 MWth) state-of-art* ** ***	+++	+	*IEA Bioenergy: ExCo,2007
			Wood residues						*Egsgaard et al., 2009, **IEA Bioenergy: ExCo,2007, ***IEA Energy, 2007
			Briquettes						

End use biofuel	Major end use	Processing	Feedstock	Site	Comments	Production Cost by 2006 (EU$/GJ)	Market potential +low/+++ high	Present deployment +low/+++high	References
			Bagasse		Concentration of chloride and potassium salts. Straw contains a lot of these salts, which can cause corrosion and slagging problems. The need to make power plants from corrosion-resistant materials has increased the cost of energy from straw, at least in Denmark*	state-the-art combustion (wood, grasses) and co-combustion**	+++	NA	*Risø Energy, 2009
			Straw						
									**Egsgaard et al., 2009
	Power	Combustion	Several solid biomass	USA	Cost of electricity delivered to consumer in EU/GWh. Cost off biomass EU$ 2/GJ	19.8*	+++	++	*Electricity from Renewable, 2009
Hydrogen	Transpor t	Gasification/Syn gas processing	Several solid biomass	USA/EU	Combined fuel and power production possible	9 to 12*	+++	NA	*Hoogwijk, 2004
						10**			**Bain, 2007
Note 1) Costs are extremely variable (from 0 monetary costs when fuelwood is collected to 8 GJ or more when fuelwood is scarce)									
Note 2) http://www.eia.doe.gov/oiaf/analysispaper/biodiesel/pdf/tbl5.pdf corrected									

Table 2.3.6: Main characteristics of the existing state of the art Bioenergy Systems

Type	**Major end-use**	**Process**	**Type of use**	**Characteristics**	**Cost US$_{2005}$$**
Improved Cookstoves	Cooking	Combustion/ Gasification	Domestic/ Commercial	Fuel Efficiency 15-40%. New stoves with optimized combustion chambers and cookstoves that gasify fuelwood are being disseminated at large scale. Stoves may be massive, with chimney and multiple pans, or small and light-weight without a flue and single pot. Newest models serve also as water heaters for bath and produce electricity using the themo-electric effect.	5-100 US$/device
Gasifiers	Cooking /Power generation	Partial combustion of woody biomass, agro residues to generate producer gas	Community /Commercial	CO + H_2 low calorific producer gas can be used for thermal energy 80% and electrical energy 60% applications	0.5-0.8 million US$ / MW thermal 0.5- 0.8 million US$ / MW electrical
Steam Boilers	Heat	Cogeneration	Power for captive and grid requirements	High pressure boilers	0.5- 0.8 million US$ / MW electrical
BiogasPlants	Cooking /Power generation /Lighting	Anaerobic Digestion /Biomethanation	Individual households /Commercial for decentralised power generation	Digestor with an inlet and outlet and a unit for storage of Gas Can digest organic waste through the biological route to produce gas and manure Efficiency is 20%	200 US$ per M^3
Biodiesel/ Ethanol plants	Power Generation /Transportation	SVO or transesterification	Commercial and for grid interactive and decentralized power production	Expellers, Transesterification plants	1 US$ per liter

2.4 Global and Regional Status of Market and Industry Development

2.4.1 Introduction

The status and development of biomass market are reviewed considering technologies, activities and products that are used regionally and in geographically widespread applications through international markets.

For local markets it is worth noting that the use of bioenergy technologies provides a simple, local and renewable solution for energy related to cooking, heating and lighting mainly in rural areas. However widespread, dissemination of these technologies may be limited by the purchasing power of the people and availability, as well as access to the biomass resource used. Lack of education, awareness and motivation are among the prime factors that obstruct regional penetration of such technologies. The extent to which they have currently penetrated into or are in use in rural areas and the limitations faced are described in the first part of this section.

For non-local biomass market barriers cover a larger area of issues and we will discuss them in section 2.5

2.4.2 Biogas Technology

Biogas systems are functional under a wide range of climatic conditions. Nonetheless, widespread acceptance and dissemination of biogas technology has not yet materialized in many countries.

A number of psychological, social, institutional, legal and economical factors present barriers that impair the development of energy from biogas.

Legal and Financial Barriers:

- lack of proper legal standards determining explicitly the programme and policy;
- insufficient economic mechanisms, in particular fiscal, to facilitate achieving the desirable profits related to the investment costs, installations and equipments;
- relatively high costs of technologies and of labour (e.g. geological investigations).

Information Barriers:

- lack of easily available information on projects feasible for technical applications;
- lack of easily accessible information on procedures for projects implementation and realisation, standard costs, economic, social and ecological benefits;
- lack of information on installations producers, suppliers and contractors
- lack of information on the certainty of the design and construction of scale anaerobic digestion systems
- limited application of knowledge gained from the operation of existing plants in the design of new plants
- lack of familiarity with biogas investments in the financial community

A number of countries have initiated biogas programmes - China and India, for example are promoting biogas on a large scale, and there is significant experience of commercial biogas use in Nepal (Hu, 2006; Rai, 2006; India, 2006). Results have been mixed, especially in the early stages (TSU: empty bracket – reference missing?). Quality control and management problems have resulted in a large number of failures. Biogas experience in Africa has been on a far smaller scale and has been often disappointing at the household level (TSU: empty bracket – reference missing?). The capital cost, maintenance, and management support required have been higher than expected. Under subsistence agriculture, access to cattle dung and to water that must be mixed with slurry has been more of an obstacle than expected. Possibilities are better where farming is done with more actively managed livestock and where dung supply is abundant - as in rearing feedlot-based livestock. (Hedon Household Network, 2006)

Experience of NGOs that are members of the Integrated Sustainable Energy and Ecological Development Association (INSEDA) for the last more than two decades in the transfer, capacity building, extension and adoption of household biogas plants in rural India has shown that for successful implementations of biogas and other RET programmes in the developing countries, the important role of NGOs networks/associations needs to be recognized. These may provide funding and support under the Clean Development Mechanism (CDM) in the implementation of household biogas programmes in target regions through north-south partnerships in which both groups gain. Developing such partnerships would lead to establishing a global data base, measurement of GHGs, as well as closer follow-up and monitoring that ensures the longer term sustainability of such programmes. In order to realize the full potential, treating biogas programmes as an important tool for empowering rural population in general and rural women in particular, appropriate changes in funding and policy support for such programmes is required (VODO, 2001).

In order to promote dissemination of biogas technology at the grassroots communities four activities are important (Hedon Household Network, 2006):

Promotion. It should make potential users aware of the existing technology and raise interest in biogas. Awareness is the starting point for later investment decision, but does not necessarily lead to active interest (TSU: empty bracket – reference missing?).

Information and education. Potential users who are aware and have some interest in the technology need be able to obtain more information and properly evaluate the usefulness of implementation under their circumstances. The information activities should not be biased, should be available for all members of the households, need to be decentralized and could include farmers' seminars, orientation workshops, but also individual contacts between potential users and extension workers or service providers (TSU: empty bracket – reference missing?).

Personal persuasion by a credible personal contact is required to solidify the interest of potential users of the technology. Persuasion to illiterate and semi-literate people requires more time than with educated population.

Implementation is an individual or intra-family matter. The period between awareness and decision for adoption varies and depends on a number of factors including the economic and socio/cultural situation of the potential user. Economical and socio/cultural constraints influence the ultimate potential.

2.4.3 Improved Cookstove Technology

Reasons for success or failure of Improved Cookstoves Programs have been outlined in Table 2.4.1 below:

Table 2.4.1

Reasons for success	**Reasons for Failure**
Program targets region where traditional fuel and stove are purchased or fuel is hard to collect.	Program targets region where traditional fuel or stove are not purchased or fuel is easy to collect.
People cook in environments where smoke causes health problems and is annoying.	People cook in the open, and smoke is not really a problem.
Market surveys are undertaken to assess potential market for improved stoves.	Outside experts determine that improved stoves are required.
Stoves are designed according to consumer preferences, including testing under actual use.	Stove is designed as a technical package in the laboratory, ignoring customers' preferences
Stoves are designed with assistance from local artisans.	Local artisans are told or even contracted to build stoves according to specifications.
Local or scrap materials are used in production of the stove, making it relatively inexpensive.	Imported materials are used in the production of the stove, making it expensive.
The production of the stove by artisans or manufacturers is not subsidized.	The production of the stove by artisans or manufacturers is subsidized.
Stove or critical components are mass-produced.	

Similar to traditional stove.	Critical stove components are custom built.
The stove is easy to light and accepts different sized wood.	Dissimilar to traditional stove.
Power output of stove can be adjusted.	The stove is difficult to light and requires the use of small pieces of wood.
The government assists only in dissemination, technical advice, and quality control.	Power output cannot be easily controlled.
The stove saves fuel, time, and effort.	The government is involved in production.
	The stove does not live up to promised economy or convenience under real cooking conditions.
Donor or government support extended over at least 5 years and designed to build local institutions and develop local expertise.	Major achievements expected in less than 3 years, all analysis, planning, and management done by outsiders.
Monitoring and evaluation criteria and responsibilities chosen during planning stages according to specific goals of project.	Monitoring and evaluation needs are not planned and budgeted, or criteria are taken uncritically from other projects or not explicitly addressed.
Consumer payback of 1 to 3 months.	Consumer payback of more than 1 year

The World Bank and the Shell Foundation, and ARTI an NGO based in Pune have developed strategies to promote improved biomass based fuels and improved cooking devices through commercialisation mode. A programme, acceptable to all the stake-holders has been chalked out and no direct subsidy would be given either to the improved fuels nor to any of the cooking devices, but financial assistance would be made available for propaganda, users' training, manufacturers' training, market research, market development and promotion. (Arti Pune artiindia.org, quoted in Muller, 2007) TSU: If this is a direct quote, please mark it as one. Ideally rephrase/shorten it. . In the eastern Democratic Republic of Congo, stoves using briquette fuel manufactured from biomass wastes are being disseminated into urban as well as rural populations through a coordinated programme that is economically stabilised through NGO funding. The aim is to decrease unsustainable charcoal use that is causing illegal deforestation in biologically diverse national parks, particularly in Virunga National Park. The programme is transitioning from the NGO-guaranteed start-up phase to economic viability on the open market in competition with traditional charcoal (Virunga National Park, www.gorilla.cd).

2.4.4 Small-Scale Bioenergy Initiatives

Linkages between livelihoods and small-scale bioenergy initiatives were studied based on a series of 15 international case studies conducted between September and November 2008 in Latin America, Africa and Asia (Energy Research Programme Consortium, 2009). The cases were selected to highlight the use of a range of bioenergy resources (residues from existing agricultural, forestry or industrial activities; both liquid and solid energy crops). These resources were matched to a range of energy needs that included cooking, mobility, productive uses and electricity for lighting and communication. The approach taken also considers the non-energy by-products of production processes where these form, or could form, a significant added benefit in terms of livelihoods, revenues and efficiency. A summary of preliminary lessons and conclusions that are drawn from these case studies are summarised as follows (Practical Action Consulting, 2009):

- Natural resource efficiency is possible in small-scale bioenergy initiatives
- Local and productive energy end-uses develop virtuous circles
- Where fossil energy prices dominate, partial insulation is an option

- Longer term planning and regulation plays a crucial role for the success of small-scale bioenergy projects.
- Flexibility and diversity can also producer risk TSU: did you mean "produce risks" or "increases produces' risks"?
- Collaboration in the market chain is key at start up
- Long local market chains spread out the benefits
- Moving bioenergy resources up the energy ladder adds value
- Any new activity raising demand will raise prices, even those for wastes
- Cases do not appear to show local staple food security to be affected
- Small-scale bioenergy initiatives offer new choices in rural communities

2.4.5 Overview of existing policies relevant for bioenergy

2.4.5.1 Global Bioenergy Partnership (GBEP) Overview

The purpose of the Global Bioenergy Partnership is to provide a mechanism for partners to organize, coordinate and implement targeted international research, development, demonstration and commercial activities related to production, delivery, conversion and use of biomass for energy, with a particular focus on developing countries. GBEP also provides a forum for implementing effective policy frameworks, identifying ways and means to support investments, and removing barriers to collaborative project development and implementation. The partnership builds in the three strategic pillars of energy security, food security and sustainable development, which demonstrates the interlinkage between these topics. It will undertake the GBEP Report (GBEP, 2007), which provides a platform for future GBEP's work towards the sustainable development of bioenergy, facilitate the sustainable development of bioenergy and collaboration on bioenergy field projects, and formulate a harmonized methodological framework on GHG emission reduction measurement from the use of biofuels for transportation and for the use of solid biomass while raising awareness and facilitating information exchange on bioenergy.

2.4.5.2 Policies that might promote bioenergy in the U.S. Research, development and demonstration

TSU: Not clear why U.S. is taken as example here. Either state reason for this ("representatice", "forerunner") or replace section with overview including/compare with other industrialized countries.

In developed countries such as the United States, there is a continued need for technology development to address issues such as contamination, improving efficiencies and reducing costs. There is also a need for more research on growing energy crops cheaply and with minimum of environmental impact.

Tax Credits

The last Energy Policy Act to be passed by Congress was in 1992 (Energy Policy Act, 1992). Section 45 of the Energy Policy Act of 1992 offers a 1.5 cent per kWh tax credit to wind power and "closed-loop biomass", which means only energy crops purchase the required biomass. Such a tax credit can be extended to include many more forms of biomass, which are cheaper than energy crops. The credit does not have to be restricted to biomass for power plants—it can include biomass for small industrial boilers and district energy operations. The tax credit allows bioenergy operators to compete with other industries that use biomass, so that a consistent, high quality supply of biomass is possible.

The US congress has been working on updating the Energy Policy Act for 2005 (Energy Policy Act, 2005) to include new incentives and support for the biomass industry. The proposed act as approved by the US senate June 28, 2005 would set an 8 billion gallon TSU: please use SI units renewable portfolio standard for ethanol by 2012 and supply $18 billion in tax breaks over the next 10 years.

Also, the National Security and Bioenergy Investment Act of 2005 would "expand research and development of biomass energy and biobased products, establish the position of Assistant Secretary of Agriculture for Energy and Biobased Products at the U.S. Department of Agriculture, and provide incentives to businesses producing biofuels." [1]

Finally, accelerated depreciation and investment tax credits can help catalyze new biomass CHP projects by making near-term economics more attractive to financiers.

Renewable fuels standard

The renewable fuels standard requires an increasing percentage of transportation fuel sold in the United States be biofuels. The policy features a credit trading system to allow refiners, blenders, and retailers to buy and sell credits from each other to meet their goals.

Renewable portfolio standard (RPS)

Biomass power plants can be included in renewable portfolio standards, which require a certain percentage of power within a state or the entire U.S. to come from renewables. The RPS also features a credit trading system similar to the renewable fuels standard. (Federal Bill, 2005)

2.4.5.3 Biofuel policies in selected Asian countries

In Asia, India has pioneered policies implementation in the renewable energy sector. The work started in 1974 with the establishment of the Fuel Policy Committee, proceeds with the creation of the Department of Non-conventional Energy Sources in 1982, creation of the Ministry of Non-conventional Energy Sources in 1992, and provided institutional and economic support to renewable through the Electricity Act (2003), National Electricity Policy (2005) and the National Tariff Policy (2006), which clearly set preferences and economic advantages to them (Singh, 2007).

Several others Asian countries have declared major policy initiatives so as to substitute petroleum products with a view to cut consumption reduce pollution and also avail CDM benefits (see Table 2.4.2). Some of these are tabulated below:

Table 2.4.2 Major Policy Initiatives in Asian Countries

Country	**Blending rate**	**Major feedstocks**	**Strategy / Goal / Economic measures**
India	E5	Jatropha, Sugarcane	Indian Biofuel National Strategy, 2008 / 20% biodiesel and bioethanol by 2017 / 11.2 mil ha of jatropha planted and matured by 2012 for the target blend of 20% / fixed prices for purchase by marketing companies.
China	E10	Corn, Cassava	Biofuel share 15% of transportation energy by 2020; incentives, subsidies and tax exemption for production
Malaysia	5%	Palm	National Biofuel Policy, 2006 / B5; Diesel : plans to subsidize prices for blended diesel
Indonesia	BDF : 10%		E5 Palm, Jatropha National Energy Program, B20 and E15 in 2025; Diesel : subsidies (at same level as fossil fuel)
Thailand	5%	Palm, Cassava	Biodiesel Development and Promotion Strategy Enforce national wide B2 in April, 2008 / B5 in 2011 / B10 in 2012; Ethanol : price incentives through tax exemptions
Philippines	BDF : 1%	Coconut	Biofuel Strategy 2006 / BDF mixing rate 1%, 2% by 2009 / Ethanol : 5% by 2009, 10% by 2011; tax exemption and priority in financing
Japan	E3, B5	Sugar, Waste oil	Plan to replace 500 ML / year of transport petrol with liquid biofuels by 2010; subsidies for production

Source: Romero J & Elder M, 2009

2.4.6 Barriers & Opportunities (institutional, regulatory issues, social, technological, economic/financial, etc.)

Bio-energy continues to play a significant share in global energy consumption. Bio-energy has often been associated with poor environment and health hazards but these attributes are not inherent to bio-energy but the consequence of under development, cultural factors and economic settings. Application of modern biomass systems supported by sustainable international trade could facilitate changes in biomass based employment in developing countries and contribute to their overall development. However, a fair trade concept and complete sustainability are still a big challenge. There are many issues which need to be resolved before biomass can take to the global markets. Some of the issues have been listed below.

2.4.6.1 Domestic production vs. import/export

Because biomass use is particularly favoured because of the desired effect of lowering GHG emissions, resources and chains should be favoured (and perhaps certified) that maximize GHG mitigation. This implies minimisation of energy inputs, but also optimization of the use of biomass, e.g., including comparison between indigenous use versus export. While many developing countries have a low energy consumption compared to developed countries, their energy demand is increasing rapidly. Hence there is need to assess the need within a country and its export.

2.4.6.2 Solving sustainability issues: International classification and certification of biomass

Certification of biomass may be one way to prevent negative environmental and social side-effects. By setting up minimum social and ecological standards, and tracing biomass from production to end-use, sustainability of biomass production can be ensured. In an exploratory study it has been shown that such social and environmental standards do not necessarily result in high additional costs (Smeets et al., 2005). However, when implementing a certification scheme for sustainable bio-energy, several other issues have to be dealt with. Firstly, criteria and indicators need to be designed/adopted according to the requirements of a region. Also, compliance with the criteria has to be controllable in practice, without incurring high additional costs. Second is avoidance of leakage effects (e.g. indirect land use emissions – see Section 2.5). Whether an independent international certification body for sustainable biomass is feasible should be investigated. Any certification scheme should on the one hand be thorough, comprehensive and reliable, but on the other also not become a barrier to markets in itself.

2.4.6.3 Setting up technical biomass standards

By setting up internationally accepted quality standards for specific biomass streams (e.g., Comité Européen de Normalisation, biofuel standards), biomass end users may have a higher confidence in using different biomass streams.

2.4.6.4 Lowering of trade barriers

Biofuels could help industrialized countries to promote reduction of carbon emissions but in some cases – as is the case of ethanol export to the US and the EU – exporting countries face trade barriers. Most of these barriers are established on the basis of technical reasons, but the aim can also be understood as a way to protect local producers whose production costs are much higher than those in developing countries. The solution pointed out by some analysts TSU: give reference here is to liberalize environmental goods and services (EGS) and to include biofuels as EGS. Building up structural international statistics (volumes and prices) on bio-energy trade is desirable, but has not been done so far.

2.4.6.5 Building up long-term sustainable international bio-energy trade

To achieve both growing markets and long-term sustainable biomass trade, a pragmatic approach is needed. It is desirable to focus first on routes with low barriers. A compromise should be found between developing certification efforts and ensuring sustainability of bio-energy and developing the market. While not all biomass types may fulfill the entire set of sustainability criteria initially, the emphasis should be on the continuous improvement of sustainability. For such an approach, public information dissemination and support is crucial (Lewandowski and Faaij, 2006). Sustainability may best be addressed by a sound certification framework, supported by international bodies. This is particularly relevant for markets that are highly dependent on consumer opinion, as is currently the case in Western Europe. It is even more important for the developing countries and rural regions to be aware of the opportunities and limitations for modern bio-energy in an international setting and to become involved in debate and collaboration for achieving sustainable development where it is most needed. The future vision for global bio-energy trade is that it develops over time into a real “commodity market”. It is clear that on a global scale and over the longer term, large potential biomass production capacity can be found in developing countries and regions such as Latin America, Sub-Saharan Africa and Eastern Europe.

2.4.7 Emerging international bio-energy markets: Developments and perspectives

2.4.7.1 Trends and drivers

Trade flows are taking place between neighboring regions or countries, but trade is increasing also over long distances. Examples are export of ethanol from Brazil to Japan, the EU and the USA, palm kernel shells from Malaysia to the Netherlands, and wood pellets from Canada to Sweden. This is happening despite the greater bulk and lower calorific value of most biomass raw material. These trade flows offer multiple benefits for both exporting and importing countries but driving forces and rationales behind the development of trade in bio-energy are diverse. They can be structured as described below. (See also Hamelink et al., 2005a; Hamelink et al., 2005b; Junginger et al., 2005) In most cases the following factors appear in combination.

1. *Raw material/biomass push.* These drivers are found in most countries with surplus of biomass resources. Ethanol export from Brazil and wood pellet export from Canada are examples of successful push strategies.

2. *Market pull.* Import to the Netherlands is facilitated by the very suitable structure of the leading big utilities. This makes efficient transport and handling possible and leads to low fuel costs compared to those available to users in other countries where the conditions are less favourable.

3. *Utilizing the established logistics of existing trade.* Most of the bio-energy trade between countries in Northern Europe is conducted in integration with the trade in forest products. The most obvious example is bark, sawdust and other residues from imported roundwood. However, other types of integration have also supported bio-energy trade, such as use of ports and storage facilities, organizational integration, and other factors that kept transaction costs low even in the initial phases. Import of residues from food industries to the UK and the Netherlands are other examples in this field.

4. *Effects of incentives and support institutions.* The introduction of incentives based on political decisions has increased the strength of the driving forces and triggered an expansion of bio-energy trade. However, the pattern has proved to be very different in the various cases, due partly to the nature of other factors, partly to the fact that the institutions related to the incentives are different. It seems obvious that institutions fostering general and free markets, e.g., CO_2 taxes on fossil fuels are more successful than specific and time-restricted support measures.

5. *Entrepreneurs and innovators.* In countries such as Austria and Sweden, individual entrepreneurs and innovators have had a leading role in the development of bio-energy trade. This has led to a more diversified pattern compared to that in, e.g., Finland, where bioenergy is handled by mature industries, especially within the forestry sector.

6. *Unexpected opportunities.* Storms, forest fires, insect attacks, etc., may lead to short-term imbalances in the supply. Technical failures and other reasons for shutdown cause disturbance in

the user and in distribution systems. Such short-term opportunities have often led to new trade patterns, some of which may remain even when the conditions return to normal. For example, last year's TSU: give year hurricanes in the eastern part of the USA led to a short-term trade in wood chips to Europe. For market parties such as utilities, companies providing transport fuels, and parties involved in biomass production and supply (such as forestry companies), good understanding, clear criteria and identification of promising possibilities and areas are of key interest. Investments in infrastructure and conversion capacity rely on minimization of risks of supply disruptions (in terms of volume, quality and price).

2.4.7.2 Barriers

On the basis of literature review and interviews, a number of potential barrier categories have been identified. Junginger et al. (2008) have listed the main barriers as follows

Economic barriers

Competition with fossil fuel on a direct production cost basis. High prices of bioenergy products cause a constraint on the supply side.

Due to the size, often small, of bio-energy markets and the fact that biomass by-products are a relatively new commodity in many countries, markets can be immature and unstable. This makes it difficult to sign long term, large-volume contracts, as doing so is seen as too risky. Also, with no harmonised support policy (e.g., on an EU level), new national incentives (and associated demand for bio-energy) may distort the market and shift supply to other countries within a short time-frame.

Technical barriers

Different types of biomass possess different physical and chemical properties making it difficult and expensive to transport and often unsuitable for direct use, say for co-firing with coal or natural gas power plants. Power producers are generally reluctant to experiment with new biomass streams, e.g., bagasse or rice husk.. While technology is available to deal with the fuels, it may take several years or even decades before the old capacity is replaced.

Logistical barriers

There is a lack of technically mature pre-treatment technologies for compacting biomass at low cost to facilitate transportation, although this is fortunately improving. Densification technology has improved significantly recently, e.g., for pellets, although this technology is only suitable for certain biomass types. In the case of the import of liquid biofuels (e.g., ethanol, vegetable oils, bio-diesel), this is not an issue, as the energy density of these biofuels is relatively high.

Various studies have shown that long-distance international transport by ship is feasible in terms of energy use and transportation costs (see below) but availability of suitable vessels and meteorological conditions (e.g., winter time in Scandinavia and Russia) need be considered.

Local transportation by truck (in both biomass exporting and importing countries) may be a high cost factor, which can influence the overall energy balance and total biomass costs. For example, in Brazil, new sugar cane plantations are being considered in the Centre- West, but the cost of transport and lack of infrastructure can be a serious constraint. Harbour and terminal suitability to handle large biomass streams can also hinder the import and export of biomass from and to certain regions.

International trade barriers

A lack of clear technical specifications for biomass (see above) and specific biomass import regulations. This can be a major hindrance to trading. For example, in the EU most residues that contain traces of starches are considered potential animal fodder and are thus subject to EU import levies. For example denaturised ethanol of 80 % concentration and above, the import levy is 102 Euro/m^3 (i.e., about 4.9 Euro/GJ) TSU: all monetary values provided in this document will need to be adjusted for inflation/deflation and then converted to USD for the base year 2005. For conversion tables see http://www.ipcc-wg3.de/internal/srren/fod, representing substantial additional costs. It is important to bear in mind that some technical trade barriers can be, in fact, imposed to constrain imports and to protect local producers.

Transport tariffs. In recent years, general transport tariffs have increased quite significantly, e.g., transport for wood pellets to the Netherlands cost on average 1.75 Euro/GJ (on a total cost of 7-7.5 Euro) in 2004.

Possible contamination of imported biomass with pathogens or pests (e.g., insects, fungi) can be another important limiting factor in international trade. However, it is important to bear in mind that these limitations are not exclusive to bio-energy.

Land availability, deforestation and potential conflict with food production

Competition for land: while theoretically large areas of (abandoned/degraded) cropland are available for biomass cultivation, biomass production costs are generally higher due to lower yields and accessibility difficulties. Deforested areas may be easier as they may have more productive soil. Food security, i.e., production and access to food, would probably not be affected by large energy plantations if proper management and policies are put in place. However, in practice food availability is not the problem, but the lack of purchasing power of the poorer strata of the population.

In developed countries, a key issue is competition with fodder production. If there was a large increase in demand for energy, say of agricultural residues, scarcity of fodder products may occur, leading to a price increase.

Sustainability issues

Large-scale biomass-dedicated energy plantations also pose various ecological and environmental issues that cannot be ignored, including long-term monoculture sustainability, potential loss of biodiversity, soil erosion, freshwater use, nutrient leaching and pollution from chemicals. However, various studies have also shown that in general these problems are less serious when compared with similar plantations for food or fodder production.

Also linked to potential large-scale energy plantations are the social implications, e.g., the effect on the quality of employment (which may increase, or decrease, depending on the level of mechanization, local conditions, etc.), potential use of child labour, education and access to health care. However, such implications will reflect prevailing situations and would not necessarily be better or worse than for any other similar activity.

Methodological barriers – lack of clear international accounting rules

A lack of clear rules and standards for, e.g., allocation of GHG credits and the related issue of methodologies to be used to evaluate the avoided emissions, considering the fuel life-cycle (see also Schlamadinger et al., 2005).

Another issue is the indirect import of biomass for energy (processed biomass). Biomass trade can be considered a direct trade in fuel and indirect flow of raw materials that end up as fuels in energy production during or after the production process of the main product. For example, in Finland the biggest international biomass trade volume is indirect trade in round wood and wood chips. Round wood is used as raw material in timber or pulp production. Wood chips are raw material for pulp production. One of the waste products of the pulp and paper industry is black liquor, which is used for energy production.

Legal (national) barriers

Biomass for energy may be limited by international environmental laws. For example, in the Netherlands, four out of five major biomass power producers consider obtaining emission permits one of the major obstacles for further deployment of various biomass streams for electricity production. The main problem is that Dutch emission standards do not conform to EU emission standards. In several cases in 2003 and 2004, permits given by local authorities have been declared invalid by Dutch courts. TSU: reference missing

2.5 Environmental and Social Issues

Studies have over the past few years highlighted environmental and socio-economic issues associated with bioenergy, stressing both possible negative and positive effects. Negative effects relate to impacts already associated with the conventional agriculture and forestry systems (e.g., biodiversity losses, groundwater overexploitation and water contamination, eutrophication and soil degradation) and new types of impact specific for bioenergy including spread of alien invasive species, soil and vegetation degradation arising from overexploitation of forests and too intensive crop residue removal – and rising food commodity prices and displacement of farmers lacking legal land ownership due to increasing land use competition. Positive effects include environmental benefits that can be derived from integrating different perennial grasses and woody crops into agricultural landscapes, including enhanced biodiversity, soil carbon increase and improved soil productivity, reduced shallow land slides and local ‘flash floods’, reduced wind and water erosion and reduced volume of sediment and nutrients transported into river systems. Forest residue harvesting improves forest site conditions for replanting and thinning generally improves the growth and productivity of the remaining stand. Removal of biomass from over dense stands can reduce wildfire risk (JRC 2008, Farrell et al. 2006; Hill et al. 2006; Keeney and Muller 2006; Tilman et al. 2006; WWI 2006; Bringezu et al. 2007; Crutzen et al. 2007; Martinelli and Filoso 2007; Scharlemann and Laurence 2008; Donner and Kucharik 2008; Searchinger et al. 2008; Simpson et al. 2008; Gallagher 2008; Keeney 2009. Howarth 2009; The Royal Society 2008; Doornbosch and Steenblik 2007; von Blottnitz and Curran 2006; Rajagopal and Zilberman 2007; Rowe et al. 2008; Bird et al., 2010, Lattimore et al. 2009, Dimitriou et al. 2009, Andersson et al. 2002, Berndes et al. 2008).

In many instances, the analysis of the socio-economic and environmental implications of bioenergy has remained speculative, uncertain, and often controversial. Given the multitude of existing and rapidly evolving bioenergy sources, complexities of physical, chemical, and biological conversion processes, and variability in site specific environmental conditions, few universal conclusions can currently be drawn. Dominant factors determining merits and associated impacts are a function of the socio-economic and institutional situation where the feedstocks and bioenergy outputs are produced and utilized; types of lands used and feedstock type; the scale of bioenergy programs and production practice employed; conversion processes utilized including type of process energy used. It is also recognized that the rate of implementation matters (The Royal Society 2008; Firbank 2008; Convention on Biodiversity 2008; Gallagher 2008; Howarth et al. 2009; Kartha 2006; Purdon et al. 2009; Rowe et al. 2008; OECD 2008).

2.5.1.1 Sustainability frameworks, standards and impact assessment tools

Governments are stressing the importance of ensuring sufficient climate change mitigation and avoiding unacceptable negative effects of bioenergy as they implement regulating instruments. Examples include the new Directive on Renewable Energy in the EU (Directive 2009/28/EC); UK Renewable Transport Fuel Obligation; the German Biofuel Sustainability Ordinance; and the

California Low Carbon Fuel Standard. The development of impact assessment frameworks and sustainability criteria involves significant challenges in relation to methodology and process development and harmonization. International organizations and forums supporting the further development of sustainability criteria and methodological frameworks for assessing GHG mitigation benefits of bioenergy include IEA Bioenergy; Roundtable on Sustainable Biofuels (RSB); the G8 +5 Global Bioenergy Partnership (GBEP); International Bioenergy Platform at FAO (IBEP); OECD Roundtable on Sustainable Development; and also standardization organizations such as European Committee for Standardization (CEN) and the International Organization for Standardization (ISO).

Impact assessments (IAs) of bioenergy systems must be evaluated based on comparing with IAs for the energy systems they replace – usually these are fossil fuel based systems, but could also be based on other primary energy sources (Table 2.5.1). Methodologies for the assessments of environmental (Section 2.5.2 and 2.5.3) and socio-economic (Section 2.5.4) effects differ. One particular challenge for socio-economic IAs is that the socio-economic environment is difficult to quantify and is in general a very complex composite of numerous – directly or indirectly – interrelated factors where several are poorly understood. Further, social processes have feedbacks commonly difficult to clearly recognize and project with acceptable level of confidence. Environmental IAs may have the benefit of managing quantifiable impact categories to a higher degree but face challenges of uncertain quantification in many areas. Furthermore, the outcome of environmental IAs depends on choice of methodological approaches – which are not yet standardized and uniformly applied throughout the world.

Table 2.5.1: Environmental and socio-economic impacts: example areas of concern with selected impact categories

Example areas of concern	**Example impact categories**
Economic and occupational status	Displacement of population or relocation in response to employment opportunities; property values, distribution patterns of services
Social pattern or life style	Resettlement; rural depopulation; population density changes; food and material goods, housing; rural-urban; nomadic-settled
Social amenities and relationships incl. psychological features	Family life styles; schools; hospitals; transportation; participation-alienation; stability-disruption; freedom of choice; involvement; frustrations; commitment; local/national pride-regret
Physical amenities incl. biodiversity and aesthetic features	Wildlife and national parks; aesthetic values of landscape; wilderness; vegetation and soil quality; local/regional air quality; water availability and quality; cultural buildings; sentimental values
Global/regional (off site) effects	Greenhouse gases; black carbon; albedo; acidification; eutrophication; hydrological changes
Health	health changes; medical standard
Cultural, religion, traditional belief	Values and value changes; taboos; heritage; religious and traditional rites
Technology	Hazards; emissions; congestion; safety
Political and legal	Authority and structure of decision making; administrative management; level and degree of involvement; resource allocation; local/minority interests; priorities; public policy

2.5.1.1.1 Environmental effects

Section 2.5.2 discusses mainly environmental impacts as reported from Life Cycle Assessments (LCA). The ISO 14040:2006 and 14044:2006 standards provide the principles, framework, requirements and guidelines for conducting an LCA study. LCA quantifies environmental effects in a more general manner than in relation to a specific bioenergy project. Basic methodology for the assessment of the effects of bioenergy systems compared to their substitutes corresponds to consequential LCA involving higher uncertainties than the conventional attributional LCA, and also auxiliary tools such as economic equilibrium or land-use models that might be needed to evaluate the consequences of bionenergy options. Complementary insights into the climate benefits can be obtained from energy system models – with or without linked land-use models – where the mitigation benefit is evaluated within a total energy system perspective considering a range of fossil as well as competing renewable energy options. In addition to comprehensive LCAs there are studies with a bifurcated focus on energy balances and GHG emissions balances (see, e.g., Fleming et al. 2006, Larson 2006, von Blottnitz and Curran 2006, Zah 2007, OECD 2008, Rowe et al. 2008, Menichetti and Otto 2009). A specific methodology for assessing greenhouse gas balances of biomass and bioenergy systems has also been developed since the late 90s (Schlamadinger et al. 1997).

LCA results need to be further analyzed in the context of specific locations considering not only natural conditions but also industrial and institutional capacity. Water use is one such aspect: in some locations with scarce water availability production processes that consume large volumes of water can be problematic and in other locations with plenty of water this is less of an issue (Berndes 2002). Another example, effluent production, leads to very different impacts depending on how these effluents are managed on site. Technical solutions for managing effluents are available but may not be installed in regions with lax environmental regulations or limited law enforcement capacity. The major reduction in sugarcane ethanol plants' effluent discharge into rivers in Brazil is illustrative of the importance of institutions in determining the actual impacts of bioenergy projects (Peres et al., 2007).

Most assumptions and data used in LCA studies are so far primarily related to conditions and practices in Europe or USA, but studies are becoming available for other countries such as Brazil and China. Most studies have concerned biofuels for transport, especially those that are produced based on conventional food/feed crops. Prospective bioenergy options (e.g., lignocellulosic ethanol and options using the biomass gasification route) are less studied and their assessment via the LCA process involves projections of performance of developing technologies that can be at various stages of development and have greater uncertainties than commercial ones. Despite that studies commonly follow ISO standards a wide range of results has often been reported for the same fuel pathway, sometimes even when holding temporal and spatial considerations constant (Fava 2005). The ranges in results may, in some cases, be attributed to actual differences in the systems being modeled but are also due to differences in method interpretation, assumptions and data issues.

Key issues in bioenergy LCAs are system definition including the definition of both spatial and dynamic system boundary and the selection of allocation methods for energy and material flows over the system boundary. Disparities in the treatment of co-products have had major impacts on results of LCA studies and the handling of uncertainties and sensitivities related to the data for parameter sets used may have significant impact on the results (Kim and Dale 2002, Farrell et al. 2006, Larson 2006, von Blottnitz and Curran 2006, OECD 2008, Rowe et al. 2008, Börjesson 2009, Wang et al. 2009).

Many biofuel production processes produce several products and bioenergy systems can be part of biomass cascading cycles, where the biomass is first used for the production of biomaterials, while the co-products and biomaterial itself after its useful life are used for energy. This introduces significant data and methodological challenges, including also consideration of space and time aspects since the environmental effects can be distributed over several decades and occurs at different geographical locations (Mann and Spath 1997).

There are in addition gaps in scientific knowledge surrounding key variables, including N_2O emissions related to feedstock production (Ammann et al. 2007, Crutzen et al. 2008), non GHG-mediated climate impacts, and nutrient depletion and soil erosion due to too high rates of agricultural residue removal (Wilhem et al., 2007).

The influence of land use change (LUC) and associated biospheric carbon stock changes on the environmental (especially GHG) performance of bioenergy has received considerable attention recently (Fargione et al. 2008, Gibbs et al. 2008, Searchinger et al. 2008, Wise et al. 2009, Melillo et al. 2009), although has been subject to analyses for many years (DeLucchi 1991, Reinhardt 1991, Marland and Schlamadinger 1997, Schlamadinger et al. 2001). Marland's and Schlamadinger's (1997) and Schlamadinger's et al. (2001) studies clearly show the significance of LUC – and that the biospheric carbon stocks can both decrease and increase as a result of bioenergy initiatives – but further methodology development is needed to improve the confidence of quantifications made.

Also, empirical data on carbon flows linked to land use and LUC in different parts of the world is uncertain, the causal chains proposed to link specific bioenergy projects with specific land use changes taking place in distant locations – and being driven by a range of additional factors – are poorly understood. Critical aspects include the land use evolution as influenced by the combined food, feed, fiber and bioenergy demand, availability of new types of energy crops, new cropping patterns, and policies influencing the land use directly or indirectly, including possible instruments such as REDD. Additional uncertain factors influential on the outcomes include assumptions concerning drivers for technological development and productivity growth in agriculture (Gallagher 2008; Kim et al. 2009; Kløverpris et al. 2008a, b). Land use effects may also impact the earth system and climate via other processes: the emissions of black carbon aerosols due to the burning of biomass, and of precursors of tropospheric ozone (nitric oxide from soils and volatile organic compounds from plants), changes in surface albedo and in the water balance of soils and the hydrological fluxes. The magnitude and sign of these additional climatic forcings arising from bioenergy development has been little investigated yet, but it might be significant.

Finally, as noted above, bioenergy systems must be evaluated based on comparing their influence on impact categories with the influence of the energy systems they replace. The climate change mitigation benefit is determined by the net change in cumulative radiative forcing resulting from the replacement of another – commonly fossil – energy system. One difficulty experienced is that it has proven to be difficult to obtain comparable LCA data for the reference energy system replaced – ideally these LCA data should come from studies with consistent methodologies, scope, level of detail, and country representativeness. Reasons include:

- the impacts of bioenergy products are often characteristic of the agriculture sector and, by extension, are difficult to compare to other elements of the reference energy system i.e. oil and coal exploration, mining and refining, storage transportation and spills;
- there is an identified lack of updated LCA studies on fossil fuels assessing recent and emerging trends in extraction and use of oil, (microbial enhanced oil recovery, deep sea drilling, use of oil sands etc.) (see Fava 2005, von Blottnitz and Curran 2006 and OECD 2008); and,
- forward-looking analyses needs to consider that also the reference system can be changing

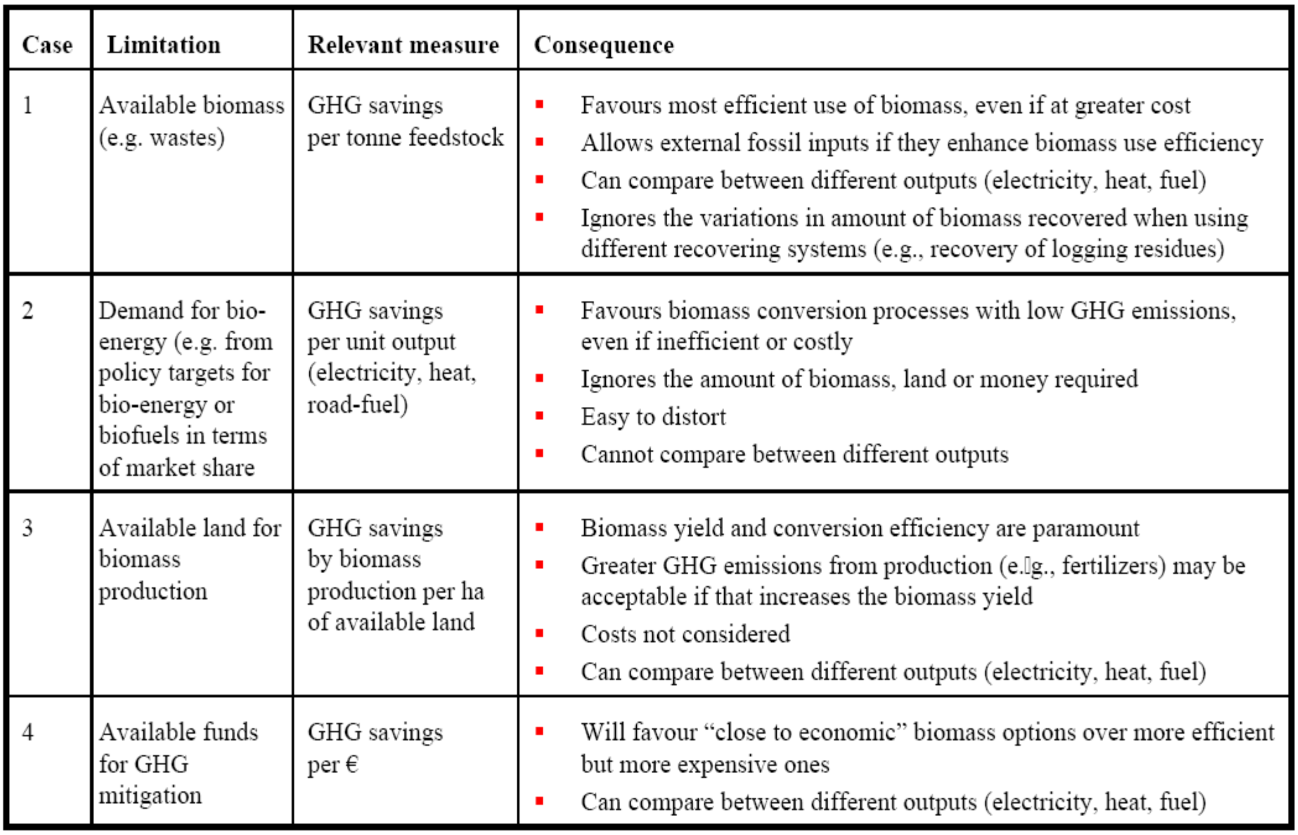
The reference energy system can also cause indirect emissions linked to LUC or other activities and these can be difficult to quantify. Examples include (i) surface mining of coal that destroys soils and eliminates existing vegetation leading to displacement or destruction of habitats and wildlife; (ii) oil and gas projects causing deforestation for access roads, drilling platforms, and pipelines; (iii) oil shale production where surface mining, processing and disposal requires extensive areas; (iv) oil sand production that requires removal of vegetation as well as the topsoil and subsurface layers atop the oil sands deposit. Indirect LUC can also arise from the easy access to previously remote primary forest provided by new roads and pipeline routes, causing increased logging, hunting, and deforestation from human settlement. A portion of military expenditures and associated GHG emissions are related to geopolitical considerations and energy security. Preliminary estimates for the case of U.S. military security associated with the acquisition of Middle Eastern petroleum indicate that this indirect source of emissions might be similar in size as the emissions usually linked to Middle Eastern petroleum (Liska and Perrin 2009).

2.5.1.1.2 Alternative indicators of net GHG effect of bioenergy

Different limiting resources may define the extent to which land management and biomass fuels can mitigate GHG emissions, and these require specific indicators (Table 2.5.2). Basic default in application of these measures is sustainable harvest of primary biomass. However, they do not explicitly value the temporal dimension of changes in biospheric carbon stocks: also sustainable biomass production systems can temporarily involve substantial decreases in biospheric carbon stocks, management of boreal forests being an illustrative example.

Ambitious climate targets such as the 2°C degree stabilization target which requires that global GHG emissions peak within a few decades, has lead the timing of net GHG emissions to become an important indicator for evaluation of bioenergy systems. In this context, upfront emissions arising from the conversion of land to bioenergy production has been subject to specific attention (e.g., Schlamadinger and Marland 1996, Fargione et al. 2008, Gibbs et al. 2008). A more complete LCA would deduct the carbon lost into the atmosphere due to land clearing and account for additional carbon added to a depleted soil over time with the bioenergy system. Near term performance needs to be balanced against long term performance (Section 2.5.2). Additional indicators such as cumulative radiative forcing have to a limited extent been used to describe the dynamic climate impacts of biomass and bioenergy (Kirkinen et al. 2009; O'Hare et al. 2009).

Table 2.5.2. Maximizing GHG emission reductions when biomass, demand for bioenergy, available land, or available funds for GHG mitigation are the limiting factor (Schlamadinger et al. 2005).



Case	Limitation	Relevant measure	Consequence
1	Available biomass (e.g. wastes)	GHG savings per tonne feedstock	▪ Favours most efficient use of biomass, even if at greater cost ▪ Allows external fossil inputs if they enhance biomass use efficiency ▪ Can compare between different outputs (electricity, heat, fuel) ▪ Ignores the variations in amount of biomass recovered when using different recovering systems (e.g., recovery of logging residues)
2	Demand for bio-energy (e.g. from policy targets for bio-energy or biofuels in terms of market share	GHG savings per unit output (electricity, heat, road-fuel)	▪ Favours biomass conversion processes with low GHG emissions, even if inefficient or costly ▪ Ignores the amount of biomass, land or money required ▪ Easy to distort ▪ Cannot compare between different outputs
3	Available land for biomass production	GHG savings by biomass production per ha of available land	▪ Biomass yield and conversion efficiency are paramount ▪ Greater GHG emissions from production (e.g., fertilizers) may be acceptable if that increases the biomass yield ▪ Costs not considered ▪ Can compare between different outputs (electricity, heat, fuel)
4	Available funds for GHG mitigation	GHG savings per €	▪ Will favour "close to economic" biomass options over more efficient but more expensive ones ▪ Can compare between different outputs (electricity, heat, fuel)

2.5.1.1.3 Socio-economic impacts

Analyzing the socio-economic impacts of bioenergy development is a daunting task, whether ex ante or ex post, since they depend on many exogenous factors and are affected by scale. The most commonly reported criteria are private production costs over the value-chain, assuming a fixed set of prices for basic commodities (e.g., for fossil fuels and fertilizers). The bioenergy costs are usually compared to current alternatives already on the market (fossil based), to judge the potential competitiveness. Possible externalities (environmental or societal) are seldom included in such cost/benefit analyses, since they are difficult to value (Costanza et al., 1997). However, policy instruments might already be in place to address these externalities, such as environmental regulations or emission-trading schemes. Bioenergy systems are most of the time analysed at a micro-economic level, although interactions with other sectors cannot be ignored because of the competition for land and other resources. Opportunity costs may be calculated from food commodity prices and gross margins to take food-bioenergy interactions into account.

Social impact indicators include consequences on local employment, although they are difficult to assess because of possible compensations between fossil and bioenergy chains. At a macro-economic level, other impacts include the social costs incurred by the society because of fiscal measures (e.g. tax exemptions) to support bioenergy chains, or additional road traffic resulting from biomass transportation (Delucchi, 2005). Symmetrically, the negative externalities related to fossil energy pathways need to be assessed, with the above-mentioned difficulties in such valuation (Bickel and Friedrich, 2005).

Socio-economic impact studies are commonly used to evaluate the local, regional and/or national implications of implementing particular development decisions. Typically, these implications are measured in terms of economic indices, such as employment and financial gains, but in effect the analysis relates to a number of aspects, which include social, cultural, and environmental issues. A complication lies in the fact that these latter elements are not always tractable to quantitative analysis and, therefore, have been excluded from the majority of impact assessments in the past, even though at the local level they may be very significant. The varied nature of biomass and the many possible routes for converting the biomass resource to useful energy make this topic a complex subject, with many potential outcomes.

2.5.2 Environmental impacts

Production and use of bioenergy influences global warming through (i) emissions from the bioenergy chain including non-CO_2 GHG emissions and fossil CO_2 emissions from auxiliary energy use in the biofuel chain; (ii) GHG emissions related to changes in biospheric carbon stocks often – but not always – caused by associated LUC; (iii) other non-GHG related climatic forcers including changes in surface albedo; particulate and black carbon emissions from small-scale bioenergy use that e.g. reduce the snow cover albedo in the Arctic; and aerosol emissions associated with forests.

2.5.2.1 Climate change effects of modern bioenergy excluding the effects of land use change

The multitude of existing and rapidly evolving bioenergy sources, complexities of physical, chemical, and biological conversion processes, feedstock diversity and variability in site specific environmental conditions – together with inconsistent use of methodology – complicate meta-analysis of large number of studies to produce generally valid quantification of the influence of bioenergy systems on climate. Review studies (e.g., IEA 2008, Menichetti and Otto 2009, Chum et al. submitted) reporting widely varying estimates of GHG emissions for biofuels are illustrative of this. Yet, some studies combining several LCA models and/or Monte Carlo analysis provide quantification with information about confidence for some bioenergy options (e.g., Soimakallio et al. 2009a, Hsu et al. submitted, Chum et al. submitted). Also, as showed in Section 2.5 maximization of GHG emission reductions is achieved differently depending on what factor is limiting for GHG mitigation (Table 2.5.2).

Biomass that substitutes for fossil fuels (especially coal) in heat and electricity generation (especially when replacing low efficiency fossil generation) in general provides larger and less costly GHG emissions reduction per unit of biomass than substituting biofuels for gasoline in transport (Figures 2.5.1) The major reasons for this are: (i) the lower conversion efficiency, compared to the fossil alternative, when biomass is processed into biofuels and used for transport; and (ii) the higher energy inputs in the production and conversion of biomass into biofuels for transport, especially when based on conventional arable crops.

Figure 2.5.1 shows net reductions in GHG emissions when biofuels replaces coal for power generation. Note that the low GHG reduction potential for the case of co-firing is due to that the share of biomass that can be co-fired currently is limited to typically 10%. On a per ton biomass basis, biomass co-firing with coal is among the best options for GHG reduction (also economically) since the biomass is converted at higher efficiency than in smaller dedicated biomass power plants ("Direct Fire" in Figure 2.5.1). The large size of the coal power plants also makes this option one of the more likely for combining biomass with CCS. The Landfil Gas option in Figure 2.5.1 is an example where systems definition is critical for the outcome; it looks much more attractive for the case where the alternative is that methane leaks into the atmosphere via uncontrolled anaerobic decomposition of landfill material, compared to the case where the methane collection technology is assumed to be installed and the alternative would be that the methane is used as vehicle fuel.

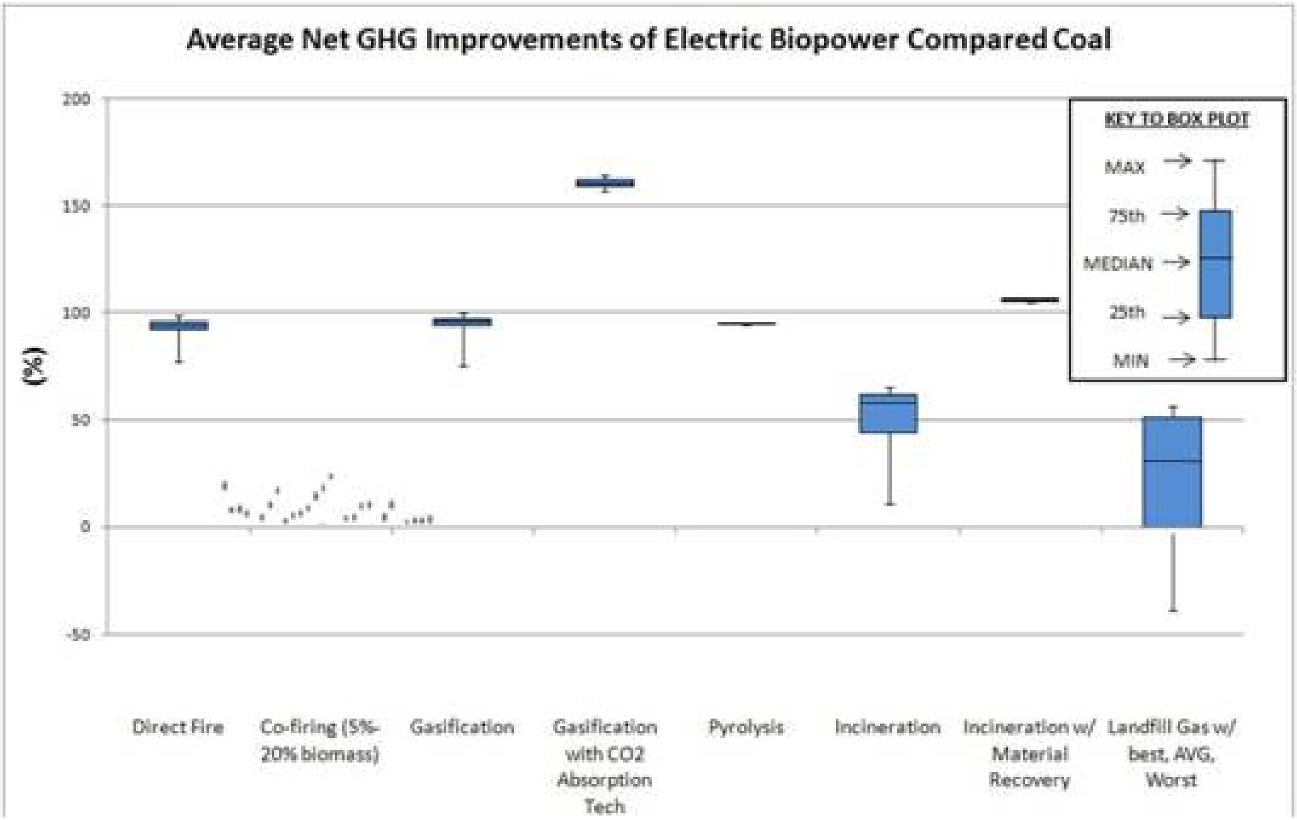


Figure 2.5.1. Net reductions in GHG emissions when biofuels replaces coal for power generation . Source: Warner and Heath, submitted TSU: readability needs improvement, align “reductions” in caption to “improvements” in graph for clarity.

Figure 2.5.2 shows the GHG emissions reduction, as a function of the net energy ratio, when ethanol from the two most common feedstocks maize and sugarcane replaces gasoline. A general tendency of increasing GHG reduction with increasing net energy ratio can be seen, but also that process fuel shifts can radically improve the GHG reduction with small improvements in net energy ratio. If coal is used in less efficient plants, the mitigation benefits might be completely lost, but if biomass (e.g., bagasse, straw, or wood chips) is used GHG emissions from the conversion can be very low. When evaluated using LCA such process fuel shifts can appear very attractive (Wang et al. 2007), but the marginal benefit of shifting to biomass depends on local economic circumstances and on how this biomass would otherwise be used. Also, the biofuel production can have relatively low emission reduction in proportion to the total volume of biomass consumed (feedstock + process fuel).

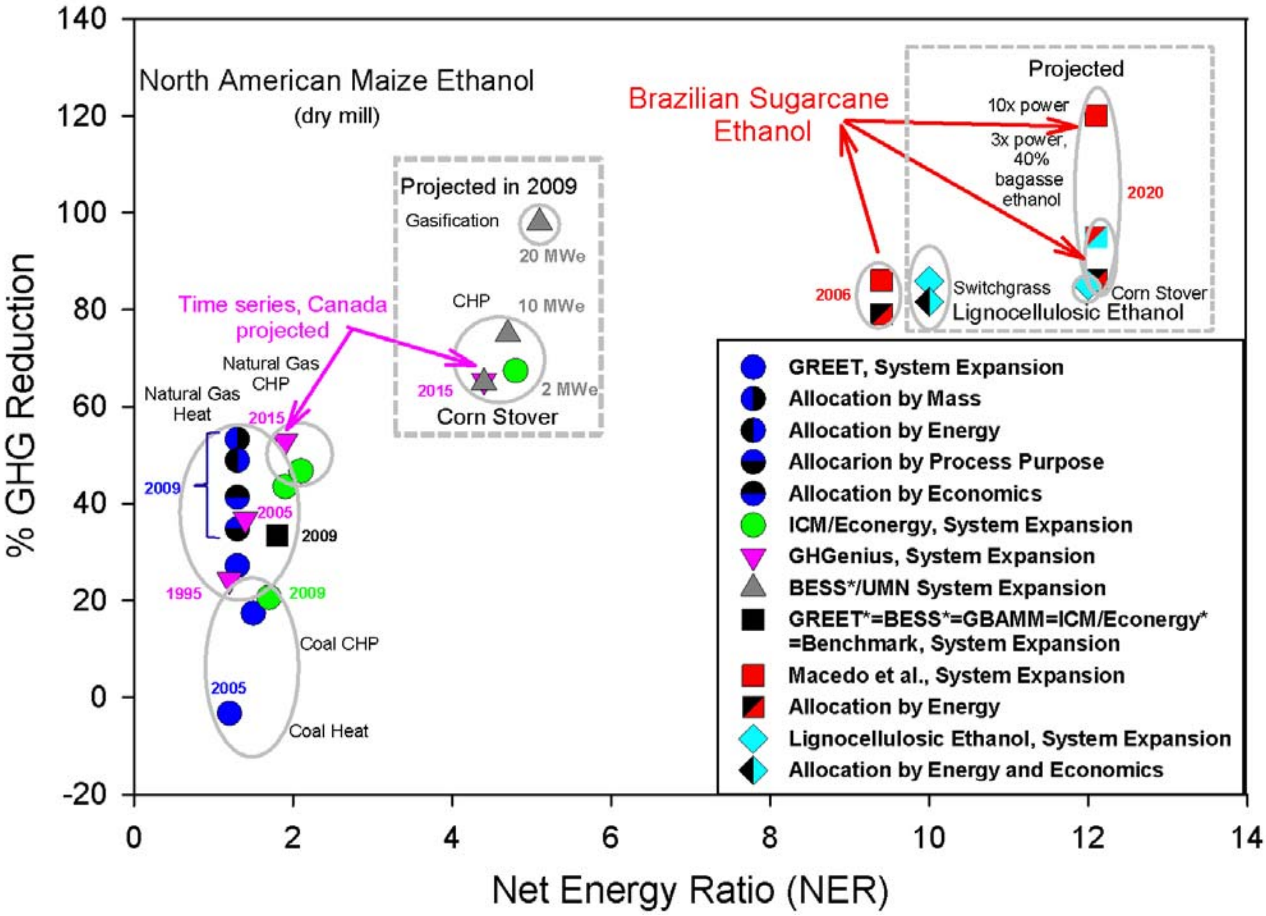


Figure 2.5.2. GHG reductions from gasoline emissions for ethanol production as a function of the net energy ratio (absent land use change) in Brazil,[a] Canada[b] and the U.S.[c] with specified co-product lifecycle assessment treatment and indicating methodological results' agreement for maize ethanold and projected values for lignocellulosic ethanol. TSU: (at least for TSU member editing this chapter:) figure not accessible, items in legend not enough explained.

[a] Red (■) points illustrate the Brazilian sugarcane ethanol industry average from mutual benchmarking (44 mills in 2006) and the 2020 projections for two scenarios of integrated biorefineries (cellulosic ethanol) or additional power production (Macedo et al. 2008). Hydrous ethanol is the product used in 2020 flex fuel vehicles in Brazil.

[b] Purple (▼) points show past and projected data for one dry grind Canadian mill (GHGenius version 3.13).

[c] Green (●) points at ~43% indicate modern maize ethanol production practices and efficient conversion that exists in the majority of natural gas mills in the U.S. Blue (●) points indicate primary energy (coal and natural gas) efficiency and process improvements with time for maize ethanol for the various process chains used in North America using GREET version 1.8c. Center dashed box gray (■), purple (▼), and green (●) points indicate biomass as a source of heat and power from various studies including projected integrated gasification combined cycle that coproduce electricity.

[d] Benchmark (■) point at 34% GHG reduction with net energy ratio of 1.4-1.6 results from three LCA models for natural gas-fired dry grind maize ethanol produced in the U.S. using the same input

data from the University of California, Berkeley, US, GREET-BESS Analysis Meta-Model, GBAMM-version 3. GREET= Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model version 1.8b; BESS= University of Nebraska, Lincoln, US, Biofuel Energy Systems Simulator version 2008.3.1; and ICM/Econergy is a commercial tool. Asterisk indicates meta-model conditions.

Sources: Chum et al. Submitted for publication and references therein; Macedo, I. C. and Seabra, J.E.A., 2008, Wang, M. et al., In press

The climate benefit of a given bioenergy systems can also vary significantly due to varying feedstock growing conditions and agronomic practices, conversion process configuration, differences in substitution effects of bioenergy and co-product use. As noted, methodologies for estimating nitrous oxide emissions from energy crops production are debated but it is clear that N2O emissions can have an important impact on the overall GHG balance of biofuels, though there are large uncertainties (Smeets, et al. 2008). The mitigation benefits can be significantly improved through minimization of nitrous oxide emissions by means of efficient fertilization strategies using nitrogen fertilizer produced in plants that have nitrous oxide gas cleaning.

2.5.2.2 Climate change effects of modern bioenergy including the effects of land use change

Conversion of natural ecosystems to biomass production systems (for food, fiber or fuel) and changes in land use (e.g., from food to fuel production) can lead to positive or negative changes in the biospheric carbon stocks. Establishment of bioenergy systems involves direct land use change (dLUC) but can also lead to indirect land use change (iLUC) if displacement of previous land use leads to LUC elsewhere. Biospheric carbon changes can also occur in the absence of LUC, such as when forest management is intensified – shorter rotations, forest residue removal, and fertilization – to increase biomass output, which at the same time can lead to smaller forest carbon stocks.

Conversion of dense forests into bioenergy plantations will likely lead to losses of biospheric carbon regardless of what type of bioenergy system becomes established. In worst case the CO_2 emissions can be much larger than the emissions displaced by bioenergy, one example being the palm oil plantations established on tropical peatlands (Hooijer et al. 2006) that in natural conditions have negligible CO_2 emissions and small methane emissions (Jauhiainen et al. 2005). Establishment of plantations requires drainage of the peatland, leading to rapid oxidation of the peat material causing annual CO_2 emissions between 70-100 Mg/ha (Hooijer et al. 2006).

In other situations, net effects of bioenergy-driven dLUC on biospheric carbon stocks varies: (i) if biofuel crops are grown on previous cropland land which has been taken out of production, soil carbon losses may be minimal; (ii) cultivating conventional crops such as cereals and oil seed crops on previous pastures or grasslands can lead to soil carbon losses, possibly mitigated under no-till management; (iii) similarly planting short or long rotation forestry on grasslands may result in soil carbon loss or gain, depending on the planting and management techniques used; (iv) if perennial grasses or short rotation woody crops are established on land with sparse vegetation and/or carbon depleted soils on degraded and marginal lands net gains of soil and aboveground carbon can be obtained. In this context, land application of bio-char produced via slow-pyrolysis offers an option where the carbon is sequestered in a more stable form and also improves the structure and fertility of soils (Laird et al. 2009).

IPCC provides default values that make it possible to consider effects of dLUC in LCA studies (IPCC 2006). Table 2.5.3 shows an example of biospheric carbon stock changes for specific cases of dLUC. However, it is preferable to use site specific data instead of general numbers for quantifying effects of dLUC in a specific case.

Table 2.5.3. Carbon stock changes for different land use changes (tC/ha). Based on (Bird et al. 2010)

To		Tropical			Temperate			Boreal	
From		Crop	Grass	Forest	Crop	Grass	Forest	Grass	Forest
Tropical	Crop		-11 to 22	35 to 351					
	Grass	-22 to -11		14 to 373					
	Forest	- 351 to - 35	-373 to -14						
Temperate	Crop					-11 to 25	34 to 730		
	Grass				-25 to 11		15 to 755		
	Forest				-730 to - 34	-755 to -15			
Boreal	Grass								11 to 138
	Forest							-138 to – 11	

Studies have shown that LUC emissions can substantially change the mitigation benefit of certain bioenergy projects. Recent studies have primarily concerned biofuels for transport (Fargione et al. 2008, JRC 2008, Gibbs et al. 2008, Searchinger et al. 2008, Wise et al. 2009, Melillo et al. 2009), but studies taking a broader view on bioenergy confirm the significance of LUC (e.g., Leemans 1996, Marland and Schlamadinger 1997, Pacca and Moreira, 2009). Figure 2.5.3 shows one example of recent quantifications of the cumulative GHG savings of expanded biofuel use for transport, including the impact of dLUC and iLUC. In this case, biofuels produced from cultivated lignocellulosic feedstocks contribute an increasing share of biofuel supply, which leads to improved cumulative GHG savings over time due to higher GHG savings from gasoline/diesel substitution and reduced LUC-GHG emissions. Figure 2.5.3 is illustrative of that LUC GHG emissions can impact net GHG savings especially on the near term while the relative importance LUC GHG emissions for cumulative net GHG savings decreases over time.

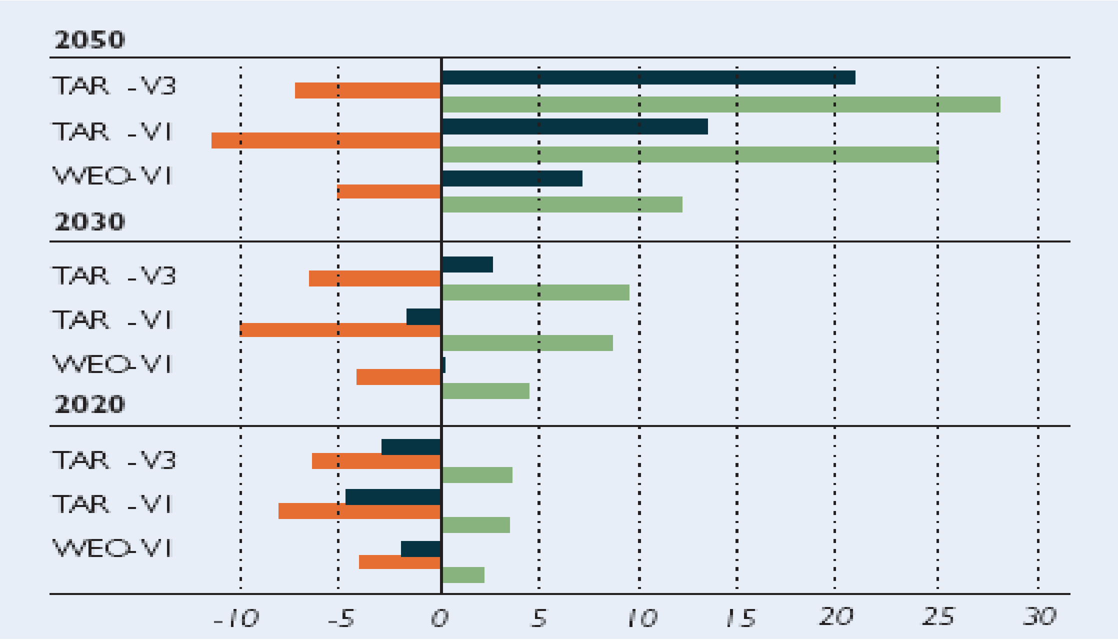


Figure 2.5.3. Cumulated net GHG savings of biofuel scenarios (Pg CO_2-eq). Green bars show the GHG savings from biofuel replacement of gasoline and diesel, orange bars show the GHG emissions caused by dLUC and iLUC, and blue bars show the net GHG balance. The share of biofuel use in total transport fuels is 3.5% in 2020 and rising to 6% in 2050. Percentage 2nd gen TSU: brief definition on biofuel generations should be given somewhere in text of total biofuels are (2020/2050): TAR-V3: 22/55; TAR-V1: 2/26; WEO-V1: 3/30. Source: Fischer et al. (2009) TSU: explanation of V1, V3 needed here

As discussed in Section 2.5.1, the quantifications of LUC effects reported so far involve a significant degree of uncertainty, especially for iLUC. The effects are complex and difficult to quantify in relation to a specific bioenergy project and the reference energy system substituted may also cause LUC. Cases much debated recent years include: (i) Brazilian sugarcane ethanol production (Sparovek et al. 2009; Zuurbier and van de Vooren 2008); (ii) Palm oil production (WWF 2007); (iii) biodiesel production from rape seed cultivated on the present cropland in Europe; (iv) the shift from soy to corn cultivation in response to increasing ethanol demand in the US, (Laurance 2007); (v) wheat based ethanol production in Europe.

Despite the substantial degree of uncertainty it can be concluded that if the expansion of biofuels production based on conventional food/feed crops results directly or indirectly in the loss of permanent grasslands and forests it is likely to have negative impacts on GHG emissions and for many biofuels it would take many years (decades to centuries) of production and use before a positive mitigation is reached. On the other hand, if biofuel and other relevant policies provide more stability and certainty in crop markets, promote improved land management, rural development and higher yields, and prevents far reaching deforestation for agriculture use (food/fiber/fuel), the LUC impacts could be substantially reduced or even contribute positively to GHG savings as bioenergy use expands.

2.5.2.3 Climate change effects of traditional bioenergy

The burning of biomass in open fires and stoves – commonly referred to as traditional bioenergy use – comprise the majority of global bioenergy uses at present. They are characterized by very low conversion efficiency compared, for instance, with their potential fossil fuel based competitors. Incomplete combustion of biomass also leads to significant emissions of short-lived GHGs such as carbon monoxide, methane and black carbon.

Consolidation of emission factors into broad fuel categories with traditional or improved stoves oversimplifies the wide range of fuel types, stove designs, cooking practices, and environmental conditions across the world. The vast majority of emission factor data comes from studies using controlled testing conditions, most commonly water boiling tests conducted in simulated kitchens. A handful of studies have been conducted in homes during normal stove use, with the available data suggesting controlled tests underestimate products of incomplete combustion from traditional stoves relative to normal stove use. In addition to emission factors, estimation of carbon offsets from improved fuels and/or stoves requires estimates of fuel consumption and the fraction of non-renewable biomass harvesting (fNRB). Local, field-based assessments provide the most robust estimation of CO_2-equivalent emissions as default emission factors and projections of fuel consumption based on laboratory testing have proved misleading (Johnson et al., 2008; Roden et al., 2009) and are not able to estimate uncertainty in the overall CO_2-eq estimate. Additionally, regional or national estimates of fNRB lack sufficient resolution to characterize fuelwood consumption for specific communities. Improved fuels and/or stoves and shifts from using non-renewable biomass (e.g., unsustainable forest biomass extraction) to using sustainably produced biomass can reduce the climate change effects of traditional bioenergy. Acknowledging the above described uncertainties, some indications of climate change mitigation in this area can be given. A recent study for instance showed that Patsari improved stoves in rural Mexico saved ~3.8 t CO_2-equivalent per year (Johnson et al., 2009). Studies indicate low costs for reducing GHG emissions in traditional bioenergy. For instance, a cost comparison using the carbon emission reduction (tC/kWh ot tC/GJ) between 10 bioenergy technologies substituting fossil fuel and traditional biomass alternatives concluded that out of the ten project case six have negative incremental costs (ICs) (negative ICs indicate that the suggested alternatives are cheaper than the original technologies) in the range of −37 to −688 \$ tC^{-1} and four have positive ICs in the range of 52–162 \$ tC^{-1} mitigation (Ravindranath et al., 2006)

2.5.3 Environmental impacts not related to climate change

Besides the impact on global warming, production, conversion, and use of biomass when transformed to various solid, liquid, and gaseous biofuels causes a wide range of both positive and negative impacts.

Much attention is presently directed to the possible negative consequences of land use change, such as biodiversity losses, greenhouse gas emissions and degradation of soils and water bodies, referring to well-documented effects of forest conversion and cropland expansion to uncultivated areas. However, the production of biomass for energy can generate additional benefits.

For instance, forest residue harvesting also has environmental or silvicultural benefits. It improves forest site conditions for replanting. Stump harvesting (as practised in Nordic Countries) reduces risk of devastating root rot attack on subsequent stands. Thinning generally improves the growth and productivity of the remaining stand. Removal of biomass from over dense stands can reduce wildfire risk. In agriculture, biomass can be cultivated in so-called multifunctional plantations that – through well chosen localization, design, management, and system integration – offer extra environmental services that, in turn, create added value for the systems.

Many such plantations provide water related services, such as vegetation filters for the treatment of nutrient bearing water such as wastewater from households, collected runoff water from farmlands and leachate from landfills. Plantations can also be located in the landscape and managed for capturing the nutrients in passing runoff water. Sewage sludge from treatment plants can also be used as fertilizer in vegetation filters. Plantations can be located and managed for limiting wind and water erosion, and will reduce the volume of sediment and nutrients transported into river systems. They may reduce shallow land slides and local ‘flash floods’.

Perennial crops can also help to reduce soil erosion, improve nutrient flows through the formation of an extensive root system that adds to the organic matter content of the soil and facilitates nutrient retention. Nutrient flow is a key issue for forest and agricultural production systems. When ploughed under or left on the field/forest, primary residues may recycle valuable nutrients to the soil and help prevent erosion, thus only a share may be available for extraction. Prevention of soil organic matter depletion and nutrient depletion are of importance to maintain site productivity for future crops.

2.5.3.1 Emissions to the air and resulting environmental impacts

Pollutant emissions to the air depend on combustion technology, fuel properties, combustion process conditions and emission reduction technologies installed. Comparing with fossil energy systems, SO_2 and NO_x emissions are in general low compared to coal and oil combustion in stationary applications. When biofuels replaces gasoline and diesel in the transport sector SO_2 emissions are reduced but the effect on NO_x emissions depends on substitution pattern and technology applied. The effects of ethanol and biodiesel replacing petrol depend on engine features. For instance, biodiesel has higher NO_x emissions than petroleum diesel in traditional direct-injection diesel

2.5.3.2 Impacts on water resources and quality

Bioenergy production can have both positive and negative effects on water resources. The impacts are also highly dependent on the supply chain element under consideration. Feedstock cultivation can lead to leaching and emission of nutrients resulting in increased eutrophication of aquatic ecosystems (Millennium Ecosystem Assessment 2005, SCBD 2006). Pesticide emissions to water bodies may also negatively impact aquatic life. Perennial herbaceous crops and short rotation woody crops generally require less agronomic input – resulting in less impacts – and can also mitigate impacts if integrated in agricultural landscapes as vegetation filters intended to capture nutrients in passing water (Börjesson and Berndes, 2006).

The subsequent processing of the feedstock into solid/liquid/gaseous biofuels and electricity can lead to negative impacts due to potential chemical and thermal pollution loading to aquatic systems from refinery effluents and fate of waste or co-products (Martinelli and Filoso 2008, Simpson et al. 2008). The environmental impacts which result from the biofuel production stage can be reduced if suitable equipment is installed (Wilkie et al. 2000, BNDES/CGEE 2008) but this may not happen in regions with lax environmental regulations or limited law enforcement capacity.

Besides pollution impacts bioenergy systems can also impact water resource availability. For bioenergy systems that use cultivated feedstock most of the water needed is used in the production of the feedstock (Berndes 2002) where it is lost to the atmosphere in plant evapotranspiration (ET). The subsequent feedstock processing into fuels and electricity requires much less water (Aden et al. 2002, Berndes 2002, Keeny and Muller 2006, Pate et al. 2007, Phillips et al. 2007), but this water needs to be extracted from lakes, rivers and other water bodies. Bioenergy processing can reduce its water demand substantially by means of process changes and recycling (Keeney and Muller 2006, BNDES/CGEE 2008).

Energy crop irrigation competes for water directly with other irrigation as well as with residential and industrial uses. But rainfed feedstock production can also compete for water by redirecting precipitation from runoff and groundwater recharge to energy crop ET and consequently reduce downstream water availability (Berndes 2008). The net effect of expanding rainfed production depends on which types of energy crops become dominating and also on which vegetation types become replaced by the energy crops. Compared to food crops, shrubs and pasture vegetation, bioenergy plantations can have higher productivity and higher transpiration and rainfall interception, particularly for evergreen species. Expanding such fast growing plantations on low-yielding cropland, shrublands or pastures will therefore often lead to increases in ET and reductions in downstream water availability, especially in drier areas (Jackson et al. 2005, Zomer et al. 2006). Establishment of energy crops that has lower ET than the previous vegetation may conversely lead to increased downstream water availability.

Rising water demand for food, growing freshwater scarcities in many world regions, and the risk that climate change will lead to an increased water stress, have lead to that many analysts see challenges in meeting future demands for the production of food, feed and bioenergy feedstocks (Alcamo et al., 2005, Bates et al., 2008, De Fraiture et al., 2008, Lobell et al., 2008, Lundqvist et al. 2007, Molden et al., 2007, Rosegrant et al., 2002, Varis, 2007, Vorosmarty et al., 2005). However, several regions in the world will not likely be constrained in their bioenergy production by scarce water availability (Berndes, 2002).

Under strategies that shift demand to alternative – mainly lignocellulosic – feedstock bioenergy expansion does not necessarily lead to increased water competition. Given that several types of energy crops are perennial leys and woody crops grown in multi-year rotations, the increasing bioenergy demand may actually become a driver for land use shifts towards land use systems with substantially higher water productivity. A prolonged growing season may facilitate a redirection of unproductive soil evaporation and runoff to plant transpiration, and crops that provide a continuous cover over the year can also conserve soil by diminishing the erosion from precipitation and runoff outside the growing season of annual crops. Since a number of crops that are suitable for bioenergy production can be grown on a wider spectrum of land types, marginal lands, pastures and grasslands, which are not suitable for conventional food/feed crops, could become available for feedstock production under sustainable management practices (if downstream water impacts can be avoided).

2.5.3.3 Biodiversity impacts

Habitat loss is one of the major causes of biodiversity decline globally and is expected to be the major driver of biodiversity loss and decline over the next 50 years (Convention on Biodiversity, 2008, Sala et al., 2009). While bioenergy can reduce global warming – which is expected to be one of the major drivers behind habitat loss with resulting biodiversity decline – it can also in itself impact biodiversity through conversion of natural ecosystems into bioenergy plantations or changed forest management to increase biomass output for bioenergy. To the extent that bioenergy systems are based on conventional food and feed crops, biodiversity impacts due to pollution resulting from pesticide and nutrient loading can be an expected outcome of bioenergy expansion.

However, bioenergy expansion can also lead to positive outcomes for biodiversity. Establishment of perennial herbaceous plants of short rotation woody crops in agricultural landscapes has been found to be positive for biodiversity (Semere et al., 2007; The Royal Society 2008).

Besides the general function of contributing to a more varied landscape, bioenergy plantations that are cultivated as vegetation filters capturing nutrients in passing water can contribute positively to biodiversity by reducing the nutrient load and eutrophication in water bodies (Borjesson and Berndes, 2006).

Bioenergy plantations can be located in the agricultural landscape so as to provide ecological corridors that provide a route through which plants and animals can move between different spatially separated natural and semi-natural ecosystems. This way they can reduce the barrier effect of agricultural lands. For example, a larger component of willow 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.

Properly located biomass plantations can also protect biodiversity by reducing the pressure on nearby natural forests. A study from Orissa showed that with the introduction of village plantations biomass consumption increased (as a consequence of increased availability) but at the same time, the pressure on the surrounding natural forests decreased (Köhling and Ostwald 2001).

When crops are grown on degraded or abandoned land, such as previously deforested areas or degraded crop- and grasslands, the production of feedstocks for biofuels could potentially have positive impacts on biodiversity by restoring or conserving soils, habitats and ecosystem functions. For instance, several experiments with selected trees and intensive management on severely degraded Indian wastelands (such as alkaline, sodic or salt affected lands) showed increases of soil carbon, nitrogen and available phosphorous after three to 13 years.

Increasing demand for oilseed has in some OECD member countries begun to put pressure on areas designated for conservation (Steenblik, 2007). Similarly, the rising demand for palm oil has contributed to extensive deforestation in parts of South-East Asia (UNEP, 2008). In general, since biomass feedstocks can be produced most efficiently in tropical regions, there are strong economic incentives to replace tropical natural ecosystems – many of which host high biodiversity values – with energy crop plantations (Doornbosch and Steenblik, 2007).

Although biomass potential assessments commonly exclude nature conservation areas from being available for biomass production, biodiversity impacts still may arise in the real world. In the short term, impacts from existing agricultural and forest land for bioenergy are dominant. For example, the use of biomass from forests could reduce the quantity or quality of natural vegetation and availability of dead wood, and consequently biodiversity.

Biodiversity loss may also occur indirectly, such as when productive land use displaced by energy crops is re-established by converting natural ecosystems into croplands or pastures elsewhere.

2.5.3.4 Impacts on soil resources

Increased biofuel production, especially based on conventional annual crops, may result in higher rates of soil erosion, soil carbon oxidation and nutrient leaching owing to the increased need for tillage (UNEP 2008). For instance, wheat, rapeseed and corn require significant tillage compared to oil palm and switchgrass (FAO 2008b; United Nations 2007). Excess removal of harvest residues such as straw may lead to similar types of soil degradation.

However, if energy crop plantations are established on abandoned agricultural or degraded land, levels of soil erosion could be decreased because of increased soil cover. This would be particularly true where perennial species are used. For example, Jatropha can stabilize soils and store moisture while it grows (Dufey 2006). Other potential benefits of planting feedstocks on degraded or marginal lands include reduced nutrient leaching, increased soil productivity and increased carbon content (Berndes 2002).

2.5.3.5 Environmental health and safety implications

Dedicated energy crops have not been subject to the same breeding efforts as the major food crops. Selection of suitable crop species and genotypes for given locations to match specific soil types and climate is possible, but is at an early stage of understanding for some energy crops, and traditional plant breeding, selection and hybridization techniques are slow, particularly in woody crops but also in grasses. New biotechnological routes to produce both non-genetically modified (non-GM) and GM plants are possible. For example, it has been shown that down-regulation of the genes for lignin synthesis resulted in taller trees although the structure of the trees was somewhat altered.

GM energy crop species may be more acceptable to the public than GM food crops, but there are still concerns about the potential environmental impacts of such plants, including gene flow from non-native to native plant relatives. As a result, non-GM biotechnologies may remain particularly attractive. On the other hand, GMO food crops have already been widely accepted in many non-EU countries. Finally, it is important to note that, especially for restoration of degraded soils, bioenergy crops must be optimized, not maximized, as low input systems involve limited nutrients and chemical inputs.

2.5.3.5.1 Novel plants utilized for bioenergy production

Currently, the crops used in fuel ethanol manufacturing are the same as those used as traditional feed sources (e.g. corn, soy, canola and wheat). However, there is considerable interest today by seed companies and the ethanol industry in new crops, with characteristics that either enhance fuel ethanol production (e.g. high-starch corn), or are not traditional food or feed crops (e.g. switchgrass). These crops, developed for industrial processing, may trigger the need for a pre-market assessment for their acceptability in feed prior to their use in fuel ethanol production, if the resultant distillers' grains (DGs) are to be used as livestock feeds, or if the new crop could inadvertently end up in livestock feeds.

2.5.3.5.2 Genetically modified bioenergy plants

As with any genetically modified or enhanced organism, the energy-designed crop may raise significant concerns related to cross-pollination, hybridisation, and other potential environmental impacts such as pest resistance and disruption of ecosystem functions (FAO, 2004).

2.5.3.5.3 Antimicrobial agents

During the fermentation process, antimicrobial agents (drugs or other chemicals) are routinely used to combat the growth of organic acid-producing bacteria that compete with yeast, competitively inhibiting ethanol production. Analysis of the fuel ethanol industry in North America shows that the antimicrobial agents that are currently used or are being considered for use in the production of fuel ethanol contain the following active ingredients either alone or in combination: ampicillin, monensin, penicillin, streptomycin, tylosin, and virginiamycin.

Veterinary drugs biological assessment capacity exists within the North American and European regulatory communities for assessing the potential impact that these antimicrobial agents present to animal and human health. Information about the antimicrobial agents, potential residual concentrations and exposure estimates, along with available literature and information provided by the ethanol industry respecting the breakdown of antimicrobial agents during ethanol production are routinely provided to government officials to conduct health risk assessment as required.

Results from this analysis within the Canadian context TSU: citation missing indicate that the use of ampicillin, penicillin, streptomycin, and virginiamycin, at the maximum inclusion rates indicated during the entire fermentation process should not result in detectable residues and, as such, are unlikely to pose adverse health risks to humans and food animals, or to contribute to the development of antimicrobial resistant bacteria.

Monitoring levels should be aligned with ingredient risks, manufacturing complexity, etc. Limits of detection (LODs) should be around 0.2 mg/kg (parts per million) in Canada and would be specific to the active ingredient. While validated antimicrobial-specific residue methods are not available, new detection methods are currently being developed and may be available shortly and we can build upon them to establish a sense as to where the rest of the global bioenergy community is moving in this regard. Further verification of the absence of residues will need to be considered when appropriate methods are available.

2.5.3.5.4 Alien invasive plant species

Non native species have wreaked havoc on biodiversity throughout the world via a number of processes that include: Facilitating native extinction; altering the composition of ecological communities; changing patterns of disturbances; and, altering ecosystem processes (Sala et al. 2009. see also Sax and Gaines 2008).

Several grasses and woody species which are potential candidates for future biofuel production also have traits which are commonly found in invasive species. (Howard and Ziller 2008).

These traits include rapid growth, high water-use efficiency and long canopy duration. It is feared that should such crops be introduced they could become invasive and displace indigenous species and result in a decrease in biodiversity. For example Jatropha curcas, a potential feedstock for biofuels, is considered weedy in several countries, including India and many South American states (Low and Booth, 2007). Similar warnings have also been raised with regard to species of Miscanthus and switchgrass (Panicum virgatum). Other biofuel crops such as Sorghum halepense (Johnson grass), Arundo donax (giant reed), Phalaris arundinacea (reed canary grass) are already known to be invasive in the United States.

Finally, a number of protocols have evolved that will allow for a more system assessment and evaluation of any inherent risk associated prior to the introduction of a new plant species into a host country environment.

2.5.4 Socio-economic impacts

2.5.4.1 Introduction

The large-scale development of bioenergy at the global level will be associated with a complex set of socio-economic issues and trade-offs, ranging from local income and employment generation, improvements in health conditions, potential changes in agrarian structure, land-tenure, land-use competition, and strengthening of regional economies, to national issues such as food and energy security and balance of trade. The degree to which these impacts turn out mostly positive depend to the extent to which sustainability criteria are clearly incorporated in project design and implementation. Participation of local stake-holders, in particular small-farmers and poor households, is key to assure socio-economic benefits from bioenergy projects.

Up to now, the large perceived socio-economic benefits of bioenergy use–such as regional employment created and economic gains-can clearly be identified as a significant driving force in the push for increasing the share of bioenergy in the total energy supply. Other “big issues” such as mitigating carbon emissions, ensuring wider environmental protection, and providing security of energy supply are an added bonus for local communities where the primary driving force is much more likely to be related to employment or job creation. Overall, these benefits will result in increased social cohesion and create greater social stability. For the public, policymakers and decision-makers, energy and bioenergy are becoming increasingly interesting and important subjects as a result of rises in the prices and more insecure supplies of fossil fuels.

On the other hand, substantial opposition has been raised against the large-scale deployment of bioenergy, particularly regarding projects aimed at producing liquid fuels out of first generation feedstocks, based on serious concerns about their potential negative impact on food security, the extent to which current strategies and policies will actually benefit poor farmers, the potential disruption of local production systems and concentration of land and other social effects

The use of sustainability indicators has been proposed as a way to better understand and assess the implications of bioenergy projects (Bauen et al., 2009a). Below we summarize the indicators proposed to address the socio-economic impacts of bioenergy.

2.5.4.2 Socio-economic sustainability criteria for bioenergy systems

Socio-economic impact studies are commonly used to evaluate the local, regional and/or national implications of implementing particular development decisions. Typically, these implications are measured in terms of economic indices, such as employment and financial gains, but in effect the analysis relates to a number of aspects, which include social, cultural, and environmental issues. A complication lies in the fact that these latter elements are not always tractable to quantitative analysis and, therefore, have been excluded from the majority of impact assessments in the past, even though at the local level they may be very significant. The varied nature of biomass and the many possible routes for converting the biomass resource to useful energy make this topic a complex subject, with many potential outcomes .

Diverse sustainability criteria and indicators have been proposed as a way to better assess the socio-economic implications of bioenergy projects (Bauen et al. 2009a; WBGU, 2009). These criteria relate to:

- Human rights, including gender issues;

- Working and wage conditions, including health and safety issues;

- Local food security, and

-Rural and social development, with special regards to poverty reduction.

These criteria also address issues of cost-effectiveness and financial sustainability (Table 2.5.4).

Table 2.5.4. Selected Socio-economic Sustainability Criteria for Bioenergy Systems

Criteria	Issues Addressed
Rural and Social Development	Improved access to basic services and livelihoods; Creation or displacement of jobs, Creation of infrastructure
Human Rights and Working Conditions	Freedom of association, Access to Social Security, Average Wages, Discrimination.
Health and Safety	Health Improvements or Impacts on Workers and Users; Safety Conditions at Work
Gender	Changes in Power or Access to resources or decision making
Land-use competition and food security	Emerging local and macroeconomic competition with other land uses; Reduced access to food
Land tenure	Changing patterns of land ownership and access to common resources; Impacts on poorest farmers

In what follows we review the main socio-economic impacts of bioenergy by main applications, separating them into three broad categories: Heat production, electricity production and production of liquid fuels. As a lot of the impacts are local in nature, we use selected case studies to illustrate the discussion.

2.5.4.3 *Socio economic impacts of small scale systems from heat and electricity production*

2.5.4.3.1 Rural industries

The small and rural industries sector is a very important component of developing countries' economies. Millions of people depend on these industries for the provision of their daily livelihoods. A large number of small and rural industries use biomass as main source of fuel to meet their thermal energy requirements such as water heating, steam generation and residential heating. There is significant potential to improve energy efficiency in these biomass-consuming industries as well as replacing the present fossil fuel consumption for thermal applications in many small and rural scale industries (FAO, 2005c). In addition to saving of fuel the other benefit that accrued were increase in productivity, better quality of products, saving in labour, water and improvement in the working condition

2.5.4.3.2 Improved cookstoves

In addition to its environmental impacts, the inefficient use of biomass in traditional devices such as open fires leads to significant social and economic impacts in terms of: The drudgery for getting the fuel, the monetary cost of satisfying cooking needs, gender issues, and significant health impacts associated to very high levels of indoor air pollution, which affects in particular women and children during cooking (Romieu et al. 2009; Masera et al. 1997; Bruce et al. 2006).

Recent research on health problems associated to traditional biomass use for cooking in households shows that 4 billion people suffer from continuous exposure to some via the process of cooking food over open wood burning fires most probably, significantly exacerbate ongoing disease processes (Pimentel et al., 2001). Human health effects from wood-smoke exposure have contributed towards an increased burden of respiratory symptoms and problems, further, it has been shown that females in these kinds of environments are particularly affected probably as a result of higher exposure to wood-smoke-polluted indoor air (Boman et al., 2006; Mishra et al. 2004; Schei et al. 2004, Thorn et al. 2001).

The pollutants include respirable particles, carbon monoxide, oxides of nitrogen and sulfur, benzene, formaldehyde, 1,3-butadiene, and polyaromatic compounds, such as benzo(a)pyrene (Smith 1987). In households with limited ventilation (as is common in many developing countries), exposures experienced by household members, particularly women and young children who spend a large proportion of their time indoors, have been measured to be many times higher than World Health Organization (WHO) guidelines and national standards (Bruce et al. 2006; Smith 1987). The burden for these deceases has been estimated in 1.6 million excess deaths/year - including 900,000 children under five - and the loss of 38.6 millions DALY/yr (Smith and Haigler, 2008) TSU: should be defined. This is similar in magnitude to the burden of disease from malaria and tuberculosis (Ezzati et al., 2002).

The new generation of improved cookstoves (ICS) and dissemination programs have shown that properly designed and implemented ICS projects can lead to improved health (Ezzati et al., 2004). ICS projects compare well with interventions in other major diseases (von Schirnding et al., 2001). Figure 2.5.4 shows high and low estimates of cost effectiveness, measured in dollars per Disability Adjusted Life Year (DALY), for treatment options related to eight major risk factors accounting for 40 percent of the global burden of disease (DCPP, 2006). Evidence from selected case studies around the world document the large socio-economic and health benefits of ICS programs in terms of a very significant reducing indoor air pollution, human exposure and reduction in respiratory and other illnesses (Armendariz et al. 2008; Romieu et al., 2009,)

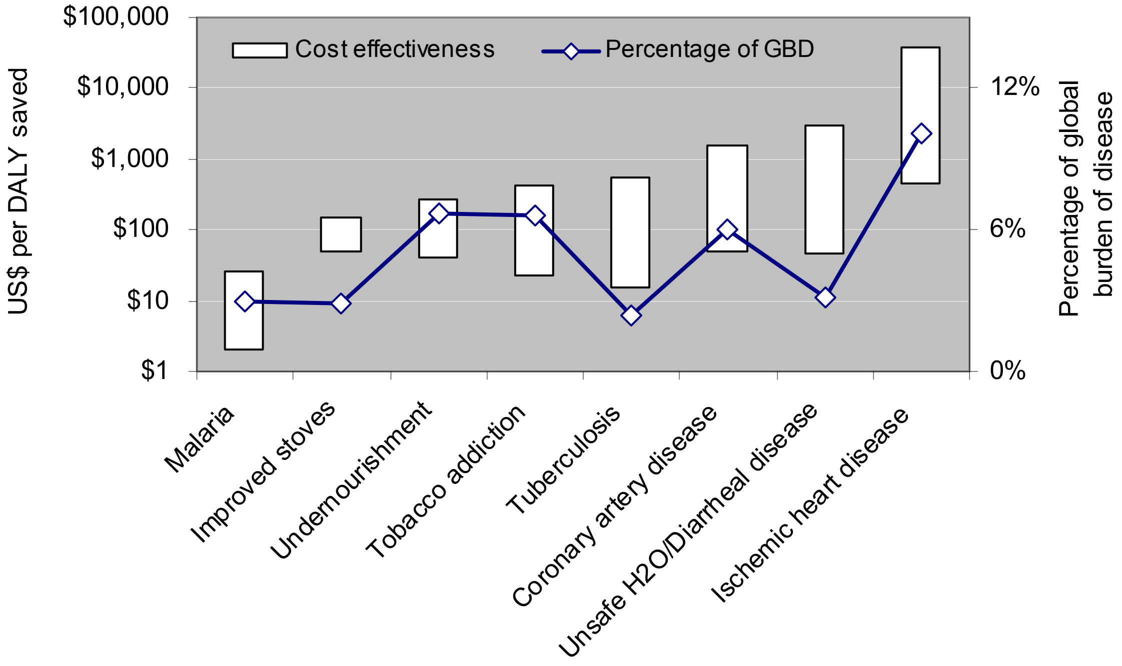


Figure 2.5.4.: Cost effectiveness of interventions in US$ per DALY avoided (DCPP, 2006) and percentage contributions to the global burden of disease from eight major risk factors and diseases. Note the left-hand vertical axis uses a logarithmic scale. Adapted from Bailis et al. 2009. TSU: GBD = global burden of disease; remove linking the GDBs with a like as x-axis is not continuous

Overall cost-effectiveness of ICS programs has been estimated for a series of case studies in Africa, Asia and Latin America. In China, the B/C TSU: define! for a switch from household use of coal for cooking in rural China to use of advanced biomass gasifier stoves that achieve dramatically lower emissions of health-damaging and methane emissions through better combustion efficiency and a cleaner fuel source, crop residues, as well as lower CO_2 emissions (because a nonrenewable fuel, coal, is replaced by crop residues, which are by definition renewable) has been estimated of 6 to 1 with a net benefit of US$ 300/stove (Smith and Haigler, 2008) TSU: maske sure that US$ 2005, see comment on first page. In Malawi, institutional ICS achieved a B/C of 5.6 to 1, while in Uganda the value was 20 to 1 when including local and global co-benefits. In Mexico, a comprehensive study with local measurements of health, social, local and global environmental costs and benefits, showed a B/C ratio of 13 to 1 from the dissemination of Wood burning ICS (Frapolli et al. 2009).

The savings in cooking time has facilitated use of this time for leisure, economic and social activities. Adoption of cookstoves has also been shown to foster other improvements in kitchens and homes leading to improving local living conditions (Masera et al., 2000). The manufacture and dissemination of ICS represents also an important source of income and employment for thousands of local small-businesses around the world (Masera et al., 2005).

2.5.4.3.3 Biogas plants

Small-scale biogas plants for household use (either for heat or for electricity generation) have also shown large social and economic benefits including the reduction in time and energy spent by women and children in collecting firewood for cooking, better sanitation to rural households, more employment for skilled people in the construction, maintenance, marketing, and financing of biogas plants. The use of biogas means negligible smoke, hence better family health. Moreover, the residual biological slurry from the biogas plants can be used as superior organic fertilizers to enhance agricultural yields . In the case of electricity villagers benefit from improved household lighting and also for street lighting, school, Panchayat Ghar, and shops. Efforts towards operating these systems sustainably include capacity building and handholding of Village Energy Committees.

2.5.4.3.4 Small Scale Electrification Using liquid biofuels

Decentralized small-scale biofuel production and application has the potential for being a major catalyst for rural development and addressing poverty, which in turn would have benefits in terms of improved livelihoods and quality of lives for the vast majority of the rural households deprived of energy service. Several success cases have been documented worldwide (Practical Action Consulting 2009)

2.5.4.3.5 Socio-economic impacts of large-scale bioenergy systems

TSU: entire section missing!

2.5.4.3.6 Bioenergy systems for heat and electricity production

Large scale systems for heat and electricity generation pose several socio-economic questions, and sustainably implemented can result in very significant benefits in terms of regional economic development, income generation and improved livelihoods, particularly in poorest regions.

As biomass is land-intensive, issues about land-use competition, in this case regarding the use of forests for fiber vs. fuel (or fuel for local needs such as cooking vs. industrial needs) may arise with an increased expansion of forest plantations for bioenergy purposes or with the increased use of native forests for these purposes. A common problem with timber plantations has been the expulsion of indigenous communities (e.g. Indonesia) from their lands. Properly managed, however, forests may sustain many services including timber, fuel and environmental services, with large gains for local populations, as is shown in many cases from developing and industrialized countries.

2.5.4.3.7 Bioenergy systems for liquid biofuels

The planned large-scale expansion of feedstocks needed for the production of liquid biofuels has sparkled a heated controversy around potential associated socio-economic issues such as: impacts on food security, land tenure, the number and type of jobs to be generated and other issues.

2.5.4.3.7.1 Risks to food security

If the food requirements of the world's growing Population are to be met, global food production will need to increase by around 50% by 2030. FAO estimates that the amount of land used for agriculture will need to be increased by 13 per cent by 2030. It is therefore likely that there will be a significant increase in competition for the use of agricultural land and, consequently, a trend towards rising food prices (FAO, 2008b). At the country level, higher commodity prices will have negative consequences for net food-importing developing countries. Especially for the low-income food-deficit countries, higher import prices can severely strain their food import bills.

Furthermore, a significant increase in the cultivation of energy crops implies a close coupling of the markets for energy and food. As a result, food prices will in future be linked to the dynamics of the energy markets. Political crises that impact on the energy markets would thus affect food prices. For around one billion people in the world who live in absolute poverty, this situation poses additional risks to food security and these risks must be taken into account by policy-makers (WBGU, 2009).

Economic aspects of sustainability are also particularly important for poorer countries. Many developing countries hope that bioenergy will bring development opportunities – perhaps by tackling rural poverty directly, by reducing dependence on imports of fossil fuels or by increasing energy supply security. They also perceive opportunities in relation to the export of modern energy, which can further a country's economic development. Another crucial issue is whether an expansion of the bioenergy sector is economically sustainable in the sense of being able to continue operations in the long term even without subsidies; if ongoing subsidy of the sector is required, funds will no longer be available for projects of greater social and economic promise.

2.5.4.3.7.2 Impacts on Rural and Social Development

A major study of FAO on the socio-economic impacts of the expansion of liquid biofuels (FAO, 2008b) indicates that in the short run, higher agricultural commodity prices will have widespread negative effects on household food security. Particularly at risk are poor urban consumers and poor net food buyers in rural areas, who tend also to be the majority of the rural poor. There is a strong need for establishing appropriate safety nets to ensure access to food by the poor and vulnerable.

In the longer run, growing demand for biofuels and the resulting rise in agricultural commodity prices can present an opportunity for promoting agricultural growth and rural development in developing countries.

It is key to focusing on agriculture as an engine of growth for poverty alleviation. This requires strong government commitment to enhancing agricultural productivity, for which public investments are crucial. Support must focus particularly on enabling poor small producers to expand their production and gain access to markets.

2.5.4.3.7.3 Impacts on Income-generation

Production of biofuel feedstocks may offer income-generating opportunities for farmers in developing countries. Experience shows that cash-crop production for markets does not necessarily come at the expense of food crops and that it may contribute to improving food security. Promoting smallholder participation in biofuel crop production requires active government policies and support. Crucial areas are investment in public goods (infrastructure, research extension, etc.), rural finance, market information, market institutions and legal systems (FAO, 2008b).

2.5.4.3.7.4 Impacts on Land tenure

In many cases, private investors will look to the establishment of biofuel plantations to ensure security of supply. Contract farming may offer a means of ensuring smallholder participation in biofuel crop production, but its success will depend on an enabling policy and legal environment.

Development of biofuel feedstock production may present equity- and gender-related risks concerning issues such as labour conditions on plantations, access to land, constraints faced by smallholders and the disadvantaged position of women.

Governments need to establish clear criteria for clearly determining the "productive use" of land and legal definitions of marginal land. Effective application of land-tenure policies that aim to protect vulnerable communities is no less important (FAO, 2008b).

2.5.5 Synthesis

The effects of bioenergy on social and environmental issues – ranging from health and poverty to biodiversity and water quality – may be positive or negative depending upon local conditions, how criteria and the alternative scenario are defined, and how actual projects are designed and implemented, among other variables.

Climate change and biomass production can be influenced by interactions and feedbacks among land use, energy and climate (see Figure 2.5.5). Bioenergy projects need to account for these interactions to maximize benefits while avoiding or mitigating risks. Climate benefits may also require trade-offs that involve diminished benefits in the short term in exchange for larger benefits in the long term.

Estimates of LUC effects require value judgments on the temporal scale of analysis, on land use under the assumed "no action" scenario, on expected uses in the longer term, and on allocation of impacts among different uses over time. Regardless, a system that ensures consistent and accurate inventory and reporting on carbon stocks is considered an important first step toward LUC carbon accounting.

Meanwhile, legitimate concerns exist because conversion of additional land can lead to significant emissions in the near term that can take decades to recuperate. It has been impossible to assess whether new land conversion (and associated anthropogenic fires) will increase or decrease in response to bioenergy policies, and the outcome hinges greatly on how those policies affect the underlying drivers of LUC in a given locale. Bioenergy and other policies affecting land-use need to be considered in unison so that they are mutually reinforcing and create incentives that reduce pressure on high-value ecosystems.

Environmental concerns over biofuels are substantially addressed by the UNFCC definition of "renewable biomass," which requires production to comply with national laws and regulations and to originate from areas where "sustainable management practices… ensure … that the level of carbon stocks on these land areas does not systematically decrease over time" TSU: reference missing!

However, compliance with the "renewable biomass" definition and other guidelines requires investments to develop sustainable management plans and monitor their implementation. These investments provide social and environmental dividends, but the additional costs must be compensated through higher returns or other incentives. Otherwise, "renewable biomass" will not be able to compete with less sustainable land uses.

Human welfare, bioenergy and the environment have been intimately entwined since the dawn of society. Yet, our ability to analyze the environmental and social dimensions of global bioenergy development is limited due to gaps in data and knowledge related to the complex and diverse interrelationships among human behavior, land use and climate. There is consensus, however, on the importance of developing more reliable and detailed data and scientific approaches to facilitate due diligence when designing policies and projects related to biofuels, as well as on the need to develop effective incentives for more sustainable land use in all sectors.

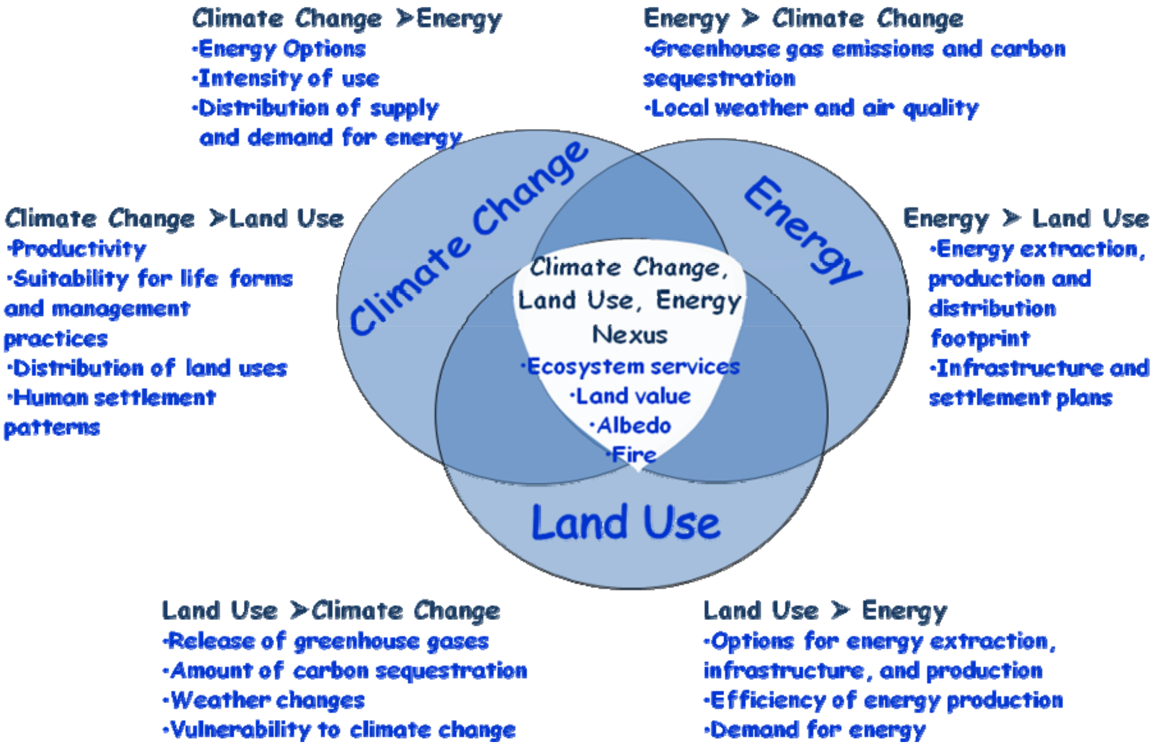


Figure 2.5.5.: Climate Change-Land Use-Energy Nexus. From Dale et al., submitted

2.6 Prospects for technology improvement, innovation and integration

This section provides an overview of potential performance of biomass-based energy in the future (within 2030) due to progress on technology.

2.6.1 Feedstock production

2.6.1.1 Yield gains

Increasing land productivity is a crucial prerequisite for realizing large scale future bioenergy potentials (section 2.2). Much of the increase in agricultural productivity over the past 50 years came about through plant breeding and improved agricultural management including irrigation, fertilizer and pesticide use. The adoption of these techniques in the developing world is most advanced in Asia, where it entailed a strong productivity growth during the past 50 years. Considerable potential exists for extending the same kind of gains to other regions, particularly Sub-Saharan Africa, Latin America, Eastern Europe and Central Asia where adoption of these techniques was slower (Figure 2.6.1). A recent long-term foresight by the FAO expects global agricultural production to rise by 1.5 percent a year for the next three decades, still significantly faster than projected population growth (World Bank, 2009). For the major food staple crops, maximum attainable yields may increase by more than 30% by switching from rain-fed to irrigated and optimal rainwater use production (Rost et al., 2009), while moving from intermediate to high input technology may result in 50% increases in tropical regions and 40% in subtropical and temperate regions. The yield increase when moving from low input to intermediate input levels can reach 100% for wheat, 50% for rice and 60% for maize (Table 2.6.1), due to better control of pests and adequate supply of nutrients. However, one should note that important environmental tradeoffs may be involved under strong agricultural intensification.

Table 2.6.1: Long-term (15-25 years) prospects for yield improvements relative to current levels (given in Table 2.3.1).

Feedstock type	Region	Yield trend (%/yr)	Potential yield increase (2030)	Improvement routes	Ref.
DEDICATED CROPS					
Wheat	Europe	0.7	50%	New energy-orientated varieties	1
	Subtropics		100%	Higher input rates, irrigation.	
Maize	N America	0.7	35%	Genotype optimization, GMOs, higher plantation density, reduced tillage. Higher input rates, irrigation.	
	Subtropics		60%		
	Tropics		50%		
Soybean	USA	0.7	35%	Breeding	2,3
	Brazil	1.0	60%		
Oil palm	World	1.0	30%	Breeding, mechanization	3
Sugar cane	Brazil	0.8	20%	Breeding, GMOs, irrigation inputs	2,3
SR Willow	Temperate	-	50%	Breeding	3
SR Poplar	Temperate	-	45%		
Miscanthus	World	-	100%	Breeding for minimal input requirements, improved management	
Switchgrass	Temperate	-	100%	Genetic manipulation	
Planted forest	Europe	1.0	30%	Traditional breeding techniques (selection for volume and stem straightness); CO_2 fertilization	4
PRIMARY RESIDUES					
Cereal straw	World	-	15%	Improved collection equipment; breeding for higher residue-to-grain ratios.	5,6
Soybean straw	N America	-	50%		
Forest residues	Europe	1.0	25%	Ash recycling.	4,7

References: 1: Fischer, 2001a; 2: IEA Bioenergy, 2009; 3: WWI, 2006; 4: Dupouey et al., 2006; 5: Paustian et al., 2006; 6: Perlack et al., 2005; 7: EEA, 2007;

These increases reflect present knowledge and technology (Fischer, 2001b: Duvick and Cassman, 1999), and vary across the regions of the world (Figure 2.6.1), being more limited in developed countries where cropping systems are already highly input-intensive. Also, projections do not always account for the strong environmental limitations that are present in many regions, e.g. limitations in water availability. Biotechnologies or conventional plant breeding could contribute to improve biomass production by focusing on traits relevant to energy production. The plant varieties currently being used for first-generation biofuels worldwide have been genetically selected for agronomic characteristics relevant to food and/or feed production and they have not been developed considering their characteristics as potential feedstocks for biofuel production. Varieties could be selected with increased biomass per hectare, increased yields of oils (biodiesel crops) or fermentable sugars (bioethanol crops) or with improvements in characteristics relevant for their conversion to biofuels. As little genetic selection has been carried out in the past for biofuel characteristics in most of these species, considerable genetic improvement should be possible (FAO, 2008d). Doubling the current yields of perennial grasses appears achievable through genetic manipulation (Turhollow 1994, Wright 1994, McLaughlin et al., 2002), possibly within 25 years timeframe (USDOE, 2002). Aggressive shifts to sustainable farming practices and large improvements in crop and residue yield could increase residue outputs from arable crops (Paustian et al., 2006). For example, the combination of no-till practices and continuous production of corn (rather than rotation of corn and soybean) is the scenario under which farmers in Iowa could collect the most residues (Sheehan et al. 2002).

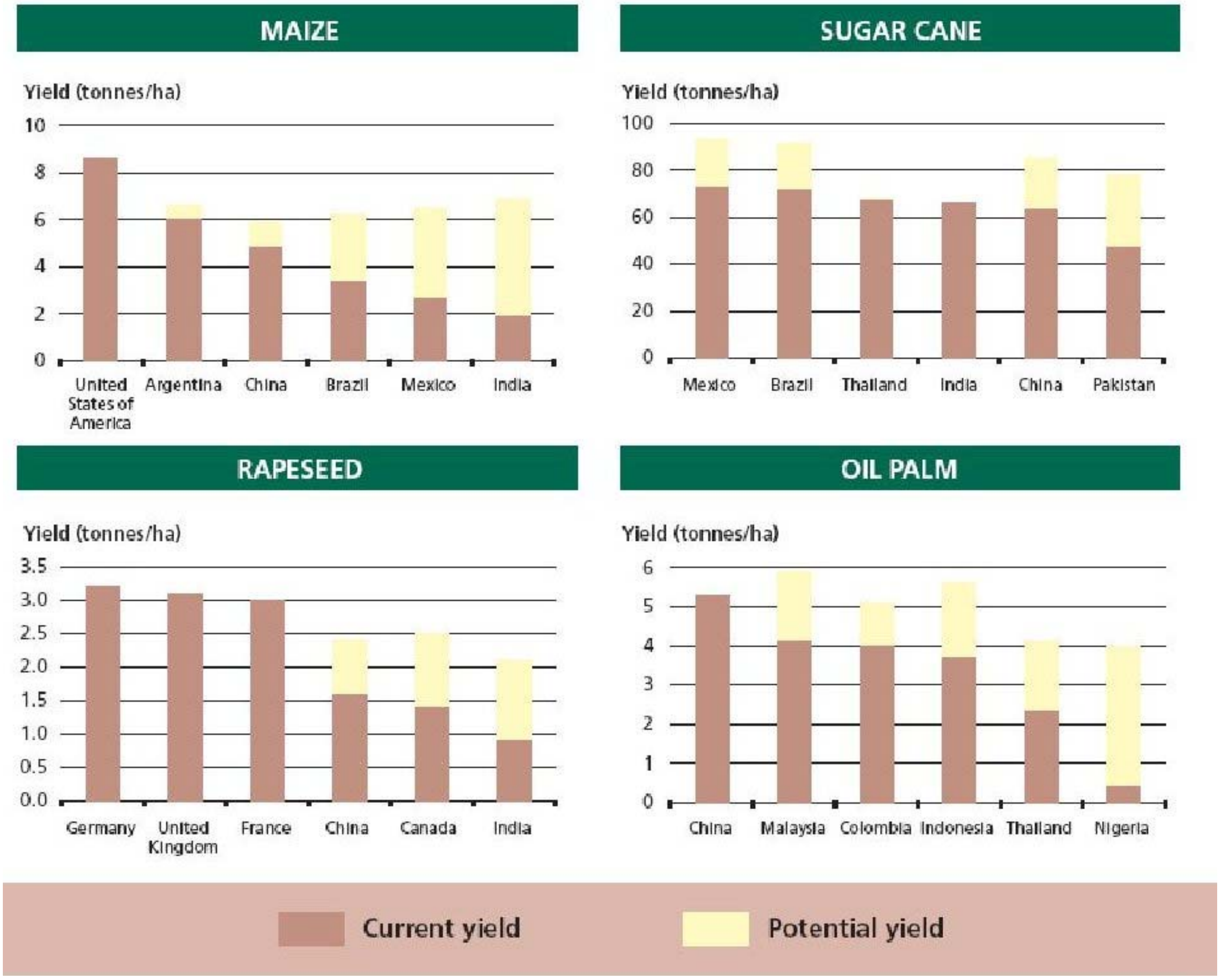


Figure 2.6.1 Potential for yield increase for four crops in various regions of the world. Source: FAO, 2008b.

2.6.1.2 Aquatic biomass

Algae have re-gained attention as an additional source of feedstock for energy in recent years. The term algae can refer to both microalgae and macroalgae (or seaweed). There are also cyanobacteria (so called “blue-green algae”) that dominate the world’s ocean, contributing to the estimated 350-500 billion metric tons of aquatic biomass produced annually (Garrison, 2008).

Of this diverse group of organisms, oleaginous microalgae have garnered the most attention as the preferred feedstock for a new generation of advanced biofuels. Lipids from microalgae, such as free fatty acids and triacyglycerides, are readily converted to fungible and energy-dense biofuels via existing petrorefinery processes (Tran et al., 2010). Certain species, such as Schizochytrium and Nannochloropsis, reportedly accumulate lipids at greater than 50% of dry cell weight (Chisti, 2007). Microalgae can be cultivated most cost-effectively in un-lined open ponds on currently unproductive land, and in offshore reservoirs (Sheehan et al., 1998; van Iersel et al., 2009). The ability of these microalgal cultivation strategies to utilize marginal lands and wastewater (Woertz et al., 2009) or brackish water (Vonshak and Richmond, 1985) - otherwise unsuitable for agriculture and human consumption- remains among the top drivers to develop algal biofuels as a sustainable energy solution. Despite of the advantages, scaling up microalgae biofuels production is not without substantial challenges, both from a feedstock logistics viewpoint (Molina Grima et al., 2003), as well as the cost to produce the biomass itself (Borowitzka, 1999).

Over a million metric tons of macroalgae are cultivated and harvested every year for human dietary consumption (Zemke-White and Ohno, 1999). Seaweeds as a bioenergy feedstock are of particular interest for countries with limited land but large coastal reserves. A few investigations into the use of seaweed for biofuels production have recently been reported (Ross et al., 2008; Aresta et al., 2005), and cultivation optimization strategies are being explored (Kraan and Barrington, 2005). However, it is unclear how large-scale production of macroalgae for bioenergy will impact marine eco-systems and competing uses for fisheries and leisure, posing zoning and regulatory hurdles at a minimum.

Interest in exploiting cyanobacteria for biofuels purposes have also begun. Cyanobacteria have long been cultivated commercially for nutraceuticals (Colla et al., 2007; Lee, 1997) and are arguably the most amenable for industrial biotechnology and genetic engineering- both for the production of biofuels (Hellingwerf and Teixeira de Mattos, 2009; Nobles and Brown, 2008; Lindberg et al., 2009) and enhancing the natural capabilities to produce bioproducts (Burja et al., 2001). It is likely that biofuels from cyanobacteria, as well as from eukaryotic microalgae face significant scale-up challenges as well as unclear regulatory status.

Potentials for algae have not been studied as extensively as the land-based biomass resources indicated in Table 2.2.2, but productivity could reach up to several hundreds of EJ for microalgae and up to several thousands of EJ for macro-algae (Sheehan et al., 1998; van Iersel et al., 2009). All types of algae, however, have relatively low dry matter content, so their applicability as a biomass feedstock is not straightforward. Other potential introduction barriers, such as ecological impacts of offshore cultivation, have not yet been fully addressed. Therefore, it is still difficult to assess the sustainability and economic competitiveness of algae options.

2.6.1.3 Vulnerability and adaptation to climate change

Climate change is expected to have significant impacts on biomass production, causing yields to increase or decrease by up to 20% relative to current levels, depending on world regions (Easterling et al., 2007). Biomass feedstocks will be affected through either a change of the agro-ecological zones suitable for them or, for those plantations already established, increased environmental stresses and higher risks of yield losses. Since most of the candidate feedstocks are perennial species with cultivation cycles of 20 or more years, climate impacts should be anticipated in the design of bioenergy-oriented agro-ecosystems, and are likely to be stronger than for annul crops (Easterling et al., 2007). However, there is currently limited knowledge on the impacts of climate change on energy feedstocks. In one example, miscanthus would yield more in Northern Europe in 2080 but less in the South, with the southernmost areas of the continent becoming unsuitable for that crop due to pronounced water shortage (Hastings et al., 2008). Whatever the latitude, the inter-annual variability of final yields in this study rose to 20% in 2080, posing a risk that will have to be carefully addressed when designing bioenergy units. Relying on a portfolio of species with various tolerances to water or other climatic stresses is probably the best option to secure a robust supply of biomass, also because it broadens the harvest time windows. Mixtures of species or varieties are also more robust to climate extremes and achieve more stable yields over time under sub-optimal conditions (Tilman et al., 2006). Genetic improvement is also a prime route, since for instance miscanthus has a large variability for environmental traits such as water or radiation-use efficiency (Clifton-Brown and Lewandowski, 2000).

The largest ecophysiological uncertainty in future production changes is the magnitude of the CO_2 fertilisation effect on plant growth, which can cause an enhancement of net primary production of around 20% under doubled free air CO_2 concentration. Most current biogeochemical models assume a strong CO_2 fertilisation effect with a levelling off at large atmospheric concentrations. This causes strong biomass yield increases through enhanced growth and increased water use efficiency as a consequence of decreased photosynthetic losses under conditions of stomatal closure due to water stress. Whether these increases can be expected to materialise under realistic conditions, where down-regulation may be a factor, currently remains unclear (Fischlin et al., 2007). Limitations of CO_2 fertilisation due to co-developing nutrient limitations could be overcome in plantations through fertiliser input.

2.6.1.4 Future outlook and costs

While area expansion for feedstock production is likely to play a significant role in satisfying an increased demand for biomass over the next decades, the intensification of land use through improved technologies and management practices will have to complement this option, especially if production is to be sustained in the long term. Crop yield increases have historically been more significant in densely populated Asia than in sub-Saharan Africa and Latin America and more so for rice and wheat than for maize and sugar cane. Actual yields are still below their potential in most regions (Figure 2.6.1). Evenson and Gollin (2003) documented a significant lag in the adoption of modern high-yielding crop varieties, particularly in Africa. Just as increased demand for bioenergy feedstock induces direct and indirect changes in land use, it can also be expected to trigger changes in yields, both directly in the production of energy crops and indirectly in the production of other crops – provided appropriate investments are made to improve infrastructure, technology and access to information, knowledge and markets. A number of analytical studies are beginning to assess the changes in land use to be expected from increased bioenergy demand, but little empirical evidence is yet available on which to base predictions on how yields will be affected – either directly or indirectly – or how quickly. In one example, ethanol experts in Brazil believe that, even without genetic improvements in sugar cane, yield increases in the range of 20 percent could be achieved over the next ten years simply through improved management in the production chain (Squizato, 2008).

Projections of future costs for biomass production are scant because of their connections with food markets (which are highly volatile and uncertain), and the fact that many candidate feedstock types are still in the research and development phase. Costs figures for growing these species in commercial farms are little known yet, but will likely reduce over time as farmers ascend the learning curves, as past experience has shown for instance in Brazil (Wall-Blake et al., 2009).

Under temperate conditions, the cost of lignocellulosic biomass from perennial grasses or short rotation coppice is expected to fall under 2.5 US$/GJ by 2020 (WWI, 2006), from a 3-16 US$/GJ range today (Table 2.3.1). However, another study in Northern Europe reports much higher projections, in a 3.7-7.5 US$/GJ range (Ericsson et al., 2009). These marginal costs will obviously depend on the overall demand in biomass, increasing for higher demand levels due to the growing competition for land with other markets (hence the notion of supply curves, addressed in section 2.7). For perennial species, the transaction costs required to secure a supply of energy feedstock from farmers may increase the production costs by 15% (Ericsson et al., 2009).

2.6.2 Logistics and supply chains

TSU: if not done in previous sections add definition of 1st/2nd-generation here.

Since biomass is mostly available in low density form, it demands more storage space, transport and handling than fossile equivalents, with consequent cost implications. It often needs to be processed to improve handling, as a result of which 20-50% of the delivered cost of biomass fuels is due to handling and transport (Allen et al., 1998), emphasizing the importance of supply chain logistical issues.

Use of a single agricultural biomass feedstock for year-round energy generation necessitates relatively large storage since this is available for a short time following harvest. Diversification to several different feedstocks will alleviate the seasonality problem but introduces more complex logistical complications due to the multiple supply chains. Among the characteristics that complicate the biomass supply chain are (Rentizelas et al., 2008):

- Multiple feedstocks with their own complex supply chains.
- Storage challenges including space constraints, fire hazards, moisture control, and health risks from fungi and spores.
- Seasonal variation in supply.

It has been pointed out (Rentizelas et al., 2008) that the impact of different storage solutions with and without out biomass drying still need further investigation. Decision support tools incorporating GIS data have a role in optimization of biomass management systems (Frombo et al. 2009). Figure 2.6.2.1 illustrates a generic supply chain with numerous interlinkages that could be optimized. Biomass is often widely dispersed, and therefore in its utilisation, collection, transportation, and pre-treatment will be important issues (Figure 2.6.2).

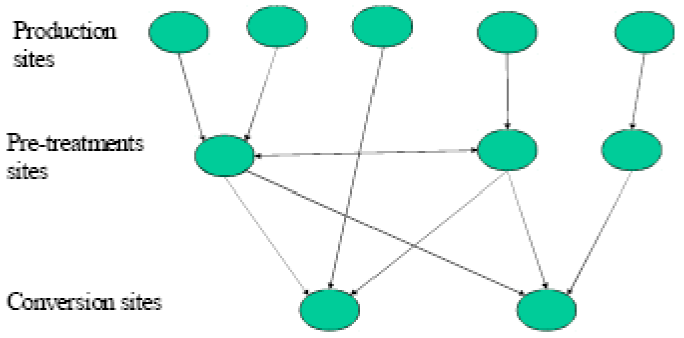


Figure 2.6.2. A generic chain from production to conversion sites. TSU: We hightly encourage the use of figures. This one we suggest to replace by text.

Pre-treatments include chipping, pellet making, and charcoal making as discussed in Section 2.3. In these cases, optimization is a key issue. Optimization could be achieved by studying optimal spatial distributions through linear optimization models that consider the locations of biomass production, transportation costs and scale economy of central plants (Nagatomi et al., 2008).

For the selection of pre-treatment technologies and conversion methods, etc., the integration of business processes from customer-order management to delivery supply chain management has to be considered. Various supply chain models and solution approaches have been extensively studied in literature (Vidal and Goetschalckx, 1997).

Planning models reflect production planning, production scheduling, and distribution planning. Biomass production generally has to address seasonal and scheduling problems as important issues. In addition, autonomous decentralized supply chains can be studied in models as to how they may form a complex biomass supply network (Nishii et al., 2005).

Developing countries have some specific issues. Charcoal in Africa is predominantly produced in inefficient traditional kilns by the informal sector, often illegally. From a developing country perspective, the application of industrial ecology through the lifecycle management concept to the charcoal industry has been advocated as one way to identify opportunities for technological improvement and loss reduction. Current production, packaging and transportation of charcoal is characterised by low efficiencies and poor handling, leading to losses. To introduce change to this industry requires that it be recognised and legalised, where it is found to be sustainable and not in contradiction with environmental protection goals. For example in Kenya the production and transportation of charcoal is illegal, whilst it is legal to buy, sell and use it. Once legalised it would be possible to regulate it and introduce standards including fuel quality, packaging standards, production kiln standards and what tree species could be used to produce charcoal (Kituyi, 2004). In regions where production is causing environmental degradation, such as in the Eastern DR Congo, fuel alternatives have to be developed while phasing out charcoal.

2.6.3 Conversion technologies & bioenergy systems

Advanced cultivation techniques could be taken up to increase the production of biomass for energy purposes all over the world. Various developments in technologies are also being explored to improve the conversion efficiencies of different feedstock types for various applications. Table 2.6.2 shows the most relevant bioenergy systems and chains expected to be in commercial operation at global level by 2030. For each energy end-use the table presents information about the feedstock, processing technology, end-use sector, the country or region, the expected production cost, and the market potential. Additional information about relevant technology development needs, and general comments, are also provided.

Table 2.6.2. Table summarizing the state of the art of the main chains for future production of end use biofuels.

End use biofuel	Major end use	Processing	Feedstock	Site	Comments	Technical Advances	Production Cost by 2030 (EU$/GJ)	Present deployment +low/ +++high	References
Ethanol	Transport	Fermentation	Sugar cane syrup	Brazil	Eff. = 0.38 by 2020 [cqvc.pdf] but historical gain is around 1%/yr; Mill size, advanced power generation and optimised energy efficiency and distillation can reduce costs further in the longer term.*	BCCS from sugar fermentation		+++	*UK DFT, 2009
						Efficient use of sugar cane straw as an extra source of heat&power	7 to 8**		
									**IEA Bioenergy: ExCo,2007
						Widespread use of GMO; evolution of biorefinery approach			
	Transport		Molasses	India				+	
				Colombia					
				Thailand					
	Transport	Fermentation	Corn grain	USA	Eff.= 0.67 for wet mill and 0.66 for dry mill*	BCCS from sugar fermentation		+++	*UK DFT, 2009
						R&D improves yield/reduced the time for processing			**Grooms, 2005; ***Rendleman and Shapouri, 2007
						Conversion of CO_2 to fuel**			
						Widespread use of GMO***			
	Transport	Fermentation	sugar beet	EU	Eff.= 0.13*		20 to30**	+	*UK DFT, 2009
	Transport	Fermentation	wheat	EU	Eff= .59*			+	**IEA Bioenergy: ExCo,2007
	Transport	Fermentation	cassava	Thailand			5 to 7**	+	
	Transport	Hydrolysis/Fermentation	Lignocellulosic	USA	Eff. = 0.49 for wood and 0.42 for straw; includes integrated electricity production of unprocessed components*	Enzymes for efficient C5 conversion** *** ****	7 to 9	NA	*UK DFT, 2008; **Jeffries, 2006; ***Jeffries et al., 2007; ****Balat et al., 2008; *****Sims et al., 2008; ******Bom and Ferrara, 2007; *******Tuskan, 2007; ******Kumar et al., 2008; *******NRC, 2009
						Significant amount of investment in R&D*****			
						Engineering of enzymes using advanced biotechnologies******			
						lignin dissolution to produce a cellulose-rich residue******* for 2020 deployable cost estimated is 22 US$/GJ with one to two cumulative volume doublings (20%/doubling)********	11.4 to 13.5 11 - 14********		

End use biofuel	Major end use	Processing	Feedstock	Site	Comments	Technical Advances	Production Cost by 2030 (EU$/GJ)	Present deployment +low/ +++high	References
Biomass to liquid	Transport	Fischer-Tropsh	Lignocellulosic	USA	via biomass gasification and subsequent syngas processing	BCCS for CO_2 from processing	20 to 30*	NA	*IEA Bioenergy: ExCo,2007
						For 2020 deployable 27 US$/GJ with one to two cumulative volume doublings (20%/doubling)**; For 2020 deployable Euro 26 US$/GJ with CCS and one to two cumulative doublings (-20%/doubling)**	14-17** 13-16**		**NRC, 2009
	Transport	Fischer-Tropsh	Lignocellulosic	EU	via biomass gasification and subsequent syngas processing	Diesel without BCCS	12.4 to 14.5*	NA	*Sims et al., 2008
Biodiesel	Transport	Tranesterification	Rape seed	OECD	For the total system it is assumed that surpluses of straw are used for power production	new methods using bio-catalysts, supercritical alcohol, and heterogeneous catalyst**	20 to 30***	+++	*Egsgaard et al., 200?
									**Bhojvaidad, 2008
					Excess supply of animal feed (globally) necessitates other uses of glycerine*				***IEA Bioenergy: ExCo,2007
					Nitrogen leakage and pesticide use are higher for annual crops than perennial crops*				
Renewable diesel	Transport	Hydrogenation	Sunflower		Technology well known. Economy is barrier	For 2030 with one or two cumulative volume doublings (-20%/doubling)	10-13*	NA	*Bain, 2007
			Soybeans						
Methanol	Transport	Gasification/Synthesis	Lignocellulosic	USA/EU	Combined fuel and power production possible	BCCS for CO_2 from processing	6 to 8*	NA	*IEA Bioenergy: ExCo,2007
Butanol	Transport	Fermentation	sugar/starch		The development of an integrated system for biobutanol production and removal may have a significant impact on commercialization of this process using the solvent producing clostridia*	recent developments in the genetics and downstream processing of biobutanol was recently reported ** ***		NA	*Wu et al., 2007
									Ezeji et al., 2007a;* Ezeji et al., 2007b
Densified biomass						Reduce the cost of fuel, by improved pre-treatment, better characterisation and measurement methods.*		+++	*Econ Pöyry, 2008

End use biofuel	Major end use	Processing	Feedstock	Site	Comments	Technical Advances	Production Cost by 2030 (EU$/GJ)	Present deployment +low/ +++high	References
						Working environment problems, caused by dust and micro-organisms, need further attention. *			
briquettes	Electricity	Drying/Mechanical compression	wood residues	EU/USA/ Canada	Large and continuously increasing co-combustion market	Reduce production costs*	5.0**	+++	*Econ Pöyry, 2008
									**Riegelhaupt et al., 2009
wood pellets	Heat	Drying/Mechanical compression	wood residues	EU/USA/ Canada	Large and continuously increasing residential market	Improved supply of feedstocks *	5.3**	+++	*Econ Pöyry, 2008
									**Riegelhaupt et al., 2009
sugar cane residue pellets	Electricity	Drying/Mechanical compression	sugar cane bagasse	Brazil	Large potential availability. Large commercial use		3.1*	+++	*Riegelhaupt et al., 2009
	Heat	Drying/Mechanical compression	sugar cane bagasse	Brazil	Large potential availability. Large commercial use		3.1	+++	
	Electricity	Drying/Mechanical compression	sugar cane straw	Brazil	Large potential availability. Small commercial use	Reduction of chlorine and potassium (to reduce corrosion) and potassium (to reduce slagging), e.g. by washing the biomass prior to combustion.*		+	*Econ Pöyry, 2008
	Heat	Drying/Mechanical compression	sugar cane straw	Brazil	Large potential availability. Small commercial use	Reduction of chlorine and potassium (to reduce corrosion) and potassium (to reduce slagging), e.g. by washing the biomass prior to combustion.*		+	*Econ Pöyry, 2008
straw pellets	Electricity	Drying	straw		straw water content is below 10%	Long-term storage of willow chips is very difficult due moisture content (55-58 %).*	4	NA	*Econ Pöyry, 2008
									Hoogwijk, 2004
	Heat	Drying	straw		straw water content is below 10%	Yield per hectare needs be increased to reduce the cost of fuel *		NA	*Econ Pöyry, 2008
Solid biofuel		Direct combustion	Forestry/agro residues	World wide					

End use biofuel	Major end use	Processing	Feedstock	Site	Comments	Technical Advances	Production Cost by 2030 (EU$/GJ)	Present deployment +low/ +++high	References
(small scale)	Cooking	harvested and cut to variable sizes; for briquettes and pellets mechanical densification required	wood; wood residues; agro residues; briquette; pellets; bagasse; straw	World wide	Improved cookstoves are presently available/reduce fuel use (up to 60%)/cut 70% indoor pollution	Optimized design of cookstoves and new materials, gasifier stoves for household use. Combined heat/electric. production already in demonstration. New stoves with 35-50% efficiency. Indoor air pollution reduced more than 90%.		+++	
(small scale)	Residential heat						2.5	+++	
(small scale)	Small industry-process heat				Existing industries have low efficiency kilns with high pollution. Improved kilns cut consumption in 50-60%. There are very large cobenefits of improved technologies in terms of public health and environment.		2.5	+++	
(large scale)	Power&heat				Low costs especially possible with advanced cofiring schemes and BIG/CC technology over 100-200 MWe.*	Gasification technology for large units** ***	Ect3-8 /kWh.	++	*UK DFT, 2009
						Indirect firing with Stirling engine or hot air turbines for medium units**			**Riegelhaupt et al., 2009; ***Electricity from Renewable, 2009
(large scale)	Power			USA	Cost of electricity delivered to consumer in EU/GWe. Cost off biomass EU$ 2/GJ	Widespread use of technology for combustion to electricity in the MW-range*	18	++	*Riegelhaupt et al., 2009
co-firing	electricity	combustion	briquettes/pellets	EU	eff., ~40%			+++	
Charcoal	industry	pyrolysis	wood	World wide		Improvement in the conversion efficiency through moderately capital intensive methods relying in well designed brick/steel kilns with good heat transfer by forcing the hot gases to pass through the unconverted wood and avoid over burning (FAO, 2009).		+++	
							2.1*		*Riegelhaupt et al., 2009
Biomass gases									
(small scale)		gas engine	agro residues		eff., 20%, Japan			+	
(large scale)	power&heat	gasification	wood residue	World wide				NA	
		gas turbine	agro residues						
(large scale)	synthetic diesel	gasification	wood residue	World wide			9*	NA	*Hamelinck, 2004
		synthesis	agro residues						

End use biofuel	**Major end use**	**Processing**	**Feedstock**	**Site**	**Comments**	**Technical Advances**	**Production Cost by 2030 (EU$/GJ)**	**Present deployment +low/ +++high**	**References**
(large scale)	power fuel cells	gasification	all solid biomass	World wide	H2 obtained or methanol synthesized from producer gas used to power fuel cell	improved gasifier efficiency*		NA	*Electricity from Renewable, 2009
Biogas									
household biogas	cooking/heat	digestion	manure	World wide	byproduct: liquid fertilizer	payback time	, 1-2 years	+++	
			human wastes						
biogas (big scale)	electricity	digestion plus gas engine/ steam turbine	MSW	World wide	byproduct: liquid fertilizer	Cost figure for 2020	Ect. 2.6/kWh*	+++	*Bauen et al., 2004
			agro residues		eff., 15-20%				
			industrial waste						
Hydrogen	Transport	Gasification/Syngas processing		USA/EU	Combined fuel and power production possible	research in gasification as basis for hydrogen production for fuel cells*	5 to 8**	NA	*Riegelhaupt et al., 2009
							5 to 10***		**Hoogwijk, 2004; ***Bain, 2007

2.6.3.1 Solid Biomass

Recent developments in the technologies for conversion of solid biomass to fuel ranging from rudimentary stoves to sophisticated large scale heat applications for production of combined heat and power. There has been a worldwide drive in improving the conversion efficiency of charcoal making. Well designed brick/steel kilns have the advantage of good heat transfer by forcing the hot gases to pass through the unconverted wood and avoid over burning (FAO, 2009a).

The use of bagasse as a feedstock for electricity production continues to grow in sugar cane mills. In Brazil, improvements in the technology and material of sugarcane bagasse have allowed an increase in steam pressure and temperature, as has been done already for the pulp and paper sector in OECD countries (Faaij, 2006). Advances in combustion technologies requires improvements in fuel efficiency which can be achieved by maintaining higher temperatures, sufficient air and optimum residence time for complete combustion. Fuel efficiency has been improved in Indian sugar mills by the conversion of boilers to fluidized bed furnace firing for use of rice husk and to traveling grate for bagasse firing (Yokoyama and Matsumura, 2008).

Gasification of solid biomass is a promising technology for production of power and or heat based in the use of solid biomass, with high efficiency gains expected especially in the case of polygeneration with Fischer-Tropsch fuels (Williams et al., 2009).

2.6.3.2 Liquid Fuels

Liquid biofuels are obtained either through 1st generation pathways (based on sugar, starch or vegetable oil feedstocks), or 2nd-generation pathways using lignocellulose. Prospects for these routes are covered in the following paragraphs.

As opposed with some views that first generation ethanol uses mature technologies with small room for improvement, future technical progress is expected to occur. Biotechnology can be applied to improve the conversion of biomass to liquid biofuels. Several strains of micro-organisms have been selected or genetically modified to increase the efficiency with which they produce enzymes (FAO, 2008d). Many of the current commercially available enzymes are produced using genetically modified (GM) micro-organisms where the enzymes are produced in closed fermentation tank installations (e.g. Novozymes, 2008). The final enzyme product does not contain GM micro-organisms (The Royal Society, 2008) suggesting that genetic modification is a far less contentious issue here than with GM crops.

Even in the simple fermentation process, high performance yeast strains[1] have recently been selected and commercialized for dry grind corn ethanol production utilizing batch fermentation processes. Some yeast strains ferment faster or are able to convert substrate to ethanol with increased yields (Knauf and Kraus, 2006). Regarding the starch-based processes, which are a mature technology, seed companies are working to create corn that will boost ethanol yield. Yield increases of 3 to 7 percent in batches using the so-called HTF corn (for High Total Fermentables) compared to unselected varieties, were reported (Haefele, 2002).

A number of process improvements (e.g. germ and fiber separation or improved yeast) are also available to reduce the cost of wet milling (Rendleman and Shapouri, 2007). In particular, CO_2 Recovery - ethanol's most abundant coproduct is CO_2, produced by yeast in about the same proportion as ethanol itself. Most of the ethanol plants, because of the low commercial value of

---

[1] A 'strain' is a group of organisms of the same species having distinctive characteristics

CO_2, simply vent it into the air. One experiment uses CO_2 to enhance the recovery of oil from depleted oilfields. Another idea is to turn the gas into ethanol or other fuel (Lynn Grooms, 2005).

Internationally, there is an increased interest in the commercialization of ligno-cellulose to ethanol technology (a 2nd-generation pathway). It involves a pre-treatment to hydrolyze fibers, usually with acid solutions or steam explosion, to release cellulose and hemicellulose compounds. The resulting sugar stream can then be fermented, using improved methods to allow both hexose and pentose sugars to be fermented simultaneously into ethanol. Research efforts have improved yields and reduced the time to complete the process, and a total of 16 plants were under construction in the USA in 2009 (US Cellulosic, 2009). Significant investment in RD&D funding by both public and private sources is occurring, but it should be expanded for commercial deployment of these technologies within the next decades (Sims et al., 2008). Nevertheless, attempts to economically transform cellulose in sugars date back at the start of the 20th-century. It is expected that, at least in the near to medium-term, the biofuel industry will grow only at a steady rate and encompass both 1st- and 2nd-generation technologies that meet agreed environmental, sustainability and economic policy goals (Sims et al., 2008).

The transition to an integrated 1st- and 2nd-generation biofuel landscape is therefore most likely to encompass the next one to two decades, as the infrastructure and experiences gained from deploying and using 1st-generation biofuels is transferred to support and guide 2nd-generation biofuel development (Sims et al., 2008).

Regarding **biodiesel**, the difficulty to reduce cost through the first generation process[2] suggests as a possible alternative the thermo-chemical route. The thermo-chemical route is largely based on existing technologies that have been in operation a number of decades. The key remaining challenges relate to the gasification of the biomass, producing a clean gas of an acceptable quality and the high intrinsic cost of the process. Gasification elements of the thermo-chemical platform for the production of biofuels are close to commercial viability today using various technologies and at a range of scales (see Table for 2006 TSU: which table is reference here? Do not reference tables outside this document!), although reliability of the process is still an issue for some designs. However, assembling the complete technological platform, including development of robust catalyst for biofuel production and modeling of capital and production costs, will require more R&D investment. It is also recognized that major technical and economic challenges still need to be resolved. Another area where some progress may be expected is the possibility of using biomass residues from vegetable oil feedstocks as a source of energy. The utilisation of straw to produce process heat and power would make a strong contribution to the total net energy supply from crops (BABFO, 2000).

There is currently no clear commercial or technical advantage between the biochemical and thermochemical pathways for liquid biofuels, even after many years of RD&D and the development of near-commercial demonstrations (Foust et. al., 2009). Both sets of technologies remain unproven at the fully commercial scale, are under continual development and evaluation, and have significant technical and environmental barriers yet to be overcome. Even with significant uncertainty about the commercial take off of any of these technologies (McAloon et al., 2000; Hamelinck et al., 2005, Kumar et al., 2008) IEA was able to make forecast for the price of 2nd-generation biofuels and such results are shown in Table (2030) TSU: see comment above for ethanol from lignocelluloses and for BTL diesel, showing a slight lower cost for the biochemical route by 2030, confirming its the present (2010) cost advantage (Sims et al., 2008). Alternative technologies for diesel and gasoline

---

[2] In the literature there are still efforts to improve the first generation approach. As an example a paper suggest newer methods of transesterification using bio-catalysts, supercritical alcohol, and heterogeneous catalyst are being explored (Bhojvaidad, 2008**)**.

substitution include biomass pyrolysis oil upgrading in conjunction with hydrodeoxygenation and catalytic upgrading. Proof of principle exists for this route for corn stover-derived pyrolysis oils.

2.6.3.3 Gaseous Fuels

Anaerobic digestion happens slowly in nature and could be accelerated in several ways, such as using more efficient micro-organisms in these processes. New technologies like fluorescence in situ hybridisation (Cirne et al., 2007) allows the development of strategies to stimulate hydrolysis further and ultimately increasing the methane production rates and yields from reactor-based digestion of these substrates (FAO, 2008d). A range of other biotechnologies are also being applied in this context, such as the use of metagenomics (i.e. isolating, sequencing and characterising DNA extracted directly from environmental samples) to study the micro-organisms involved in a biogas producing unit in order to improve its operation (e.g. http://www.jgi.doe.gov/sequencing/why/99203.html TSU: proper reference needed or remove). Recently marine algae have also been studied for biogas generation (Vergana-Fernandez, 2008).

Microbial fuel cells using organic matter as a source of energy are being developed for direct generation of electricity, through what may be called a microbiologically mediated “incineration” reaction. This implies that the overall conversion efficiencies that can be reached are potentially higher for microbial fuel cells compared to other biofuel processes. Microbial fuel cells could be applied for the treatment of liquid waste streams (Rabaey and Verstraete, 2005).

Synthesis gas is expected to become more widely used in the future. Progresses in scale-up, exploration of new and advanced applications, and efforts to improve operational reliability, have identified several hurdles to advance the state-of-the-art of biomass gasifiers. They include among others handling of mixed feed stocks, minimising tar formation in gasification, tar removal, and process scale-up (Yokoyama and Matsumura, 2008). To tackle the problem of tar content, particularly for power generation, multistage gasification systems (BMG) technologies are being designed and developed to produce Medium Calorific Value (MCV) gas by distinctly separate drying, devolatalization, gasification and combustion zones. Another promising technology is the development of two stage combined fluidized bed gasifier with combustion process by circulating catalytically active fluidized bed of solids (Fargernas et al., 2006).

2.6.3.4 Biomass with CO_2 capture and storage (CCS): negative emissions

Biomass-CCS (Obersteiner et al., 2001; Yamashita and Barreto, 2004; Mollersten et al., 2003; Rhodes and Keith, 2007, Pacca and Moreira, 2009) could substantially change the role of biomass-based mitigation. Biomass-CCS may be capable of cost-effective indirect mitigation—through emissions offsets—of emission sources that are expensive to mitigate directly (Rhodes and Keith, 2007). More generally, the most expensive emissions to abate directly could be mitigated indirectly with offsets from biomass-CCS systems deployed wherever (in the world) they are least expensive.

CO_2 capture from sugar fermentation to ethanol is possible (Mollersten, et al., 2003) and a pilot plant is under construction in Decatur, Illinois (http://www.istc.illinois.edu/about/SeminarPresentations/2009-04-15.pdf TSU: proper reference needed or remove!). For corn-based ethanol an evaluation of the impact of this technology on ethanol energy and GHG balance was performed (S&T2 Consultants Inc., 2009) and it is possible to reduce CO_2 emissions from 40,068g CO_2/GJ[3] to 12,362g CO_2/GJ at the expenses of degrading the energy balance by only 3.5%. Biomass and coal with CO_2 capture TSU: add might allow zero emissions TSU remove “–“ and add: as Larson et al., 2009 claim that it is possible to install

---

[3] This is the expected emission by 2015 with incorporation of several improvements in crop practice and ethanol processing according with IEA Task 39, 2008.

facilities co-producing Fischer-Tropsch Liquid (FTL) fuels and electricity from a co-feed of biomass and coal, with capture and storage of by-product CO_2. Comparing these combined feedstock plant with one fed only with coal, the cost of production on US$/GJ is still higher but the difference is not very big when accounting for a CO_2 value of US$ 20/t. Essentially the coal-based FT plant is cost effective for oil price of US$ 59/bb, while the biomass/coal one is cost effective at US$ 89. Nevertheless, with biomass and coal is possible to obtain zero emissions of CO_2 while even carrying CCs TSU: define in the coal fed plant the amount of GHGs emission is 94 kg CO_2/GJ of liquid fuel produced.

2.6.3.5 Biorefineries

The conversion of biomass to energy carriers and a range of useful products, including food and feed, can be carried out in multi-product biorefineries. Although the biofuel and associated co-products market are not fully developed, first generation operations that focus on single products (such as ethanol and biodiesel) are regarded as a starting point in the development of sustainable biorefineries. It may be argued that advanced biorefineries have a distinct advantage over conventional refineries (mineral oil) and first generation ‘single product focus’ operations e.g., recovered vegetable oil (RVO), or rapeseed oil to biodiesel plants, in that a variety of raw materials may be utilised to produce a range of added-value products. Advanced or second generation biorefineries are developing on the basis of more sustainably-derived biomass feedstocks, and cleaner thermochemical and biological conversion technologies to efficiently produce a range of different energy carriers and marketable co-products (de Jong et al., 2009).

A main driver for the establishment of biorefineries is sustainability. All biorefineries should be assessed through the entire value chain for environmental, economic, and social sustainability. A biorefinery is the integrated upstream, midstream and downstream processing of biomass into a range of products.

A general classification of biorefineries as found in the literature (Denmark; de Jong et al., 2009) is:

- The **energy-driven biorefinery**, of which the main target is the production of biofuels/energy. The biorefinery aspect adds value to co-products.
- The **product-driven biorefinery**, which the main target is the production of food/feed/chemicals/materials, in general by biorefinery processes. Often side-products are used for the production of secondary energy carriers (power/heat) both for in-house applications as well as for distribution into the market.

Task 42 TSU: not defined, not referenced! has further classified the different biorefineries. The classification approach consists of four main features that identify, classify and describe the different biorefinery systems: platforms, energy/products, feedstocks, and conversion processes. Some examples of classifications are: C6 sugar platform biorefinery for bioethanol and animal feed from starch crops, and syngas platform biorefinery for FT-diesel and phenols from straw.

An overview of all the biorefinery demonstration plants, pilot plants, and R&D initiatives within the Task 42 Participating Countries can be found on the Task website (www.iea-bioenergy.task42-biorefineries.com). TSU: please reference, no “ads” for websites They can produce a spectrum of bio-based products (food, feed, materials, chemicals) and bioenergy (fuels, power and/or heat) feeding the full bio-based economy. There is general international agreement TSU: too bold statement; reference? that biomass availability is limited so raw materials should be used as efficiently as possible, hence the development of multi-purpose biorefineries in a framework of scarce raw materials and energy.

2.7 Cost trends

2.7.1 Determining factors

Determining the costs of production of energy (or materials) from biomass is complex because of the regional variability of the costs of feedstock production and supply and the wide variety of biomass – technology combinations that are either deployed or possible. Key factors that affect the costs of bioenergy production are:

- For crop production: the cost of land and labour, crop yields, prices of various inputs (such as fertilizer) and the management system (e.g. mechanized versus manual harvesting).
- For the supply of biomass to a conversion facility: spatial distribution of biomass resources, transport distance, mode of transport and the deployment of pre-treatment technologies (early) in the chain. Supply chains ranges from use on-site (e.g. fuel wood or use of bagasse in the sugar industry) up to international supply chains with international shipment of pellets or liquid fuels such as ethanol.
- For final conversion to energy carriers (or biomaterials): scale of conversion, interest rate, load factor, production and value of co-products and costs of energy carriers (possibly) required for the process. Factors vary between technology and location.

Biomass supplies are, as any commodity, subject to pricing mechanisms. Biomass supplies are strongly affected by fossil fuel prices (see e.g. Schmidhuber, OECD analysis, GTAP analysis TSU: reference missing) as well as agro-commodity and forest product markets. Although in an ideal situation demand and supply will balance and production and supply costs provide a good measure for actual price levels, this is not a given. At present market dynamics determine the costs of the most important feedstocks for biofuels, such as corn, rapeseed, palm oil and sugar. For the wood pellets, another important fuel for modern biomass production which is internationally traded, prices have been strongly influenced by oil prices (since wood pellets are partly used to replace heating oil) and by supportive measures to stimulate green electricity production, such as feed-in tariffs of co-firing. (see e.g. Junginger et al., 2008). In addition, prices of solid and liquid biofuels are determined by national settings and specific policies and the market value of biomass residues is often determined by price mechanisms of other markets for which there may be alternative applications (see Junginger et al., 2001).

On a global scale and longer term, the analyses of Hoogwijk et al. (2009) provides a long term outlook of potential biomass production costs (focused on perennial cropping systems) on the long term, related to the different SRES scenarios (see Table 2.7.1, and Figure 2.7.1). Based on these analyses, a sizeable part (100 – 300 EJ) of the technical biomass potentials on long term could lay in a cost range around 2 Euro/GJ TSU: US$2005 as currency.

Table 2.7.1: Estimated geographical potential of energy crops for the year 2050, at abandoned agricultural land and rest land at various cut off costs (in U$2000) for the two extreme land-use scenarios A1 and A2. (Hoogwijk et al., 2009)

Region	**A1**			**A2**		
	> 1 $\$ \text{GJ}^{-1}$	**> 2 $\$ \text{GJ}^{-1}$**	**> 4 $\$ \text{GJ}^{-1}$**	**> 1 $\$ \text{GJ}^{-1}$**	**> 2 $\$ \text{GJ}^{-1}$**	**> 4 $\$ \text{GJ}^{-1}$**
Canada	0	11	14	0	8	9
USA	0	18	34	0	7	19
C. America	0	7	13	0	2	3
S.America	0	12	74	0	5	15
N.Africa	0	1	2	0	1	1
W Africa	7	26	28	8	15	15
E. Africa	8	24	24	4	6	6
S.Africa	0	13	17	0	0	1
W.Europe	0	3	12	0	6	12
E. Europe	0	7	9	0	6	6
F.USSR	0	79	85	1	42	47
Middle East	0	0	3	0	0	1
South Asia	0	12	15	1	8	10
East Asia	0	16	64	0	0	6
S. East Asia	0	9	10	0	7	7
Oceania	1	33	35	2	17	18
Japan	0	0	0	0	0	0
Global	16	271	438	15	129	177

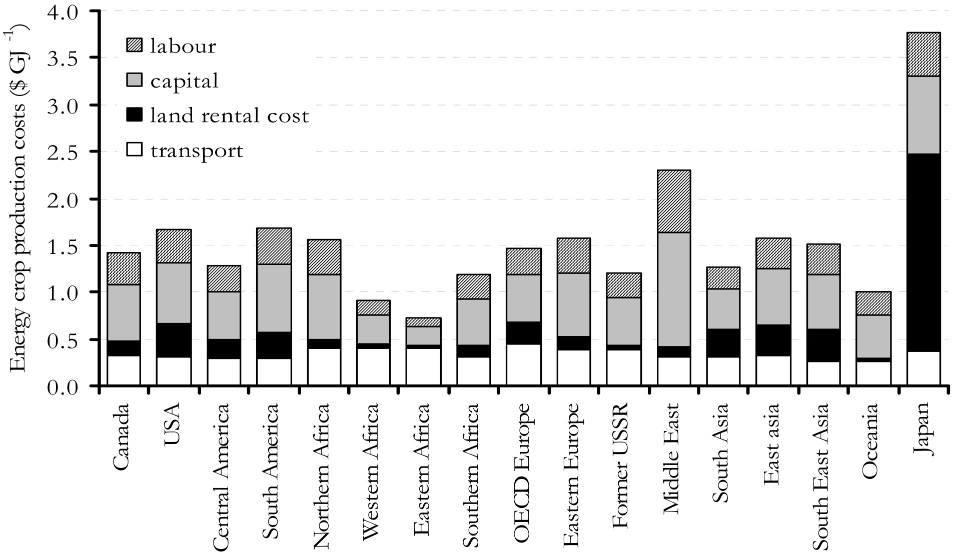


Figure 2.7.1: Cost breakdown for energy crop production costs in the grid cells with the lowest production costs within each region for the SRES A1 scenario in year 2050.

The costs figures reported here aim to summarize and aggregate the information compiled in sections 2.3, 2.5, and 2.6. Below, a preliminary compilation of costs data for bioenergy chains for current and future performance is given (Table 2.7.2, for power and heat and table 2.7.3 for biofuels)

Table 2.7.2: Generic overview of performance projections for different options to produce heat and power from different biomass resource categories on shorter (~5) and longer (>~20) years (e.g. based on: Hamelinck and Faaij, 2006, Faaij, 2006, Bauen et al., 2009b, IEA Bioenergy, 2007). TSU: are there more sources that were considered or is data in table set of examples and there could be many more?

Biomass feedstock category	**Heat**		**Electricity**	
	Short term; roughly stabilizing market	*Longer term*	*Short term; strong growth market worldwide*	*Longer term; growth may stabilize due to competition of alternative options*
Organic wastes (i.e. MSW etc.)	Undesirable for domestic purposes (emissions); industrial use attractive; in general competitive.	Especially attractive in industrial setting and CHP. (advanced combustion and gasification for fuel gas)	<3 – 5 U$ct for state-of-the art waste incineration and co-combustion. Economics strongly affected by tipping fees and emission standards.	Similar range; improvements in efficiency and environmental performance, in particular through IG/CC technology at large scale.
Residues: - Forestry - Agriculture	Major market in developing countries (<1-5 U$/kWhth); stabilizing market in industrialized countries.	Especially attractive in industrial setting and CHP. Advanced heating systems (domestic) possible but not on global scale	4-12 U$ct/kWh (see below; major variable is supply costs of biomass); lower costs also in CHP operation and industrial setting depending on heat demand.	2-8 U$ct/kWh (see below; major variable is supply costs of biomass)
Energy crops: (perennials)	N.A.	Unlikely market due to high costs feedstock for lower value energy carrier; possible niches for pellet or charcoal production in specific contexts	6-15 U$ct/kWh High costs for small scale power generation with high quality feedstock (wood) lower costs for large scale (i.e. >100 MWth) state-of-the art combustion (wood, grasses) and co-combustion.	3-9 U$ct/kWh Low costs especially possible with advanced co-firing schemes and BIG/CC technology over 100-200 MWe.

Table 2.7.3: Global overview of current and projected performance data for the main conversion routes of biomass to fuels (e.g. based on: Hamelinck and Faaij, 2006, Faaij, 2006, Bauen et al., 2009, IEA Bioenergy, 2007.

	Energy efficiency (HHV) + energy inputs		**Investment costs (Euro/kWth input capacity)**		**O&M (% of inv.)**	**Estimated production costs (Euro/GJ fuel)**	
Concept	**Short term**	**Long term**	**Short term**	**Long term**		**Shorter term**	**Longer term**
Hydrogen: via biomass gasification and subsequent syngas processing. Combined fuel and power production possible; for production of liquid hydrogen additional electricity use should be taken into account.	60% (fuel only) (+ 0.19 GJe/GJ H2 for liquid hydrogen)	55% (fuel) 6% (power) (+ 0.19 GJe/GJ H2 for liquid hydrogen)	480 (+ 48 for liquefying)	360 (+ 33 for liquefying)	4	9-12	4-8
Methanol: via biomass gasification and subsequent syngas processing. Combined fuel and power production possible	55% (fuel only)	48% (fuel) 12% (power)	690	530	4	10-15	6-8
Fischer-Tropsch liquids: via biomass gasification and subsequent syngas processing. Combined fuel and power production possible	45% (fuel only)	45% (fuel) 10% (power	720	540	4	12-17	7-9
Ethanol from wood: production takes place via hydrolysis techniques and subsequent fermentation and includes integrated electricity production of unprocessed components.	46% (fuel) 4% (power)	53% (fuel) 8% (power)	350	180	6	12-17	5-7
Ethanol from beet sugar: production via fermentation; some additional energy inputs are needed for distillation.	43% (fuel only) 0.065 GJe + 0.24 GJth/GJ EtOH	43% (fuel only) 0.035 GJe + 0.18 GJth/GJ EtOH	290	170	5	25-35	20-30
Ethanol from sugar cane: production via cane crushing and fermentation and power generation from the bagasse. Mill size, advanced power generation and optimised energy efficiency and distillation can reduce costs further on longer term.	85 litre EtOH per tonne of wet cane, generally energy neutral with respect to power and heat	95 litre EtOH per tonne of wet cane. Electricity surpluses depend on plant lay-out and power generation technology.	100 (range depending on scale and technology applied)	230 (higher costs due to more advanced equipment)	2	8-12	7-8
Biodiesel RME: takes places via extraction (pressing) and subsequent esterification. Methanol is an energy input. For the total system it is assumed that surpluses of straw are used for power production.	88%; 0.01 GJe + 0.04 GJ MeOH per GJ output Efficiency power generation on shorter term: 45%, on longer term: 55%		150 (+ 450 for power generation from straw)	110 (+ 250 for power generation from straw)	5 4	25-40	20-30

- Assumed biomass price of clean wood: 2 Euro/GJ. RME cost figures varied from 20 Euro/GJ (short term) to 12 Euro/GJ (longer term), for sugar beet a range of 12 to 8 Euro/GJ is assumed. All figures exclude distribution of the fuels to fueling stations.
- For equipment costs, an interest rate of 10%, economic lifetime of 15 years is assumed. Capacities of conversion unit are normalized on 400 MWth input on shorter term and 1000 MWth input on longer term

2.7.2 Technological learning in bioenergy systems

Cost trends and technological learning in bioenergy systems have long been less well described compared to e.g. solar and wind energy. Recent literature however gives more detailed insights in the experience curves and progress ratio's of various bioenergy systems. Table 2.7.4 and Figure 2.7.2 gives an overview of a number of analyses that have quantified learning and experience curves for e.g. sugarcane based ethanol production (Van den Wall Bake et al.; 2009), corn based ethanol production (Hettinga et al., 2009), wood fuel chips and CHP in Scandinavia (Junginger et al., 2005 and a number of other sources.

Table 2.7.4. Overview of experience curves for biomass energy technologies / energy carriers

Learning system	**PR (%)**	**Time frame**	**Region**	**n**	**R2**	**Data qual.**
Feedstock production						
Sugarcane (tonnes sugarcane) Van den Wall Bake et al.; 2009	68±3	1975-2003	Brazil	2.9	0.81	II
Corn (tonnes corn) Hettinga et al., 2009	55±0.02	1975-2005	USA	1.6	0.87	II
Logistic chains						
Forest wood chips (Sweden) Junginger et al., 2005	85-88	1975-2003	Sweden / Finland	9	0.87-0.93	II
Investment & O&M costs						
CHP plants (€/kWe) Junginger et al., 2005	75-91	1983-2002	Sweden	2.3	0.17-0.18	II
Biogas plants (€/m3 biogas/day) Junginger et al., 2006a	88	1984-1998		6	0.69	II
Ethanol production from sugarcane Van den Wall Bake et al.; 2009	81±2	1975-2003	Brazil	4.6	0.80	II
Ethanol production from corn (only O&M costs) Hettinga et al., 2009	87±1	1983-2005	USA	6.4	0.88	II
Final energy carriers						
Ethanol from sugarcane Goldemberg et al., 2004	93 / 71	1980-1985	Brazil	~6.1	n.a.	II
Ethanol from sugarcane Van den Wall Bake et al.; 2009	80±2	1975-2003	Brazil	4.6	0.84	II
Ethanol from corn Hettinga et al., 2009	82±1	1983-2005	USA	6.4	0.96	II
Electricity from biomass CHP Junginger et al., 2006a	91-92	1990-2002	Sweden	~9	0.85-0.88	II
Electricity from biomass IEA, 2000	85	Unknown	EU (?)	n.a.	n.a.	n.a.
Biogas Junginger et al., 2006a	85- 100	1984-2001	Denmark	~10	0.97	II

n	Number of doublings of cumulative production on x-axis.
I	cost/price data provided (and/or confirmed) by the producers covered
II	cost/ price data collected from various sources (books, journals, press releases, interviews)
III	cost/price data (or progress ratio) being assumed by authors, i.e. not based on empirical data

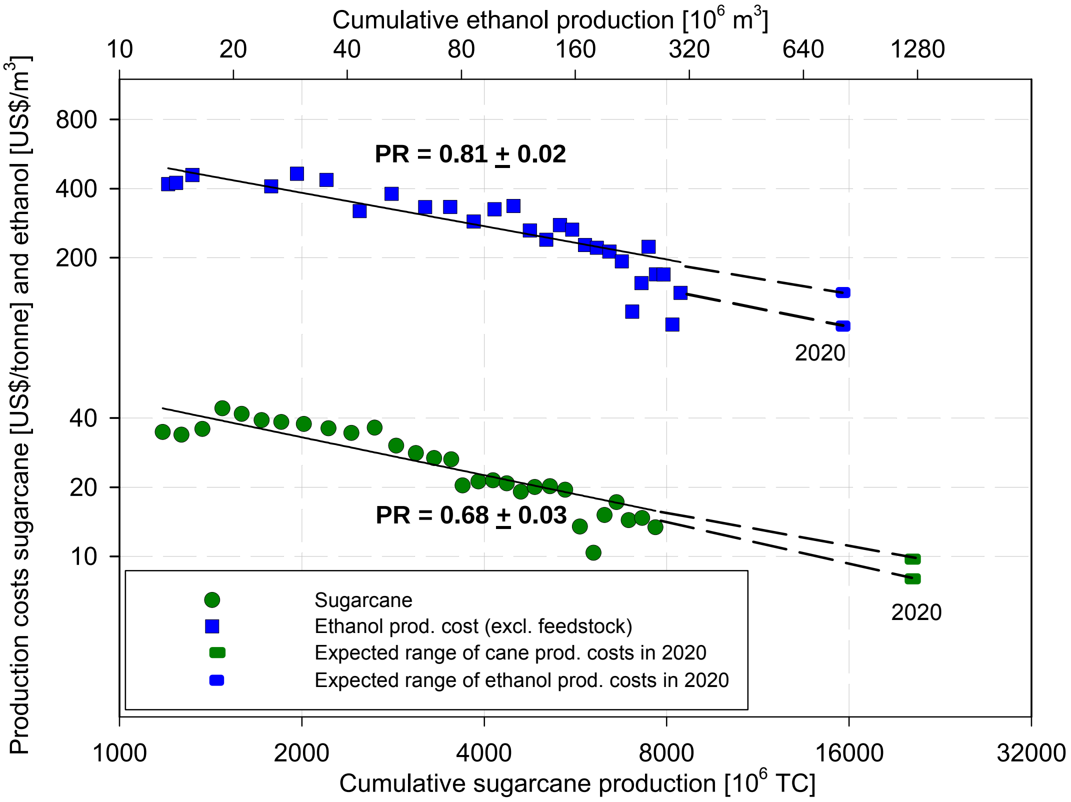


Figure 2.7.2: Experience curves for sugarcane production costs and ethanol production costs in Brazil between 1975-2005, and extrapolation to 2020 (Wall-Bake et al., 2009).

As discussed above, biomass energy systems are differing strongly in terms of feedstock, conversion technology and scale and final energy carrier. Yet, there are a number of general factors that drive cost reductions that can be identified:

- For the production of sugar crops (sugarcane) and starch crops (corn) (as feedstock for ethanol production), increasing yields have been the main driving force behind cost reductions.
- Specifically for sugarcane, also increasing strength of different varieties of sugarcane (developed through R&D efforts by research institutes), prolongation of the ratoon systems, increasingly efficient manual harvesting and the use of larger trucks for transportation reduced feedstock costs (Wall Bake et al. 2009). For the production of corn, highest cost decline occurred in costs for capital, land and fertilizer. Main drivers behind cost reductions are higher corn yields by introducing better corn hybrids and the upscaling of farms (Hettinga et al., 2009). While it is difficult to quantify the effects of each of these factors, it seems clear that both R&D efforts (realizing better plant varieties) and learning-by-doing (e.g. more efficient harvesting) played important roles.
- Industrial production costs for ethanol production from both sugarcane and corn mainly decreased because of increasing scales of the ethanol plants. Cost breakdowns of the sugarcane production process showed reductions of around 60 percent within all sub processes. Ethanol production costs (excluding feedstock costs) declined by a factor of three between 1975 and 2005 (in real terms, i.e. corrected for inflation). Investment and operation and maintenance costs declined mainly due to economies of scale. Other fixed costs, such as administrative costs and taxes did not fall dramatically, but cost reduction can be ascribed to application of automated administration systems. Declined costs can mainly be ascribed to increased scales and load factors.

- For ethanol from corn, ethanol processing costs (without costs for corn and capital) declined by 45% from 240US$$_{2005}$/m^3 in the early 1980's to 130$$_{2005}$/m^3 in 2005. Costs for energy, labour and enzymes contributed in particular to the overall decline in costs. Key drivers behind these reductions are higher ethanol yields, the introduction of specific and automated technologies that require less energy and labour and lastly the upscaling of average dry grind plants (Hettinga et al., 2009).

2.7.3 Future scenarios for cost reduction potentials

Only for the production of ethanol from sugarcane and corn, future production cost scenarios based on direct experience curve analysis were found in the literature:

- For ethanol from sugarcane (Wall Bake et al., 2009), total production costs at present are approximately 340 US$/m3 ethanol (16 US$/GJ). Based on the experience curves for feedstock and industrial costs, total ethanol production costs in 2020 are estimated between US$ 200-260/m3 (9.4-3 12.2 US$/GJ).

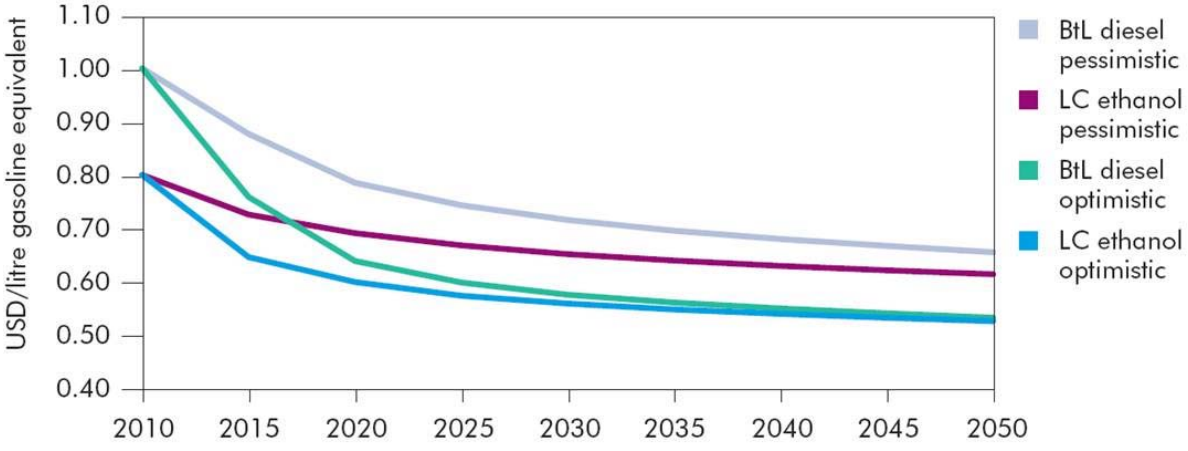
- For ethanol from corn (Hettinga et al., 2009), production costs of corn are estimated to amount to 75US$2005 per tonne by 2020 and ethanol processing costs could reach 60 - 77 US$/m3 in 2020. Overall ethanol production costs could decline from currently 310 US$/m3 to 248 US$/m3 in 2020. This estimate excludes the effect of probably higher corn prices in the future.

In the REFUEL project that focused on deployment of biofuels in Europe, (Wit et al., 2009, Londo et al., 2009) specific attention was paid to forecasts for learning for 2nd-generation biofuels. The analyses showed two key things:

- 2nd-generation biofuels do have considerable learning potential with respect to crop production, supply systems and the conversion technology. For conversion in particular, economies of scale are a very important element of the future cost reduction potential. Clearly, specific capital costs can be reduced (partly due to improved conversion efficiency). Biomass resources may become somewhat more expensive due to a reduced share of (cheaper) residues over time. Note that the results shown indicate that 2nd-generation biofuel production cost can compete with gasoline and diesel from oil of around 60-70 U$/barrel.

- The penetration of 2nd-generation biofuel options depends considerably on the rate of learning. Although this is a straightforward finding at first, it is more complex in policy terms, because learning is observed with increased market penetration (which allows for producing with larger production facilities).

In the IEA Energy Technology Perspectives report and IEA-WEO 2009 TSU: reference properly, especially between 2020 and 2030 sees a rapid increase in production of 2nd-generation biofuels, accounting for all incremental biomass increase after 2020. The analysis on biofuels projects an almost complete phase out of cereal and corn based ethanol production and oilseed based biodiesel after 2030. The projected potential cost reductions for production of 2nd-generation biofuels is given in figure 2.7.3.



Note: BtL = Biomass-to-liquids; LC= ligno-cellulose.

Figure 2.7.3. Cost projections for lignocellulosic ethanol and BTL diesel. Source: IEA-ETP, 2008 and see also IEA (2008) for data figures.

2.7.4 Closing remarks on cost trends

Despite the complexities of determining the economic performance of bioenergy systems and regional specificities there are several key conclusions that can be drawn from available experiences and literature:

- There are several important bioenergy systems today, most notably sugar cane based ethanol production and heat and power generation from residual and waste biomass that can be deployed competitively.
- There is clear evidence that further improvements in power generation technologies, supply systems of biomass and production of perennial cropping systems can bring the costs power (and heat) generation from biomass down to attractive cost levels in many regions, especially when competing with natural gas. In case carbon taxes of some 20-30 U$/ton would be deployed (or when CCS would be deployed), biomass can also be competitive with coal based power generation. Nevertheless, the competitive production of bio-electricity depends also on the performance of alternatives such as wind and solar energy, CCS and nuclear energy.
- There is clear evidence that technological learning and related cost reductions do occur with comparable progress ratio’s as for other renewable energy technologies. This is true for cropping systems (following progress in agricultural management when annual crops are concerned), supply systems and logistics (as clearly observed in Scandinavia, as well as international logistics) and in conversion (ethanol production, power generation, biogas and biodiesel).
- With respect to second generation biofuels, recent analyses have indicated that the improvement potential is large enough to make them compete with oil prices of 60-70 US$/barrel. Currently available scenario analyses indicate that if R&D and market support on shorter term is strong, technological progress could allow for this around 2020 (depending on oil price developments as well as carbon pricing). Scenarios also indicate that this would mean a major shift in the deployment of biomass for energy, since competitive production would decouple deployment from policy targets (mandates) and demand from biomass would move away from food crops to biomass residues, forest biomass and perennial cropping systems. The implications of such a (rapid) shift are so far poorly studied.

- Data availability is poor with respect to production of biomaterials; cost estimations of for example production of chemicals from biomass are very rare in peer reviewed literature and future projections and learning rates even more so. This is also the case for bio-CCS concepts, which are not deployed at present and cost trends are not available in literature. Nevertheless, recent scenario analyses indicate that advanced biomaterials (and cascaded use of biomass) as well as bio-CCS may become very attractive mitigation options on medium term. It is therefore important to gain experience and more detailed analyses on those options.

2.8 Potential Deployment

In total, bioenergy has a significant potential for both near and longer term greenhouse gas emission reductions.

Biomass is the most important renewable energy source, providing about 10% (46 EJ) of the annual global primary energy demand. A major part of this biomass use (37 EJ) is non-commercial and relates to charcoal, wood and manure used for cooking and space heating, generally by the poorer part of the population in developing countries. Modern bioenergy use (for industry, power generation, or transport fuels) is making already a significant contribution of 9 EJ and this share is growing. Today, biomass (mainly wood) contributes some 10% to the world primary energy mix, and is still by far the most widely used renewable energy source (Figure 2.8.1). While bioenergy represents a mere 3% of primary energy in industrialised countries, it accounts for 22% of the energy mix in developing countries, where it contributes largely to domestic heating and cooking, mostly in simple inefficient stoves.

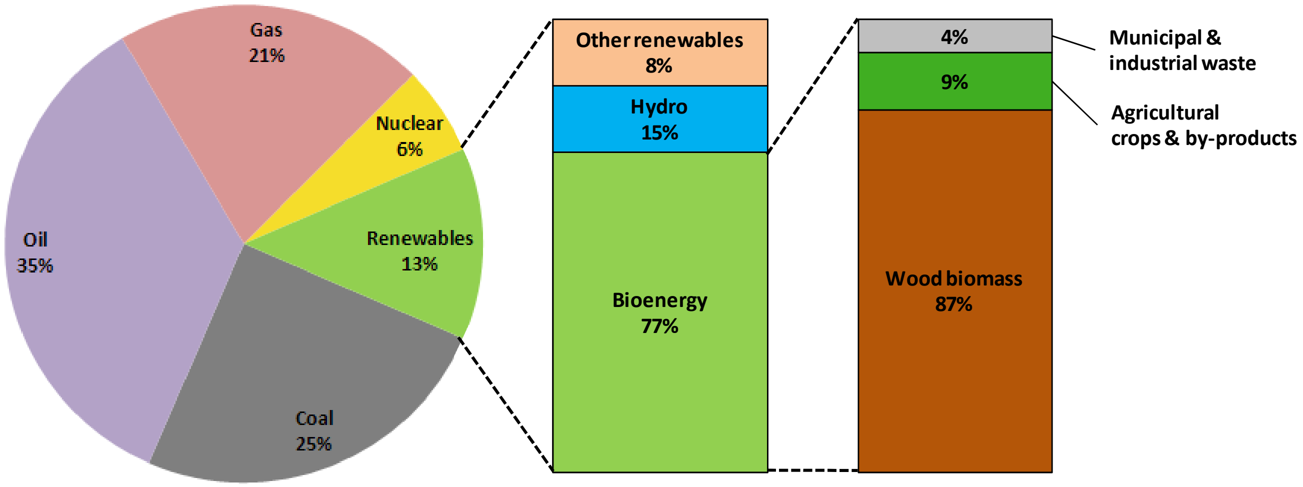


Figure 2.8.1. Share of bioenergy in the world primary energy mix. Source: based on IEA (2008) and IPCC (2007).

The expected deployment of biomass for energy on medium to longer term differs considerably between various studies. A key message from the review of currently available insights on large scale biomass deployment is that it’s role is largely conditional: deployment will strongly depend on sustainable development of the resource base and governance of land-use, development of infrastructure and on cost reduction of key technologies, e.g. efficient and complete use of primary biomass energy from most promising first generation and new generation biofuels.

2.8.1 Summary of IPCC AR 4 results on the potential role of biomass

2.8.1.1 Demand for biomass

Demand projections for primary biomass for production of transportation fuel were largely based on IEA-WEO (2006) global projections, with a relatively wide range of about 14 to 40 EJ of primary biomass, or 8-25 EJ of fuel. However, higher estimates were also included, ranging between 45-85 EJ demand for primary biomass in 2030 (or roughly 30-50 EJ of fuel).

Demand for biomass for heat and power was stated to be strongly influenced by (availability and introduction of) competing technologies such as CCS, nuclear power, wind energy, solar heating, etc). The projected demand in 2030 for biomass would be around 28-43 EJ according to the data used in AR4. These estimates focus on electricity generation. Heat is not explicitly modeled or estimated in the WEO, therefore underestimating total demand for biomass.

Also potential future demand for biomass in industry (especially new uses as biochemicals, but also expansion of charcoal use for steel production) and the built environment (heating as well as increased use of biomass as building material) was highlighted as important, but no quantitative projections were included in potential demand for biomass on medium and longer term.

2.8.1.2 Biomass supplies

The largest contribution could come from energy crops on arable land, assuming that efficiency improvements in agriculture are fast enough to outpace food demand so as to avoid increased pressure on forests and nature areas. A range of 20-400 EJ is presented for 2050. Degraded lands for biomass production (e.g. in reforestation schemes: 8-110 EJ) can contribute significantly. Although such low yielding biomass production generally result in more expensive biomass supplies, competition with food production is almost absent and various co-benefits, such as regeneration of soils (and carbon storage), improved water retention, protection from (further) erosion may also off-set part of the establishment costs. An example of such biomass production schemes at the moment is establishment of Jathropa crops (oilseeds) on marginal lands.

The energy potentials in residues from forestry (12-74 EJ/yr) and agriculture (15-70 EJ/yr) as well as waste (13 EJ/yr). Those biomass resource categories are largely available before 2030, but also partly uncertain. The uncertainty comes from possible competing uses (e.g. increased use of biomaterials such as fibreboard production from forest residues and use of agro-residues for fodder and fertilizer) and differing assumptions on sustainability criteria deployed with respect to forest management and intensity of agriculture. The current energy potential of waste is approximately 8 EJ/yr, which could increase to 13 EJ in 2030. The biogas fuel potentials from waste, landfill gas and digester gas, are much smaller.

2.8.2 SRREN Chapter 10 review

The results of the review of studies with respect to bioenergy deployment under different scenarios as presented in chapter 10 of the SRREN are summarized in figures 2.8.2 and 2.8.3.

For medium term (2030), estimates for primary biomass use range (rounded) between 7 to 180 EJ for the full range of results obtained. The 25-75% quantiles deliver a range of 30-117EJ. This is combined with a total final energy delivered of 0-61 EJ. For 2050, these ranges amount for primary biomass supplies 10-305 EJ for the full range and 22-184 EJ for the 25-75% quantiles and 0 – 76 EJ (22-57 EJ for the 25-75% quantiles) for final energy delivered.

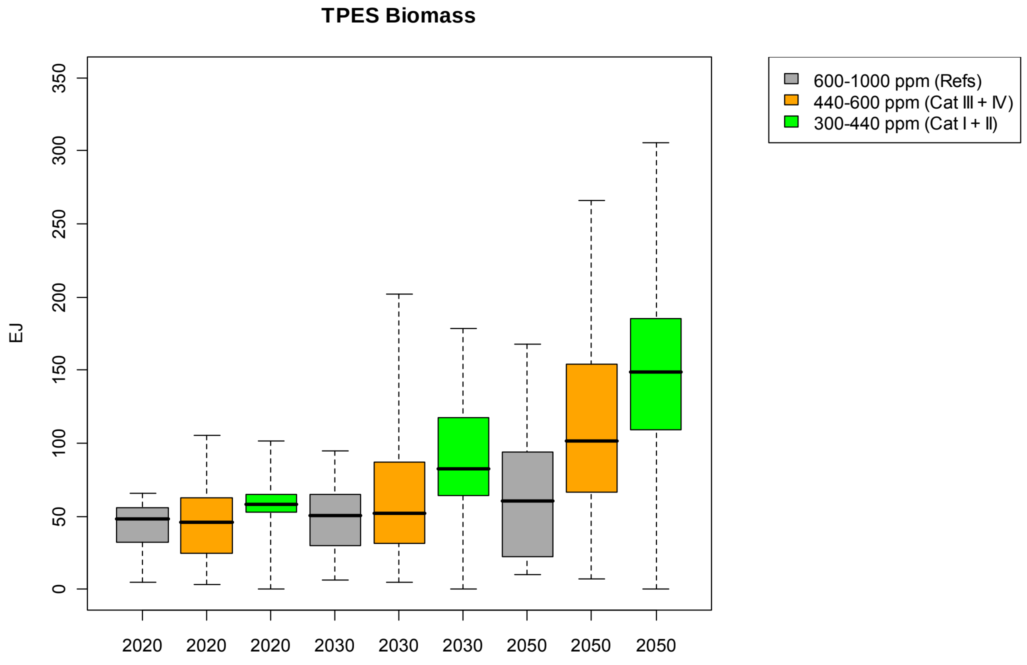


Figure 2.8.2. The primary biomass utilization according to the scenario review of Chapter 10, divided into projections for reference scenarios, scenarios that target 440-600 ppm and scenarios that target 330-440 ppm. The colored bars represent the 25-75% quantiles of the obtained results. The dotted bars represent the full range of estimates.

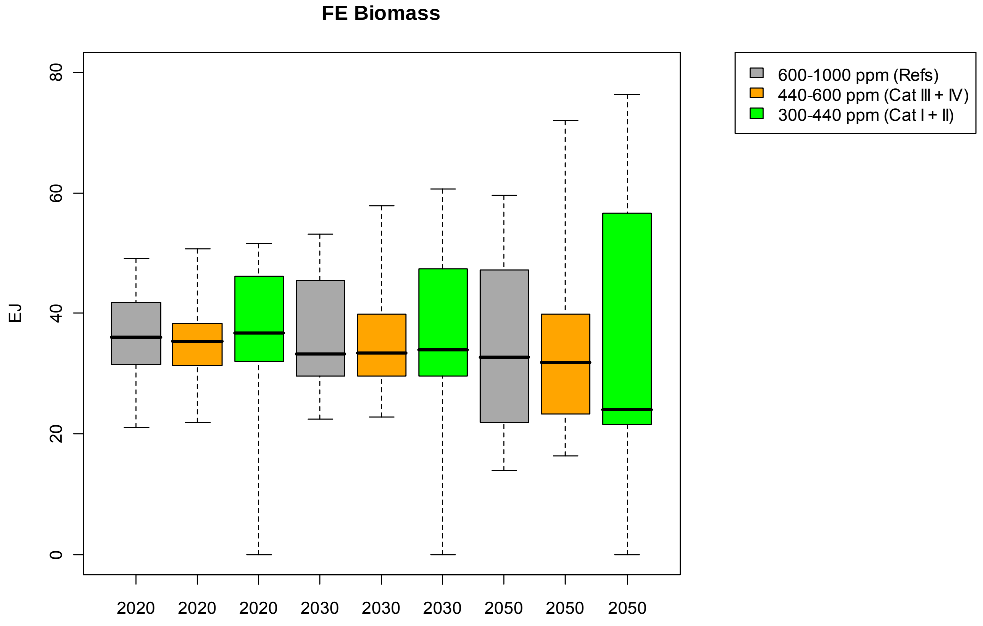


Figure 2.8.3. The final energy delivered via biomass utilization according to the scenario review of Chapter 10, divided into projections for reference scenarios, scenarios that target 440-600 ppm and scenarios that target 330-440 ppm. The colored bars represent the 25-75% quantiles of the obtained results. The dotted bars represent the full range of estimates.

In the reference scenario of the WEO (IEA 2009), biomass is expected to contribute 1604 Mtoe TSU: SI units, please (66 EJ) in 2030 (compared to 1176 Mtoe (48 EJ) in 2007), this includes traditional biomass use. Biofuels contribute 5% of world road transport energy demand (2.7 Mb/day), an almost four-fold increase compared to current production. One fifth of this increase is expected to come from second generation technologies.

Biomass for power increases from 259 TWh in 2007 (about 1 EJ_e) to 839 TWh (about 3 EJ_e) in 2030, mostly from CHP, as well as co-firing.

In the 450 ppm scenario, the contribution of biomass is projected to be 1952 Mtoe (81 EJ), a 22% difference compared to the reference scenario. In addition it should be noted that in this scenario a decreased contribution of traditional biomass is assumed and the relative increase of modern bioenergy is larger than the 22% compared to modern biomass use in the reference scenario.

Use of biomass in CHP and electricity only increases to 172 Mtoe (67% higher than the ref scenario). Biofuel production increases to 278 Mtoe (more than double that in the ref scenario). Especially between 2020 and 2030 sees a rapid increase in production of 2nd-generation biofuels, accounting for all incremental biomass increase after 2020.

The latter is also confirmed by the results of the IEA-ETP study of 2008 (IEA-ETP, 2008). The analysis on biofuels projects a rapid penetration of 2nd-generation biofuels after 2010 and an almost complete phase out of cereal and corn based ethanol production and oilseed based biodiesel after 2030. This was a sharp contrast to the World Energy Outlook studies of 2006 and 2007 (IEA-WEO 2006, IEA-WEO 2007) where 2nd-generation biofuels were excluded from the scenario analysis and thus biofuels at large played a marginal role in the projections for 2030. This is clear example of the importance of high quality data on performance prospects (and thus learning potential and rates) of energy technologies and in general for such strategic studies.

2.8.3 Synthesis of findings from this chapter and chapter 10

Although there is an impressive literature base on the global potentials of bioenergy and the impacts the development of those potentials may have on the environment, there are very few analyses available that provide a coherent and integrated picture taking all key relevant relations (see section 2.2 of this chapter) into account. Over the past few years, many analyses have focused on the possible conflicts and limitations for the deployment of first generation biofuels (see e.g. FAO's State of Food & Agriculture, 2008 for an overview).

However, the use of biomass for heat and power, biomaterials and second generation biofuels, taking into account different potential biomass resources as residues and organics wastes and perennial crops cultivated on arable, pasture and marginal and degraded lands, provide a different outlook. Furthermore, the ecological and socio-economic impacts further deployment of bioenergy can have is also fully conditional. The way bioenergy is developed, under what conditions and what options will have a profound influence on whether those impacts will largely be positive or negative (see for example van Dam et al., 2008 and van Dam et al., 2009, where this is demonstrated for future land-use and bioenergy scenarios for Argentina).

It is therefore impossible to deliver conclusive information on the deployment of biomass for energy and climate change mitigation on shorter and longer term. Based on the current state-of-the-art analyses that take key sustainability criteria into account, the upper bound of the biomass resource potential halfway this century can amount over 400 EJ. This could be roughly in line with the conditions sketched in the IPCC SRES A1 and B1 storylines, assuming sustainability and policy frameworks to secure good governance of land-use and improvements in agricultural and livestock management are secured (see also van Vuuren et al., 2009). These findings are summarized in Figure 2.8.4 based on an extensive assessment of recent literature and additional modelling exercises with the IMAGE-TIMER modelling framework that include future water limitations, biodiversity protection, soil degradation and competition with food (Dornburg et al., 2008).

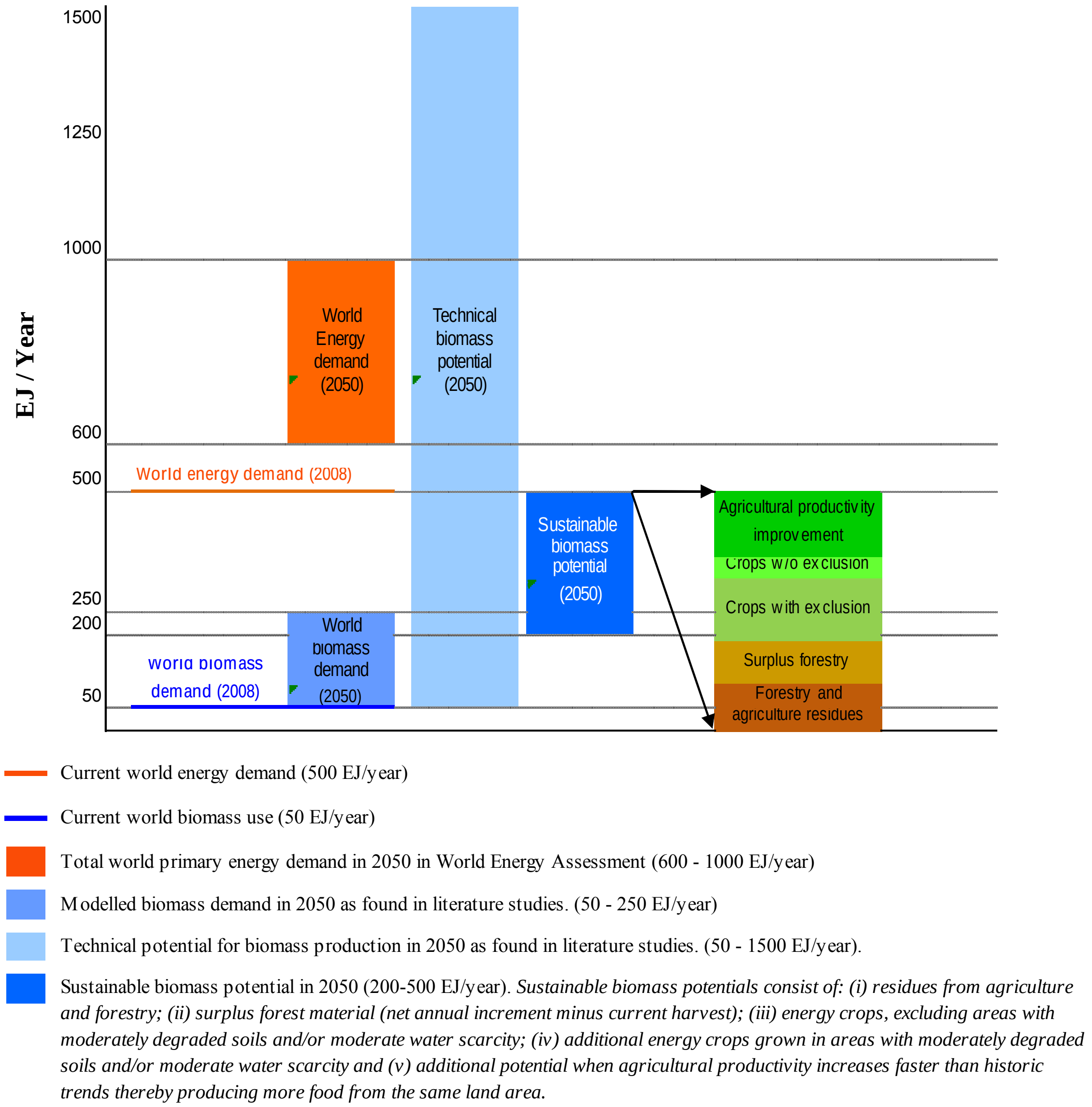
Table 2.8.1 provides an overview (derived from an assessment reported in Dornburg et al., 2008) of key factors and their impact on biomass resource potentials as they have been discussed and identified in this chapter. It is also briefly described under what conditions (policies, technology choices, etc.) the mentioned potentials may be developed over time.

Table 2.8.1. Key factors influencing bioenergy potentials, their respective weight and key recommendations on how potentials could be developed and uncertainties reduced.

Issue/effect	**Importance**	**Recommended activities to reduce uncertainties**
Supply potential of biomass		
Improvement agricultural management	***	Insight in development pathways in how efficiency of agriculture and livestock can be increased in a sustainable manner and for different settings and feasible rates of improvement need to be integrated in modelling frameworks.
Choice of crops	***	Importance of lignocellulosic biomass production systems for different settings. Under certain conditions, sugar cane and palm oil could still be feasible options on longer term as well. Much more market experience with such production systems needed in different settings, including degraded and marginal lands, intercropping schemes (e.g. agro-forestry) and management of grasslands. The latter is an important land-use category on which current understanding and data needs improvement.
Food demand	***	Increases in food demand beyond the base scenarios (e.g. up to 9 billion people in 2050) that were the focus in this study will strongly affect possibilities for bio-energy.
Use of degraded land	***	Represents a significant share of possible biomass resource supplies. Experiences with recultivation and knowledge on these lands (that represent a wide diversity of settings) are limited so far. More research is required to assess the cause of marginality and degradation and the perspectives for taking the land into cultivation.
Competition for water	***	Energy crop production potentials may be constrained by water availability in different regions, which is significant already in some regions and will increase in the future. Constraints in water supplies and sustainable management need ultimately to be studied at water basins scale.
Use of agricultural /forestry by-products	**	Their net availability can be improved by better infrastructure and logistics. Key areas for research and sustainable management are maintaining sound organic matter levels in soils and nutrient balances.
Protected area expansion	**	Increased ambition levels for nature reserves on global scale can have a significant impact on net land availability for biomass production. Land exclusion assumptions in the available studies, however, seem to overlap with the potential future land claims for nature and further modelling work and improved databases are desired. Furthermore, more insights are desired in how land use planning including new bio-energy crops can maximize biodiversity benefits. Evaluating biodiversity impacts on regional level is still a field under scientific development and more fundamental work is needed in this arena.
Water use efficiency	**	An important factor in the equation is improvement of water use efficiency in both current agriculture (and of biomass production itself. This suggests that for various areas water management is prime design parameter for sustainable biomass production and land-use management.
Climate change	**	The impact of climate change on agricultural production and productivity of lands could be significant, but exact effects are also uncertain. Although agriculture may face serious barriers due to climate change, this may also enhance the need for alternative adaptation measures to avoid soil losses and maintain vegetation covers. Biomass production (again especially via perennial systems) may than play a role as adaptation measure.
Alternative protein chains	**	Possible but very uncertain reversal of current diet trends, i.e. introduction of more novel plant protein products (as alternative for meat) could on the longer term strongly reduce land and water demand for food.
Demand for biomaterials	*	Demand for biomass to produce biomaterials (both conventional as building material as new ones as bulk bio-based chemicals and plastics) can be a significant factor, but is limited due to market size (compared to demand for energy carriers). Furthermore, biomaterials will also end up as (organic) waste material later in their lifecycle, indirectly adding to increased availability of organic wastes. In many cases this ‘cascaded use’ of biomass increases the net mitigation effect of biomass use. For some biomaterial markets

		specific cropping and plantation systems may be required due to demands of the biomass composition. Biomaterials are so far poorly integrated as a factor in energy models and as mitigation option. This can be improved in further work to understand the interactions between different flows and markets better (also in macro-economic terms).
GHG balances of biomass chains	*	The net GHG performance of biomass production systems is not identified as a limiting factor for the potential provided perennial cropping systems are considered. Also, striving for biomass production that is similar or better than previous land use (e.g. grasslands that remain grasslands or trees that replace annual crops) generally improves the overall carbon balance. This can also be true for replanting of degraded lands. The key factor in the net carbon balance is leakage. Avoiding leakage is directly related to increased efficiency in agriculture and livestock and net carbon impacts of biomass production should include this dimension. Such dynamics should ideally also be incorporated in future modelling exercises.

Importance of the issues on the range of estimated biomass potentials: ***- large, ** - medium, * – small



Current world energy demand (500 EJ/year)

Current world biomass use (50 EJ/year)

Total world primary energy demand in 2050 in World Energy Assessment (600 - 1000 EJ/year)

Modelled biomass demand in 2050 as found in literature studies. (50 - 250 EJ/year)

Technical potential for biomass production in 2050 as found in literature studies. (50 - 1500 EJ/year).

Sustainable biomass potential in 2050 (200-500 EJ/year). *Sustainable biomass potentials consist of: (i) residues from agriculture and forestry; (ii) surplus forest material (net annual increment minus current harvest); (iii) energy crops, excluding areas with moderately degraded soils and/or moderate water scarcity; (iv) additional energy crops grown in areas with moderately degraded soils and/or moderate water scarcity and (v) additional potential when agricultural productivity increases faster than historic trends thereby producing more food from the same land area.*

Figure 2.8.4. Technical biomass supply potentials, sustainable biomass potential, expected demand for biomass (primary energy) based on global energy models and expected total world primary energy demand in 2050. Sustainable biomass potentials consist of: (i) Residues: Agricultural and forestry residues; (ii) Forestry: surplus forest material (net annual increment minus current harvest); (iii) Exclusion of areas: potential from energy crops, leaving out areas with moderately degraded soils and/or moderate water scarcity; (iv) No exclusion: additional potential

from energy crops in areas with moderately degraded soils and/or moderate water scarcity; (v) Learning in agricultural technology: additional potential when agricultural productivity increases faster than historic trend. Adapted from Dornburg et al. (2008) based on several review studies.

The following ranges are found for the different main biomass resource categories:

- Residues from forestry and agriculture and organic waste, which in total represent between 40 - 170 EJ/yr, with a mean estimate of around 100 EJ/yr. This part of the potential biomass supplies is relatively certain, although competing applications may push the net availability for energy applications to the lower end of the range.
- Surplus forestry, i.e. apart from forestry residues an additional amount about 60-100 EJ/yr of surplus forest growth is likely to be available.
- Biomass produced via cropping systems:
    - A lower estimate for energy crop production on possible surplus good quality agricultural and pasture lands, including far reaching corrections for water scarcity, land degradation and new land claims for nature reserves represents an estimated 120 EJ/yr (“with exclusion of areas” in figure 2.8.4)
    - The potential contribution of water scarce, marginal and degraded lands for energy crop production, could amount up to an additional 70 EJ/yr. This would comprise a large area where water scarcity provides limitations and soil degradation is more severe and excludes current nature protection areas from biomass production (“no exclusion” in figure 2.8.4).
    - Learning in agricultural technology assumes that improvements in agricultural and livestock management or more optimistic than in the baseline projection (i.e. comparable to conditions sketched in the SRES A1 and B1 scenarios) would add some 140 EJ/yr to the above mentioned potentials of energy cropping.

The three categories added together lead to a biomass supply potential of up to about 500 EJ.

Energy demand models calculating the amount of biomass used if energy demands are supplied cost-efficiently at different carbon tax regimes, estimate that in 2050 about 50-250 EJ/yr of biomass are used. This is roughly in line with the projections given in chapter 10 and figure 2.8.4. At the same time, scenario analyses predict a global primary energy use of about 600 – 1040 EJ/yr in 2050. Thus, up to 2050, biomass has the potential to meet a substantial share of the worlds energy demand; the average of the range given in figure 2.8.4 results in a contribution bioenergy of some 30% to total primary energy demand.

However, if the sketched conditions are not met, the biomass resource base may be largely constrained to a share of the biomass residues and organic wastes, some cultivation of bioenergy crops on marginal and degraded lands and some regions where biomass is evidently a cheaper energy supply option compared to the main reference options (which is the case for sugar cane based ethanol production). Biomass supplies may than remain limited to an estimated 100 EJ in 2050. Also this is discussed in van Vuuren et al., 2009 and confirmed by the scenario review in chapter 10 of the SRREN.

A more problematic situation arises when the development of biomass resources (both residues and cultivated biomass) may fail to keep up with demand. Although the higher end of biomass supply estimates (2050) further than the maximum projected biomass demand, the net availability of biomass can also be considerably lower than the 2050 estimates. If biomass supplies fall short, this is likely to lead to significant price increases of raw material, thereby directly affecting the economic feasibility of various biomass applications. Generally, biomass feedstock costs can cover 30-50% of the production costs of secondary energy carriers, so increasing feedstock prices will quickly slow down growth of biomass demand (but simultaneously stimulate investments in biomass production). To date, very limited research on such interactions, especially on global scale, is available.

2.8.4 Limitations in available literature and analyses

The demand for bioenergy will, as argued earlier, depend on the relative competitive position of bioenergy options in the energy system compared to main alternatives. Available analyses indicate that on the longer term, biomass will especially be attractive for production of transport fuels and feedstock for industry and that the use of biomass for electricity may become relatively less attractive in the longer run.

Innovations in biofuel production and biorefining technologies however, combined with high oil prices as projected in IEA's World Energy Outlook and in addition CO_2 pricing, are likely to result in competitive biofuel production in many parts on the globe on medium term and may lead to an acceleration of biomass use and production compared to available projections. This mechanism is basically projected in the 2020-2030 timeframe of the 450 ppm scenario in the 2009 World Energy Outlook (IEA-WEO, 2009). In such a scenario, the sustainable development of the biomass resource base may become the limiting factor, especially after 2030.

Also poorly investigated so far is the possible role of biomass with Carbon Capture & Storage, an option that may become very important under stringent mitigation scenarios (i.e. aiming for a 350 ppm scenario in 2050) where negative emissions are required to meet set targets. When such pathways are strived for, the use of biomass becomes absolutely essential to achieve the set targets and demand may further increase.

It is also still poorly understood what the impact of electric vehicles and drive chains in transport may be on the potential demand for biofuels. So far, the impact of electric vehicles on reducing baseline demand for liquid transport fuels seems very limited. This is to a large extent explained by the impossibility to implement electric drives for aviation and marine transport (where energy demand grows strongly), as well as for truck transport (which is roughly responsible for half the demand for road transport fuels).

The data on potential biomass demand in future energy scenarios reviewed hint that biomass demand may in fact be lower than the biomass supplies that could be generated in baseline scenarios used. At ambitious levels of climate change abatement, the key demand factor is likely to be the use of biomass for transport fuels due to the very few alternatives available for oil and reducing CO_2 emissions in the transport sector. Nevertheless, long term energy demand projections are also characterized by considerable variability (especially caused by GDP and population growth and the rate of deployment of energy efficiency measures at large). Demand for example transport fuels could therefore also be significantly higher than projected in this report and this could be further enhanced when policies target increased energy security and rural development as other priorities that are likely to favour biomass and biofuels.

It is recommended to incorporate (dynamic) biomass supply projections and a more diverse portfolio of conversion options (e.g. including hydrogen production from biomass and combined with CCS) in current models to obtain more coherent analyses and scenarios.

The costs of biomass supplies in turn are influenced by the degree of land-use competition, availability of (different) land (classes) and optimisation (learning) in cropping and supply systems. The latter is still relatively poorly studied and incorporated in scenarios and (energy and economic) models, which can be improved. Nevertheless, the variability of biomass production costs seems far less than that of oil or natural gas, so uncertainties in this respect are relatively limited.

To date, limited modelling efforts are available to fully interlink macro-economic/market models with biomass potential studies, especially when lignocellulosic biomass is concerned. To date, price dynamics and, longer term, responses of agriculture (in terms of increased land use and/or increased efficiency) are also addressed to a limited extent. Although the long term impacts on actual physical biomass resource potentials may be limited, understanding the economic responses to increased demand for food and bio-energy and how these affect the relative competitiveness of bio-energy compared to other energy supply options is extremely important for defining balanced policy strategies. Linked to this, the understanding of socio-economic implications (such as impacts on rural income, rural employment) of bioenergy production should be understood better.

Given the relatively small number of comprehensive scenario studies available to date, it is fair to characterize the role of biomass role in long-term stabilization (beyond 2030) as very significant but with relatively large uncertainties. Further research is required to better characterize the potential; for regional conditions and over time. A number of key factors have been identified in this last section. Given that there is a lack of studies on how biomass resources may be distributed over various demand sectors, no detailed allocation of the different biomass supplies for various applications is suggested here. Furthermore, the net avoidance costs per tonne of CO_2 of biomass usage depends on a large variety of factors, including the biomass resource and supply (logistics) costs, conversion costs (which in turn depends on availability of improved or advanced technologies) and fossil fuel prices, most notably of oil.

2.8.5 Key messages and policy

Table 2.8.2 describes key preconditions and impacts for two possible extreme biomass scenarios.

Table 2.8.2. Two opposing storylines and impacts for bioenergy on long term.

Storyline	Key preconditions	Key impacts
- High biomass scenario		
Largely follows A1/B1 SRES scenario conditions,	Assumes: - well working sustainability frameworks and strong policies - well developed bioenergy markets - progressive technology development (biorefineries, new generation biofuels, - successful deployment of degraded lands.	- Energy price (notably oil) development is moderated due to strong increase supply of biomass and biofuels. - Some 300 EJ of bioenergy delivered before 2050; 35% residues and wastes, 25% from marginal/degraded lands (500 Mha), 40% from arable and pasture lands 300 Mha). - Conflicts between food and fuel largely avoided due to strong land-use planning and aligning of bioenergy production capacity with efficiency increases in agriculture and livestock management. - Positive impacts with respect to soil quality and soil carbon, negative biodiversity impacts minimised due to diverse and mixed cropping systems.
Low biomass scenario		
Largely follows A2 SRES scenario conditions, assuming limited policies, slow technological progress in both the energy sector and agriculture, profound differences in development remain	- High fossil fuel prices expected due to high demand and limited innovation, which pushes demand for biofuels for energy security perspective - Increased biomass demand directly affects	- Increased biomass demand partly covered by residues and wastes, partly by annual crops. - Total contribution of bioenergy about 100 EJ before 2050. - Additional crop demand leads to significant iLUC effects and impacts on biodiversity. - Overall increased food prices

between OECD and DC's.	food markets	linked to high oil prices. - Limited net GHG benefits. - Socio-economic benefits sub-optimal.

2.8.6 Key messages and policy recommendations from the Cchapter 2:

- The biomass resource potential, also when key sustainability concerns are incorporated, is significant (up to 30% of the world's primary energy demand in 2050) but also conditional. The larger part of the potential biomass resource base is interlinked with improvements in agricultural management, investment in infrastructure, good governance of land use and introduction of strong sustainability frameworks.
- If the right policy frameworks are not introduced, further expansion of biomass use can lead to significant conflicts in different regions with respect to food supplies, water resources and biodiversity. However, such conflicts can also be avoided and synergies with better management of natural resources (e.g. soil carbon enhancement and restoration, water retention functions) and contributing to rural development are possible. Logically, such synergies should explicitly be targeted in new policy frameworks.
- Bioenergy at large has a significant GHG mitigation potential, provided resources are developed sustainably and provided the right bioenergy systems are applied. Perennial cropping systems and biomass residues and wastes are in particular able to deliver good GHG performance in the range of 80-90% GHG reduction compared to the fossil energy baseline.
- Optimal use and performance of biomass production and use is regionally specific. Policies therefore need to take regionally specific conditions into account and need to incorporate the agricultural and livestock sector as part of good governance of land-use and rural development interlinked with developing bioenergy.
- The recently and rapidly changed policy context in many countries, in particular the development of sustainability criteria and frameworks and the support for advanced biorefinery and second generation biofuel options does drive bioenergy to more sustainable directions.
- Technology for lignocellulose based biofuels and other advanced bioelectricity options, CCS, advanced biorefinery concepts, can offer fully competitive deployment of bioenergy on medium term (beyond 2020). Several short term options can deliver and provide important synergy with longer term options, such as co-firing, CHP and heat production and sugar cane based ethanol production. Development of working bioenergy markets and facilitation of international bioenergy trade is another important facilitating factor to achieve such synergies.
- Biomass potentials are influenced by and interact with climate change impacts but the detailed impacts are still poorly understood; there will be strong regional differences in this respect. Bioenergy and new (perennial) cropping systems also offer opportunities to combine adaptation measures (e.g. soil protection, water retention and modernization of agriculture) with production of biomass resources.

REFERENCE

Adam J . C . 2009. Improved and more environmentally friendly charcoal production system using a low - cost retort - kiln (Eco - charcoal). Renewable Energy. 34(8):1923-1925

Agrolink, 2009. Demanda extra por biodiesel vem junto com alta dos preços, http://www.agrocim.com.br/noticia/Demanda-extra-por-biodiesel-vem-junto-com-alta-dos-precos.html

Alcamo, J.; Van Vuuren, D.; Ringler, C.; Cramer, W.; Masui, T.; Alder, J.; Schulze, K. (2005) Changes in natures balance sheet: model-based estimates of future worldwide ecosystem services. Journal of Ecology and Society. 10(2):19

Alexandratos, N. World food and agriculture to 2030/50: highlights and views from mid-2009. Paper for the Expert Meeting on "How to Feed the World in 2050," FAO, Rome, 24-26 June 2009

Allen J, Browne M., Hunter A., Boyd J., Palmer H. 1998. Logistics management and costs of biomass fuel supply. International Journal of Physical Distribution & Logistics Management. 1998; 28: 463–77.

Ammann, C., Spirig, C., Fischer, C., Leifeld, J., Neftel, A. (2007). Interactive comment on "N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels" by P. J. Crutzen et al. Atmos. Chem. Phys. Discuss., 7, S4779–S4781, 2007.

Anderson-Texeira, K. J., Davis, S.C., Masters, M.D., Delucia, E.H., 2009. Changes in soil organic carbon under biofuel crops GCB Bioenergy 1: 75-96.

Andersson, G., Asikainen, A., Björheden, R., Hall, P.W., Hudson, J.B., Jirjis, R., Mead, D.J., Nurmi, J. and Weetman, G.F. 2002. Production of forest energy. In Richardson, J., Björheden, R., Hakkila, P., Lowe, A.T. and Smith, C.T. (eds.). 2002. Bioenergy from Sustainable Forestry: Guiding principles and practice. Kluwer Academic Publishers, The Netherlands.

Armendariz, C., R. Edwards, M. Johnson, y O.R. Masera 2008. Reductions in personal exposures to particulate matter and carbon monoxide as a result of the installation of a Patsari improved cook stove in Michoacan Mexico. Indoor Air 18: 93-105. ISSN 0905-6947.

Ausubel JH (2000) The great reversal: nature's chance of restore land and sea. Technology in Society, 22, 289–301.

BABFO, 2000. British Association of Bio Fuels Oil, Energy balances in the growth of oilseed rape for biodiesel and of wheat for bioethanol, prepared by I.R Richards. June 2000, LEVINGTON AGRICULTURE REPORT for the British Association for Bio Fuels and Oils (BABFO), carried out by: Levington Agriculture Ltd. Levington Park lPSWlCH Suffolk

Babu, S. P., 2005. Leader of Task 33: Thermal Gasification of Biomass.

Bailis, R., V.Berrueta, C. Chengappa, K. Dutta, R. Edwards, O R. Masera, D. Still, K.S. Smith. 2007. Performance testing for monitoring improved biomass stove interventions: Experiences of the Household Energy and Health Project. Energy For Sustainable Development 11: 57-69

Bailis, Rob; Amanda Cowan, Victor Berrueta, Omar Masera, 2009. Arresting the Killer in the Kitchen: The Promises and Pitfalls of Commercializing Improved Cookstoves World Development, 37 (10) pp. 1694-1705

Bain,R. World Biofuels Assessment Worldwide Biomass Potential: Technology Characterizations, Milestone Report, NREL/MP-510-42467, December 2007, http://www.nrel.gov/docs/fy08osti/42467.pdf

Balmford, A., Rhys. E. Green and Jörn P. W. Scharlemann, 2005. Sparing land for nature: exploring the potential impact of changes in agricultural yield on the area needed for crop production, Global Change Biology, Volume 11 Issue 10, Pages 1594 - 1605

Bauen, A.; F. Vuille; Watson, P. & K. Vad, 2009a. The RSB GHG accounting scheme. Feasibility of a meta¬-methodology and way forward. A report prepared by E4tech for the Roundtable on Sustainable Biofuels, Lausanne.

Bauen Ausilio, Berndes Göran, Junginger Martin, Londo Marc, Vuille François, Ball Robert, Bole Tjasa, Chudziak Claire, Faaij André, Mozaffarian Hamid, Bioenergy; A review of status and prospects, Report prepared for the Bioenergy Agreement of the International Energy Agency, by E4tech, ECN, Chalmers University of Technology, Copernicus Institute of the University of Utrecht, (2009b)

Bates, B.C., Kundzewicz, Z.W., Wu, S., Palutikof, J.P., (eds.), 2008. Climate change and water. Technical paper VI of the IPCC

Bauen, A., J. Woods and R. Hailes, 2004. Bioelectricity Vision: Achieving 15% of Electricity from Biomass in OECD Countries by 2020, Prepared for WWF International and Aebiom by Imperial College London, Centre for Energy Policy and Technology and E4tech (UK) Ltd, April 2004.

Bentsen, N., Thorsen, B., Felby, C. (2009). Energy, feed and land-use balance of refining winter wheat to ethanol, Biofuels, Bioprod, Bioref. 3:521-533.

Berndes, G. (2002). Bioenergy and water -the implications of large-scale bioenergy production for water use and supply. Global Environmental Change 12(4):7-25

Berndes, G. (2008): Water demand for global bioenergy production: trends, risks and opportunities. Report commissioned by the German Advisory Council on Global Change (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen -- WBGU).

Berndes, G. and Börjesson, P. (2007). Multifunctional bioenergy systems. The AGS Pathways Reports 2007: EU1. The Alliance for Global Sustainability, an international partnership between Chalmers University of Technology, Swiss Federal Institute of Technology Zurich, Massachusetts Institute of Technology and Tokyo University Berndes, G., Fredriksson, F. and Börjesson, P. (2004). Cadmium accumulation and Salix based phytoextraction on arable land in Sweden. Agriculture, Ecosystems and Environment 103(1): 207-223.

Berndes, G., Börjesson, P., Ostwald, M. and Palm, M. (2008). Multifunctional biomass production systems —an introduction with presentation of specific applications in India and Sweden. Biofuels, Bioproducts and Biorefining, 2: 16-25.

Berndes, G., Fredriksson, F. and Börjesson, P. (2004). Cadmium accumulation and Salix based phytoextraction on arable land in Sweden. Agriculture, Ecosystems and Environment 103(1): 207-223

Berndes, G., M. Hoogwijk, and R. van den Broek. 2003. The contribution of biomass in the future global energy supply: a review of 17 studies. Biomass and Bioenergy 25: 1-28. doi:10.1016/S0961-9534(02)00185-X.

Berndes, Göran, 2008. Future Biomass Energy Supply: The Consumptive Water Use Perspective . International Journal of Water Resources Development , 24 (2) pp. 235-245, 2008.

Bessou, C.; Ferchaud, F.; Gabrielle, B. & Mary, B. 2009. Biofuels, greenhouse gases & climate change. A review. Submitted to Agron. for Sustain. Dev., March 2009.

Bhojvaidad, P.P., 2008. Recent Trends In Biodiesel Production In Biofuels towards a greener and secure energy future Editor P. P . TERI India 2008

Bickel, P. & Friedrich, R. (eds.) (2005) ExternE - Externalities of Energy: Methodology 2005 Update,Brussels, European Commission

Biofuels Digest, 2008. “The Hottest 50 Companies in Bioenergy for 2008-09” http://biofuelsdigest.com/blog2/2008/12/22/the-hottest-50-companies-in-bioenergy

Bird, D.N., Cherubini, F., Jungmeier, G. 2010. Life-Cycle Assessment (LCA) of biomass fuels, power, heat, and products as compared to their petroleum counterparts and other renewables. IEA Bioenergy. In press.

Blanco-Canqui, H., Lal, R.. Corn Stover Removal for Expanded Uses Reduces Soil Fertility and Structural Stability. Soil Sci Soc Am J 73:418-426 (2009). DOI:10.2136/sssaj2008.0141

BNDES/CGEE, FAO, ECLAC, Sugarcane-based bioethanol: Energy for sustainable development (BNDES - Brazilian Development Bank - and CGEE - Center for Strategic Studies and Management Science, Technology and Innovation, Rio de Janeiro, ed. 1, 2008), [first edition]

Boman BC, Forsberg AB, Jarvholm BG. 2003. Adverse health effects from ambient air pollution in relation to residential wood combustion in modern society. Scand J Work Environ Health 2003; 29:251–260.

Börjesson, P. (2008). Good or bad bioethanol from a greenhouse gas perspective – What determines this? Good or bad bioethanol from a greenhouse gas perspective – What determines this?

Börjesson, P., 2009. Are biofuels better than fossil fuels for the reduction of climate changes? Plantekongres 2009 13-14 January, Herning Pål Environmental and Energy Systems Studies, Lund University, Sweden

Börjesson, P., Berndes G. (2006). The prospects for willow plantations for wastewater treatment in Sweden. Biomass and Bioenergy 30: 428-438.

BP (2007). Statistical review of world energy 2007. (http://www.bp.com/statisticalreview)

Bradley, R.L., A. Olivier, N. Thevathasan & J. Whalen, 2008. Environmental and economic benefits of tree-based intercropping systems. Policy Options 29 : 46-49.

Bringezu, S., S. Ramesohl, K. Arnold, M. Fischedick, J. von Geibler, C. Liedtke, H. Schutz, 2007. What we know and what we should know – Towards a sustainable biomass strategy, Wuppertal Paper N0. 163, June 2007, Wuppertal Institute, http://www.wupperinst.org/uploads/tx_wibeitrag/WP163.pdf

Bruce N, Rehfuess E, Mehta S, Hutton G, Smith KR. 2006. Indoor air pollution. pp. 793–815

Bruinsma, J. (Ed), 2003. World agriculture: towards 2015/2030. An FAO perspective. Food and Agriculture Organization (FAO)/Earthscan Publications, Rome/London.

Bruinsma, J. The resource outlook to 2050: by how much do land, water and crop yields need to increase by 2050? Paper for the Expert Meeting on “How to Feed the World in 2050,” FAO, Rome, 24-26 June 2009

Bureau J.C., Guyomard H., Jacquet F., Treguer D., 2009 (in press). European Biofuel Policy: How Far Will Public Support Go? In Handbook of Bioenergy Economics and Policy, Ed Springer, Series: Natural Resource Management and Policy , Vol. 33 ,Khanna, M; Scheffran, J; Zilberman, D (Eds.)

Burja, A. M., Banaigs, B., Abou-Mansour, E., Grant Burgess, J., and Wright, P. C. (2001). Marine cyanobacteria--a prolific source of natural products. Tetrahedron 57, 9347-9377.

Campbell, J. E., Lobell,D.B., Field, C.B. 2009. Greater Transportation Energy and GHG Offsets from Bioelectricity Than Ethanol. Science 324, 1055-1057.

Cassman KG. 1999. Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture. Proc. Natl. Academy of Science 96:5952-9.

Cassman, K. G.,A. Dobermann, D.T. Walters, H. Yang, 2003. Meeting cereal demand while protecting natural resources and improving quality, Annual Reviews of Energy and Environment 28, 315-358.

Castiglioni P,Warner D, Bensen RJ, Anstrom DC, Harrison J, StoeckerM,Abad M, Kumar G, Salvador S, D'Ordine R, et al. Bacterial RNA chaperones confer abiotic stress tolerance in plants and improved grain yield in maize under water-limited conditions. Plant Physiol 147 (2008): 446–455

Chisti, Y. (2007). Biodiesel from microalgae. Biotechnology Advances 25, 294-306.

Chum, H.L.; Hill, J.; Tiffany, D.; Morey, R. V.; Goss Eng, A. and Haq, Z. 2009. Improvements in U.S. Dry Grind Corn Ethanol Inputs and Processes: Impacts on Greenhouse Gas Emissions," submitted for publication in the Environmental Science and Technology

Cirne, D.G., Lehtomaki, A., Bjornsson, L. and L.L. Blackall., 2007. Hydrolysis and microbial community analyses in two-stage anaerobic digestion of energy crops. Journal of Applied Microbiology 103: 516-527.

Clifton-Brown, J., and Lewandowski, I., 2000. Water Use Efficiency and biomass partitioning of three different Miscanthus genotypes with limited and unlimited water supply. Annals of Botany, 86: 191-200.

Clifton-Brown, J. C.; Stampfl, P. F, Jones, M. B., 2004. Miscanthus biomass production for energy in Europe and its potential contribution to decreasing fossil fuel carbon emissions Global Change Biology 10: 509-518.

Cline, W. 2007. Global warming and agriculture: Impact estimates by country. Center for global development. Washington DC, USA.

Convention on Biodiversity, 2008. the Potential impacts of biofuels on biodiversity. UNEP / CBD / COP / 9 /26

Costanza, R., J. H. Cumberland, H. Daly, R. Goodland, R. B. Norgaard, 1997. An Introduction to Ecological Economics, St. Lucie Press and International Society for Ecological Economics, ISBN: 1884015727

Crutzen, P., Moiser, A., Smith, K., Winiwarter, W. (2008). N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmos. Chem. Phys., 8, 389–395, 2008.

Crutzen, R. J., A. R. Mosier, K. A. Smith, and W. Winiwarter, 2007. N2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. Atmos. Chem. Phys. Discuss. 7: 11191-11205.

CSIRO, 2000. Life Cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles, CSIRO, Atmospheric Research Report C0411/1.1/F2 for the Australian Greenhouse Office, March 2000

Dale, V., Efroymson, R., Kline, K. "The land use - climate change - energy nexus". to be submitted to Landscape Ecology.

Dantas, D.N., F. F. Mauad and A. R. Ometto, 2009. Potential for generation of thermal and electrical energy from biomass of sugarcane: a exergetic analysis, 11th. International Conference on Advanced Material, Rio de Janeiro, September, 20-25.

DCPP, 2006. Disease Control Priorities in Developing Countries (2nd Edition), New York: Oxford University Press.

de Fraiture, C. and Berndes, G. (2009). Biofuels and Water. In: Howarth, R.W. (ed.) Biofuels: Environmental Consequences & Implications of Land Use. SCOPE – Scientific Committee on Problems of the Environment..

de Fraiture, C., M. Giordano, Y. Liao. 2008. Biofules and implications for agricultural water uses: blue impacts of green energy. Water Policy 10(S1), 67–81

de Wit, Marc, Martin Junginger, Sander Lensink, Marc Londo, André Faaij, Competition between biofuels: Modeling technological learning and cost reductions over time, Biomass and Bioenergy, In Press, Corrected Proof, Available online 20 August 2009

DeLucchi, M. (1991). Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity. Center for Transportation Research, Argonne National Laboratory. November 1991. ANL Publication No. ANL/ESD/TM-22, vol. 1. Publication No. UCD-ITS-RP-91-30.

Delucchi, M.A., 2005. A Multi-Country Analysis of Lifecycle Emissions from Transportation Fuels and Motor Vehicles. Publication No. UCD-ITSRR- 05-10, Davis, CA: ITS, University of California at Davis. http://www.its.ucdavis.edu/ people/ faculty/ delucchi/ (24.5.2006).

Dimitriou, I., Baum, C. Baum, S. Busch, G. Schulz, U. Köhn, J. Lamersdorf, N. Leinweber, P. Aronsson, P. Weih, M. Berndes, G., Bolte, A. Short Rotation Coppice (SRC) cultivation and local impact on the environment. Landbauforschung vTI Agriculture and Forestry Research 3 (59) 159162

Dingra S, Mande S and Kishore V V N,1996. Briquetting of Biomass in India- status and potential [FAO's Regional Wood Energy Develpoment Program Report no 23], Edited by P.D Grover and S.K Mishra pp.24-30, Bangkok FAO

DOE, 2009. U.S. Department of Energy Office of Science, Bioenergy Research Centers- An Overview of the Science, DOE/SC-0116, genomicsgtl.energy.gov/centers/brcbrochure.pdf

Döll, P., Kaspar, F., Lehner, B. A global hydrological model for deriving water availability indicators: model tuning and validation. Journal of Hydrology 270 (2003): 105–134.

Donner SD, Kucharik CJ Corn-based ethanol production compromises goal of reducing nitrogen export by the Mississippi River. PNAS 105 (2008): 4513–4518

Doornbosch, R. and Steenblik, R., 2007. Biofuels: Is the Cure Worse than the Disease? Round Table on Sustainable Development. SG/SD/RT(2007).

Dornburg, V., van Dam, J., Faaij, A. Estimating GHG emission mitigation supply curves of large-scale biomass use on a country level. Biomass and Bioenergy 31 (2007): 46-55.

Dornburg, V.,Faaij, A., Verweij, P., Langeveld, H., Wester, P., Meeusen, M.J.G., Banse, M.A.H., Ros, J., Smout, F., Aiking, H., Londo, M., Mozaffarian, H., Sm, 2008. Assessment of global biomass potentials and their links to food, water, biodiversity, energy demand and economy. Main report (2008), Wageningen University and Researchcenter Publications, Wageningen, the Netherlands, http://de.scientificcommons.org/repository/wageningen_university_and_researchcenter_publications

Dufay, Annie, 2006. Biofuels production, trade and sustainable development: emerging issues, IIED, November, 2006

Dupraz, C. & Liagre, F., 2008. Agroforestry: trees and crops. La France Agricole, Paris (in French).

Duvick, D.N. and K.G. Cassman, 1999. Post–green revolution trends in yield potential of temperate maize in the north-central United States. Crop Sci. 39:1622-1630.

Easterling, W.E., P.K. Aggarwal, P. Batima, K.M. Brander, L. Erda, S.M. Howden, A. Kirilenko, J. Morton, J.-F. Soussana, J. Schmidhuber and F.N. Tubiello, 2007: Food, fibre and forest products. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 273-313.

Edgerton, M. Increasing crop productivity to meet global needs for feed, food, and fuel. Plant Physiology 149 (2009) 7-13

EEA (European Environmental Agency). 2007. Estimating the environmentally compatible bio-energy potential from agriculture. Tech. Rep. No. 12/2007, EEA, Copenhagen.

EEA, 2006. How much bioenergy can Europe produce without harming the environment? Environmental Energy Agency. Report 7/2006. ISBN 92–9167–849-X © EEA, Copenhagen, 2006, 72 p.

Egeskog, A., Hansson, J., Berndes, G., Werner, S. Co-generation of biofuels for transportation and heat for district heating systems – an assessment of the national possibilities in the EU. Energy Policy, accepted for publication

Egsgaard, H. U. Hansen, P. Arendt, J., P. Glarborg and C. Nielsen, 2009. Combustion and gasification technologies, Risø Energy Report 2, Riso. Denmark

Electricity from Renewable Resources: Status, Prospects, and Impediments - America's Energy Future Panel on Electricity from Renewable Resources, 2009. National Research Council, National Academies Press at: http://www.nap.edu/catalog/12619.html

Energy Policy Act of 1992. Congress of United States, http://thomas.loc.gov/cgi-bin/query/z?c102:H.R.776.ENR:

Energy Policy Act of 2005. Congress of United States, http://www.epa.gov/oust/fedlaws/publ_109-058.pdf

Energy Research Programme Consortium, 2009. FAO-PISCES Case Studies: Small scale bioenergy can benefit poor, FAO & PISCES, a UK government, http://www.hedon.info/1372/news.htm

Ericsson, K., H. Rosenqvist, and L. J. Nilsson, 2006. Energy crop production costs in the EU, Biomass and Bioenergy, Volume 33, Issue 11, November 2009, Pages 1577-1586

Erikson, S. and M. Prior, The Briquetting of Agricultural Wastes for Fuel. FAO paper No. 11. Rome, Italy (1990).

European Automotive Fuels Briefing, Paris 21/11/2002, http://www.ifqc.org/

European Environment Agency (EEA). Estimating the environmentally compatible bioenergy potential from agriculture. Report no. 12/2007. Copenhagen: EEA; 2007.

Evans LT (2003) Agricultural intensification and sustainability, Outlook on Agriculture, 32, 83–89.

Evenson and Gollin, 2003: Evenson, R.E. & Gollin, D. 2003. Assessing the impact of the green revolution 1960–2000. Science, 300(5620): 758–762.

Ezeji, T, Qureshi, N., and H.P. Blaschek, 2007b. Butanol production from agricultural residues: impact of degradation products on Clostridium beijerinckii growth and butanol fermentation. Biotechnol. and Bioengineering. 97:1460-1469.

Ezeji, T.C, Qureshi, N. and H.P. Blaschek, 2007a. Bioproduction of butanol from biomass: from genes to bioreactors. Current Opinion in Biotechnology.18:220-227.

Ezzati M, Lopez A, Vander Hoorn S, Rodgers A, Murray CJL, Comparative Risk Assessment

Collaborative Group. Selected major risk factors and global regional burden of disease. Lancet 2002; 360(9343):1347-1360

Ezzati, M., Bailis, R., Kammen, D. M., Holloway, T., Price, L., Cifuentes, L. A., et al. (2004). Energy management and global health. Annual Review of Environmental Resources, 29.

Faaij, Andre, 2006. Modern biomass conversion technologies. Mitigation and Adaptation Strategies for Global Change, Volume 11, No. 2, March 2006, Pages 335-367.

FAO, 2004. THE STATE OF FOOD AND AGRICULTURE 2003-2004- Agricultural Biotechnology Meeting the needs of the poor?, Fao, Rome

FAO, 2005a. World Forest Assessment. FAO, Rome.

FAO, 2005c. Bioenergy, Committee on Agriculture, Nineteenth Session, Item 7 of the Provisional Agenda, Rome, 13-16 April 2005

FAO, 2008b. Food and Agriculture Organization of the United Nations , THE STATE OF FOOD AND AGRICULTURE 2008– BIOFUELS: prospects, risks,and opportunities, Food and Agriculture Organization of the United Nations, Rome, Italy

FAO, 2008d. Food and Agriculture Organization of the United Nations,The role of agricultural biotechnologies for production of bioenergy in developing countries. Background Document to Conference 15 of the FAO Biotechnology Forum (10 November to 14 December 2008): http://www.fao.org/biotech/C15doc.htm

FAO, 2009. Food and Agriculture Organization of the United Nations, Biofuel Technologies' Contribution to Life Cycle Emissions http://www.fao.org/docrep/X5555E/x5555e02.htm#1.1%20what%20are%20industrial%20charcoal%20making%20methods

FAO, 2009: Case Studies – Small scale Bioenergy Initiatives, 2009, http://www.fao.org//docrep/011/aj991e/aj991e00.htm)

FAO, 2009c. Food and Agriculture Organization of the United Nations, http://www.fao.org/docrep/X5555E/x5555e02.htm#1.1%20what%20are%20industrial%20charcoal%20making%20methods

FAO. 2005b. Fuelwood "hot spots" in Mexico: a case study using WISDOM – Woodfuel Integrated Supply-Demand Overview Mapping. Prepared by R. O. Masera, , G. Guerrero, A. Ghilardi, A. Velasquez, J. F. Mas, M. Ordonez, R. Drigo and M. Trossero. FAO Wood Energy Programme and Universidad Nacional Autonoma de Mexico (UNAM), http://www.fao.org/docrep/008/af092e/af092e00.HTM

FAO. 2006a. Woodfuel Integrated Supply / Demand Overview Mapping (WISDOM) - Slovenia - Spatial woodfuel production and consumption analysis. Prepared by R. Drigo and Ž. Veselič. FAO Forestry Department – Wood Energy Working Paper. See: http://www.fao.org/docrep/009/j8027e/j8027e00.HTM

FAO. 2007. Woodfuels Integrated Supply/Demand Overview Mapping – WISDOM. Prepared by O.R. Masera, R. Drigo and M.A. Trossero. See: http://www.fao.org/DOCREP/005/Y4719E/Y4719E00.HTM

FAO. 2008a. WISDOM for Cities. Analysis of wood energy and urbanization aspects using WISDOM methodology. Prepared by R. Drigo and F. Salbitano. FAO Forestry Department Urban forestry – Wood energy. (in English and French), English version: http://www.fao.org/documents/advanced_s_result.asp?QueryString=wisdom+for+cities&search=Search

FAO. 2009a. Análisis del balance de energia derivada de biomasa en Argentina – WISDOM Argentina. Prepared by R. Drigo, A. Anschau, N. Flores Marcos and S. Carballo. Edited by E. Baumont Roveda. Supervision of M. Trossero. FAO Forestry Department, Forest Products and Services (FOIP) Wood Energy. 2009 See: http://www.fao.org/docrep/011/i0900s/i0900s00.htm

FAOSTAT-Agriculture. FAO (http://faostat.fao.org/faostat)

Fagernäs, L., Johansson, A., Wilén, C., Sipilä, K., Mäkinen, T., Helynen, S., Daugherty, E., den Uil, H., Vehlow, J., Kåberger, T., and Rogulska, M., 2006. Bioenergy in Europe: Opportunities and Barriers. VTT Res. Notes #2532, Espoo, Finland.

Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne, 2008. Land clearing and the biofuels carbon debt. Science 319: 1235-1238.

Farrel, A. E., R. J. Plevin, B. T. Turner, A. D. Jones, M.O'Hare, and D. M. Kammen, 2006. Ethanol can contribute to energy and environmental goals. Science 311: 506-508.

Fava, J., 2005. Can ISO Life Cycle Assessment Standards Provide Credibility for LCA? Building Design& Construction. Nov. 2005.

Federal Bill Addresses Bioenergy, Cellulosic biofuels, Renewable Energy World.com, http://www.renewableenergyaccess.com/rea/news/story?id=33201

Field, C. B., J. E. Campbell, and D. B. Lobell, 2007. Biomass energy: The scale of the potential resource.Trends in Ecology & Evolution 29: 65-72.

Firbank, LG, 2008. Assessing the Ecological Impact of Bioenergy Projects. BioEnergy Research Published on-line 26 January 2008. pp.17-20. .

Fischer, G. and L. Schrattenholzer, 2001a, 'Global bioenergy potentials through 2050', Biomass and bioenergy 20, 151-159.

Fischer, G., M. Shah, H. van Velthuizen, and F. O. Velthuizen, 2001b. Global Agro-ecological Assessment for Agriculture in the 21st Century, International Institute for Applied Systems Analysis, Schlossplatz 1, A-2361 Laxenburg, Austria

Fischer, G., 2009. World food and agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability? Paper for the Expert Meeting on "How to Feed the World in 2050," FAO, Rome, 24-26 June 2009

Fischer, G., E. Hizsnyik, S. Preiler, M. Shah, H. van Velthuizen (2009). Biofuels and food security. IIASA, Laxenburg, Austria and OFID, Vienna, Austria.

Fischer, G., E. Hizsnyik, S. Preiler, M. Shah, H. van Velthuizen (2009). Biofuels and food security. IIASA, Laxenburg, Austria and OFID, Vienna, Austria.

Fischer, G., Nachtergaele, F., Prieler, S., Teixeira, . van Velthuizen, H. Verelst, L. Wiberg, D.(Global Agro-ecological Zones Assessment for Agriculture (GAEZ 2008). IIASA, Laxenburg, Austria and FAO, Rome, Italy.

Fischer, G., Prieler, S., van Velthuizen, H., Berndes, G., Faaij, A., Londod, M., de Wit, M. Biofuel production potentials in Europe: Sustainable use of cultivated land and pastures, Part II: Land use scenarios. Biomass and Bionergy (2009) in press.

Fischer, G., van Velthuizen, H., Shah, M.,Nachtergaele, F. Global Agro-ecological Assessment for Agriculture in the 21st Century: Methodology and Results. International Institute for Applied Systems Analysis, Austria, 2002.

Fischer, R., Byerlee, D., Edmeades, G. Can technology deliver on the yield challenges to 2050? Paper for the Expert Meeting on "How to Feed the World in 2050," FAO, Rome, 24-26 June 2009

Fischlin, A., G.F. Midgley, J.T. Price, R. Leemans, B. Gopal, C. Turley, M.D.A. Rounsevell, O.P. Dube, J. Tarazona, A.A. Velichko, 2007. Ecosystems, their properties, goods, and services. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, 211-272.

Fleming, J.S., Habibi, S., MacLean, H.L., 2006. Investigating the Sustainability of Lignocellulose – Derived Light-Duty Vehicle Fuels through Life Cycle Analysis. Transportation Research Part D: Transport and Environment. 2006. 11. 146-159.

Folha, 2005. "Bagaço da cana será usado para fabricação de papel", Newspaper Folha da Região - Araçatuba, Oct 25, 2005, São Paulo, Brazil, http://www.folhadaregiao.com.br/noticia?49623

Foust, T. D., Aden, A., Dutta, A., Phillips, S., 2009. Economic and Environmental Comparison of a Biochemical and a Thermochemical Lignocellulosic Ethanol Conversion Process.Cellulose. 16:. 547-565. NREL Report No. JA-510-45976 (June 2009).

Frapolli et al., 2009. .http://209.85.129.132/search?q=cache:IQEbVXrXQIAJ:www.cidiroax.ipn.mx/gramos/images/stories/File/Garcia-Frapolli%2520et%2520al%25202009_published.pdf+Frapolli+2009+wood&cd=14&hl=fr&ct=clnk&gl=fr&client=firefox-a

Frombo F., Minciardi R., Robba M., Rosso F., Sacile R. 2009. Planning woody biomass logistics for energy production: A strategic decision model. Biomass and bioenergy 33 (2009) 372 – 383.

Gallagher, E., 2008. The Gallagher Review of the Indirect Effects of Biofuels Production. Renewable Fuels Agency, London, United Kingdom.

Gallagher, Paul, Mark Dikeman, John Fritz, Eric Wailes, Wayne Gauther, and Hosein Shapouri. Biomass from Crop Residues: Cost and Supply Estimates. U.S. Department of Agriculture, Office of the Chief Economist, Office of Energy Policy and New Uses. Agricultural Economic Report No. 819

Gan, J. Supply of biomass, bioenergy, and carbon mitigation: Method and application. Energy Policy 35 (2007) 6003-6009.

Garrison, T. (2008). Essentials of Oceanography (Brooks Cole).

GBEP (Global Bioenergy Partnership) (2008) A Review of the Current State of Bioenergy Development in G8+5 Countries. GBEP, Food and Agriculture Organization of the United Nations (FAO), Rome.

GBEP, 2007. Global Bioenergy Partnership, A review of the current state of bioenergy development in G8+5 countries. Rome, GBEP, Secretariat, FAO. www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/BIOENERGY_INFO/0805_GBEP_Report.pdf, November.

Gerasimov, Y., Karjalainen, T. Estimation of supply and delivery cost of energy wood from Northwest Russia. Working Papers of the Finnish Forest Research Institute 123. 2009.

Gerbens-Leenes, W.; Hoekstra, A. Y. and van der Meer, T. H., 2009. The water footprint of bioenergy Proceedings of the National Academy of Sciences, 106: 10219-10223.

Gibbs, Holly K., Matt Johnston, Jonathan A Foley, Tracey Holloway, Chad Monfreda, Navin Ramankutty and David Zaks, 2008. Carbon payback times for crop-based biofuel expansion in the tropics: the effects of changing yield and technology, Environ. Res. Lett. 3 (2008) 034001 (10pp)

Green RE, Cornell SJ, Scharlemann JPW, Balmford A., 2005. Farming and the fate of wild nature. Science 307:550–555.

Grove, S., Hanula, J (eds). Insect biodiversity and dead wood: proceedings of a symposium for the 22nd International Congress of Entomology. Gen. Tech. Rep. SRS–93. Asheville, NC:U.S. Department of Agriculture, Forest Service, Southern Research Station. 2006

GTZ. 2008. Analysis of charcoal value chains - general considerations. Prepared for GTZ Household Energy Programme by Steve Sepp – Eco Consulting Group. Germany.

Guille, T. Evaluation of the potential uses of agricultural residues for energy purposes. Masters Thesis, Montpellier SupAgro (France), 2007 (in French).

Haefele,D., 2002. Elite Grain Hybrids for Dry Grind Ethanol Production. 2002 Corn Utilization and Technology Conference Proceedings, pp. 70-73.

Hall, D. O., F. Rosillo-Calle, R. Williams, J. Woods, 1993. Biomass for Energy: Supply Prospects, in (eds.T. B. Johansson, H. Kelly, A. K. N. Reddy, R. Williams, L. Burnham) Renewable Energy – Sources for Fuels and Electricity, Island Press, Washington, D.C.

Hamelinck C, Koop K, Croezen H, Koper M, Kampman B, Bergsma G. Technical specification: greenhouse gas calculator for biofuel, SenterNovem, Ecofys 2008; http://www.senternovem.nl/mmfiles/ Technicalspecificationv2.1b20080813 tcm24-280269.pdf; 2008.

Hamelinck CN, Suurs RAA, Faaij APC, 2005a. International bioenergy transport costs and energy balance. Biomass Bioenergy 2005;29(2):114–34.

Hamelinck CN, Suurs RAA, Faaij APC, 2005b. Techno-economic analysis of International Bio-energy Trade Chains. Biomass & Bioenergy, Vol. 29, Issue 2, August 2005, Pages 114-134

Hamelinck, C. and A.Faaij, 2006. Outlook for advanced biofuels. Energy Policy, Volume 34, Issue 17, November 2006, Pages 3268-3283

Hamelinck, C. N., 2004. Outlook for Advanced Biofuels, PhD Thesis, University of Utrecht, The Netherlands.

Hastings, A.; Clifton-Brown, J.; Wattenbach, M.; Stampfl, P.; Mitchell, C. & Smith, P. Potential of Miscanthus grasses to provide energy and hence reduce greenhouse gas emissions Agron. Sustain. Dev., 2008, 28, 465-472

Hedon Household Network, 2006. First Meeting of Network of Experts on Domestic Biogas April 5-6, 2006, Hanoi, Vietnam, http://www.hedon.info/docs/20060531_Report_(final)_on_Biogas_Experts_Network_Meeting_Hanoi.pdf

Heggenstaller, Andrew H., Robert P. Anex, Matt Liebman, David N. Sundberg and Lance R. Gibson. Productivity and Nutrient Dynamics in Bioenergy Double-Cropping Systems. Agron J 100:1740-1748 (2008). DOI: 10.2134/agronj2008.0087

Hellingwerf, K., and Teixeira de Mattos, M. (2009). Alternative routes to biofuels: Light-driven biofuel formation from CO_2 and water based on the [`]photanol' approach. Journal of Biotechnology 142, 87-90.

Hettinga, W.G., H.M. Junginger, S.C. Dekker, M. Hoogwijk, A.J. McAloon, K.B. Hicks, 2009. Understanding the reductions in US corn ethanol production costs: An experience curve approach, Energy Policy, Volume 37, Issue 1, January 2009, Pages 190-203

Hill, J., E. Nelson, D. Tilman, S. Polasky, and D. Tiffany, 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. PNAS 103: 11206-11210.

Hill, J. Environmental costs and benefits of transportation biofuel production from food- and lignocellulose-based energy crops. A review. Agron. Sustain. Dev., 2007, 27, 1-12

Hoogwijk, M, Faaij, A., van den Broek, R., Berndes, G., Gielen, D. and Turkenburg, W. Exploration of the ranges of the global potential of biomass for energy. Biomass and Bioenergy 25 (2003):119-133

Hoogwijk, M, Faaij, A., van den Broek, R., Berndes, G., Gielen, D. and Turkenburg, W., 2003. Exploration of the ranges of the global potential of biomass for energy. Biomass and Bioenergy 25 (2003):119-133.

Hoogwijk, M., 2004. 'On the global and regional potential of renewable energy sources. PhD thesis', Utrecht University, Utrecht, the Netherlands, p. 256.

Hoogwijk, M., A. Faaij, B. de Vries, W. Turkenburg, 2009. Exploration of regional and global cost–supply curves of biomass energy from short-rotation crops at abandoned cropland and rest land under four IPCC SRES land-use scenarios is available in Biomass & Bioenergy, Volume 33, Issue 1, January 2009, Pages 26-43

Hoogwijk, M., Faaij, A., deVries, B., Turkenburg, W. (2008).ying individual plants to rom local on of degraded/marginal land and n landl.ary curvess of studiesfiod Exploration of regional and global cost–supply curves of biomass energy from short-rotation crops at abandoned cropland and rest land under four IPCC SRES land-use scenarios. Biomass and Bioenergy 33: 26-43

Hooijer, A., Silvius, M., Wösten, H. & Page, S. 2006. PEAT- CO_2, Assessment of CO_2 emissions from drained peatlands in SE Asia. Delft Hydraulics report Q3943 (2006)

Howarth, R.W., S. Bringezu, L.A. Martinelli, R. Santoro, D. Messem, O.E. Sala, 2009. Introduction: biofuels and the environment in the 21st century. Pages 15- 36, in R.W. Howarth and S. Bringezu (eds) Biofuels: Environmental Consequences and Interactions with Changing Land Use. Proceedings of the Scientific Committee on Problems of the Environment (SCOPE) International Biofuels Project Rapid Assessment, 22-25 September 2008, Gummersbach Germany. Cornell University, Ithaca NY, USA. (http:// cip.cornell.edu/biofuels/).

Howard G and, Ziller S (2008) Alien alert – plants for biofuel may be invasive. Bioenergy Business July/August: 14–16

Hsu, D. D.; Inman, D.; Heath, G.A.; Wolfrum, E.J.; Mann, M.K.; Aden, A., Life Cycle Environmental Impacts of Selected U.S. Ethanol Production and Use Pathways in 2022, Submitted to Publication in Environmental Science and Technology, https//client-ross.com/lifecycle.../

Hu Qichun, 2006. The Promotion of Rural Domestic Plants in P. R. China, http://www.hedon.info/docs/20060406_Biogas_promotion_China.pdf

IAASTD (2009). Agriculture at a crossroads. International Assessment of Agricultural Knowledge, Science and Technology for Development. Global Report. IAASTD/Island Press, Washington, DC.

IEA Bioenergy (2009). Bioenergy – a sustainable and reliable energy source. A review of status and prospects, IEA Bioenergy: ExCo: 2009:05

IEA Bioenergy, 2007. Potential Contribution of Bioenergy to the Words's Future Energy Demand, IEA\ Bioenergy: ExCo: 2007:02

IEA Energy Technology Essentials, 2007. Biomass for Power Generation and CHP, ETE 03, ECD/IEA, January 2007, www.iea.org/Textbase/techno/essentials.htm

IEA, 2002. Penetration of Alternative Fuels in the EU and Potential Impact on the Conventional Fuels, International Energy Agency, Paris.

IEA, 2005. International Energy Agency, Biofuels for transport: An international perspective. International Energy Agency, Paris.

IEA, 2008. International Energy Agency and IEA Bioenergy, From 1st to 2nd-generation biofuels technologies – A review of current industry and RD&D activities, November 2008

IEA-ETE, 2007a. International Energy Agency, IEA Energy Technology Essentials: Biofuel Production. ETE02, International Energy Agency.

IEA-ETP, 2008. Energy Technology Perspectives Report, Paris-France, 2008

IEA-WEO, 2006. World Energy Outlook 2006. International Energy Agency, Paris.

IEA-WEO. 2007. World Energy Outlook 2007. International Energy Agency, Paris, France, Paris

IEA-WEO. 2009. World Energy Outlook 2009. International Energy Agency, Paris, France, Paris

IMAGEteam (2001). The IMAGE 2.2 implementation of the SRES scenarios: a comparative analysis of emissions, climate change and impacts in the 21st century. Bilthoven: National Institute for Public Health and the Environment (CD-Rom).

India, 2006. Biogas Promotion in India. 1st. Meeting of Network of Experts on Domestic Biogas, April 4-5, 2006, Hanoi, Vietnam, http://www.hedon.info/docs/20060406_Biogas_promotion_India.pdf

IPCC, 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment

IPCC. Guidelines for national greenhouse gas inventories, volume 4, Agriculture,forestry and other land use, Intergovernmental Panel on Climate Change; 2006.

Iyer, P. V. R., T. R. Rao and P. D. Grover. 2002. Biomass: Thermochemical characterization. 3rd ed.1-42, Indian Institute of Technology, Delhi, India.

J. Wolf, P. S. Bindraban, J. C. Luijten and L. M. Vleeshouwers. Exploratory study on the land area required for global food supply and the potential global production of bioenergy. Agricultural Systems 76 (2003): 841-861

Jackson, R. B., Jobbagy, E. G., Avissar, R., Roy, S. B., Barrett, D. J., Cook, C. W., Farley, K. A., le Maitre, D. C., McCarl, B. A., Murray, B. C. (2005) Trading water for carbon with biological carbon sequestration. Science, 310(2005): 1944–1947.

Jalani, B S., Yusof Basiron, Ariffin Darus, Chan, K W and N Rajanaidu, 2002. Prospects of Elevating National Oil Palm Productivity: a Malaysian Perspective, Oil Palm Industry Economic Journal (VOL. 2(2)/2002), http://palmoilis.mpob.gov.my/publications/opiejv2n2-1.pdf

Janske van Eijck, J. and H. Romijn, 2006. Prospects for Jatropha Biofuels in Developing Countries: An analysis for Tanzania with Strategic Niche Management, Eindhoven Centre for Innovation Studies; see also “Innovation Systems for Competitiveness and Shared Prosperity in Developing Countries”, Thiruvananthapuram, India, 4-7, October 2006.

Jauhiainen, J., Takahashi, H., Heikkinen, J.E.P., Martikainen, P.J. & Vasander, H. 2005. Carbon fluxes from a tropical peat swamp forest floor. Global Change Biology 11, 1788-1797..

Jensen, E.S. 1996. Grain yield, symbiotic N-2 fixation and interspecific competition for inorganic N in pea-barley intercrops Plant and soil, 1996, 182, 25-38

Johansson, D. and Azar, C. (2007). A scenario based analysis of land competition between food and bioenergy production in the US. Climatic Change, 82 (3-4) pp. 267-291.

Johnson, M., R. Edwards, C. Alatorre y O. Masera, 2008. In-field greenhouse gas emissions from cookstoves in rural Mexican households. Atmospheric Environment 42 (2008): 1206–1222. (ISI FI:2.549) ISSN 1352-2310 ð

Johnson, M., Rufus, E., Ghilardi, A., Berrueta, V., Gillen, D., Alatorre-Frenk, C., Masera. O. 2009. Quantification of carbon savings from improved biomass cookstove projects. Environmental Science & Technology. 43 (7), pp 2456-2462 (ISI FI: 4.45) ISSN 0013-936X

Johnston, M. and T. Holloway, 2007. A Global Comparison of National Biodiesel Production Potentials,

JRC - Joint Research Center, 2008. Forest Fires in Europe 2008, JRC Scientific and Technical Reprts, Report No. 9, European Commission, Joint Research Centre, Institute for Environment and Sustainability

JRC, EUCAR, CONCAWE, 2007. Well-to-wheel analysis of future automotive fuels and powertrains in the European context JRC, Ispra, 2007.

Junginger, M., A. Faaij, A. Koopmans, R. van den Broek, W. Hulscher, Setting up fuel supply strategies for large scale bio-energy projects - a methodology for developing countries. Biomass & Bioenergy, Vol 21. No. 4, pp. 259-275, 2001

Junginger, M., A. Faaij, R. Björheden, W. Turkenburg, 2005. Technological learning and cost reductions in woodfuel supply chains in Sweden Biomass and Bioenergy, Vol. 29, Issue 6, December 2005, Pp. 399-418

Junginger, M., E. de Visser, K. Hjort-Gregersen, J. Koornneef, R. Raven, A. Faaij, W.C. Turkenburg, 2006a. Technological learning in bio-energy systems. Energy Policy, Volume 34, Issue 18, December 2006, Pages 4024-4041Junginger, M., Faaij, A., Rosillo-Calle, F., Wood, J., 2006b. The growing role of biofuels - Opportunities, challenges and pitfalls, International Sugar Journal, Volume 108, Issue 1295, November 2006, Pages 618-629

Junginger, Martin, Torjus Bolkesjø, Douglas Bradley, Paulo Dolzan, André Faaij, Jussi Heinimö, Bo Hektor, Øyvind Leistad, Erik Ling, Miles Perry, Erik Piacente, Frank Rosillo-Calle, Yves Ryckmans, Peter-Paul Schouwenberg, Birger Solberg, Erik Trømborg, Arnaldo da Silva Walter, Marc de Wit, Developments in international bioenergy trade, Biomass and Bioenergy, Volume 32, Issue 8, August 2008, Pages 717-729.

Jungk, N and Reinhardt, G. (2000). Landwirtschaftliche Referenzsysteme in Ökologischen Bilanzierungen: eine Basis Analyse. IFEU – Institute für Energie- und Umweltforschung Heidelberg.

Karjalainen, T.; Asikainen, A.; Ilavsky, J.; Zamboni, R; Hotari, KE.; Röser, D., 2004. Estimation of Energy Wood Potential in Europe. Working Papers of the Finnish Forest Research Institute, Helsinki.

Kartha, S., 2006. Environmental effects of bioenergy. In Bioenergy and Agriculture: Promises and Challenges. Hazel, P. and Pachauri, R.K. (eds). A 2010 Vision for Food, Agriculture and the Environment – Focus 14. International Food Policy Research Institute.

Keeney, D., 2009. Ethanol USA. Environ. Sci. Technol. 43: 8-11. doi: 10.1021/es8016182

Keeney, D. and M. Muller. (2006). "Water Use by Ethanol Plants Potential Challenges", Minneapolis, Minnesota: Institute for Agriculture and Trade Policy. 7 pages.

Kim, H. Kim, S, Dale, B., 2009. Biofuels, Land Use Change, and Greenhouse Gas Emissions: Some Unexplored Variables. Environmental Science & Technology 43 (3): 961–967.

Kim, S., Dale, B. Global potential bioethanol production from wasted crops and crop residues. Biomass and Bioenergy 26 (2004) 361-375

Kim, S., Dale, B., 2002. Allocation Procedure in Ethanol Production System from Corn Grain. InternationalJournal of Life Cycle Assessment. Volume 7. Pages 237-243.

Kirkinen, J., Palosuo, T., Holmgren, K., Savolainen, I.: Greenhouse impact due to the use of combustible fuel: Life cycle viewpoint and Relative Radiative Forcing Commitment. Environmental Management (2008) 42:458-469

Kituyi E. 2004. Towards sustainable production and use of charcoal in Kenya: exploring the potential in life cycle management approach. Journal of Cleaner Production. 12 (2004):1047-1057.

Kløverpris J, Wenzel H, Banse M, Milà i Canals L, Reenberg A., 2008a. Conference and Workshop on Modelling Global Land Use Implications in the Environmental Assessment of Biofuels. The International Journal of Life Cycle Assessment 13 (3) 178–183

Knauf, M. and K. Kraus, 2006. Specific yeasts developed for modern ethanol production, Sugar Industry vol. 131 (2006), pp. 753-758

KöhlinG and Ostwald M, 2001. Impact of plantations on forest use and forest status in Orissa, India. Ambio 30:37–42.

Koning, N., Van Ittersum, M., Becx, G., Van Boekel, M., Brandenburg, W., Van Den Broek, J.,Goudriaan, J., Van Hofwegen, G., Jongeneell , R., Schiere, J., Smies, M. Long-term global availability of food: continued abundance or new scarcity? NJAS - Wageningen Journal of Life Sciences 55/3 (2008): 229-292.

Kraan, S., and Barrington, K. A., 2005. Commercial farming of Asparagopsis armata (Bonnemaisoniceae, Rhodophyta) in Ireland, maintenance of an introduced species? Journal of Applied Phycology 17, 103-110.

Krausmann, F., Erb, K., Gingrich, S., Lauk, C., Haberl, H. Global patterns of socio-economic biomass flows in the year 2000: a comprehensive assessment of supply, consumptino and constraints. Ecological Economics 65 (2008) 471-487

Krich, K; Augenstein, D., Batmale, JP:, Benemann, J.; Rutledge, B.; and Salour, D. (2005). Biomethane from Dairy. http://www.suscon.org/news/biomethane_report/index.asp.

Kumar, Linoj N.V and Maithel S, 2008. Alternative feedstock for Bio –ethanol production in India In Biofuels towards a greener and secure energy future Editor P. P . Bhojvaidad 2008

Laird, D., Brown, R., Amonette, J., Lehmann, J. Review of the pyrolysis platform for coproducing bio-oil and biochar. Biofuels, Bioprod. Bioref. 3(2009):547-562

Lal R, Pimentel D. Bio-fuels from crop residues. Soil & Tillage Research 2007;93(2):237–8.

Lal, R. 2004. Soil Carbon Sequestration impacts on global climate change and food security. Science 304:1623–1627.

Lal, R., 2005. World crop residues production and implications of its use as a biofuel. Environ. Int., 31: 575-584.

Lal, R., 2008. Crop residues as soil amendments and feedstock for bioethanol production. Waste Management 28: 747-758.

Larson, E. D, 2006. A review of life cycle analysis studies on liquid biofuel systems for the transport sector. Energy for Sustainable Development. Vol. X No. 2. June 2006. p. 109-126.

Larson, E.D., G. Fiorese, G. Liu, R.H. Williams, T.G. Kreutz, S.Consonni, 2009. Co-production of synfuels and electricity from coal + biomass with zero net carbon emissions: an Illinois case study, Energy Procedia 1: 4371-4378

Lattimore, B., Smith, C.T., Titus, B.D., Stupak, I. and Egnell, G. 2009. Environmental factors in woodfuel production: Opportunities, risks, and criteria and indicators for sustainable practices. Biomass and Bioenergy (2009), doi:10.1016/j.biombioe.2009.06.005. (available on-line, in press).

Laurance, W.F. (2007). Switch to Corn Promotes Amazon Deforestation. Science 318: 1721.

Lee, Y., Kuo, C. H., Lee, C. H., Lee, C. H., Tsou, C. S. (2006). The strategic research for agricultural biotechnology development in Taiwan. Scientific Agriculture, 54(7), 107-117.

Leemans, R., van Amstel, A., Battjes, C., Kreilman, E., Toet, S., 1996. The land cover and carbon cycle consequences of largescale utilizations of biomass as an energy source. Global Environmental Change 6(4):335-357.

Lewandowski, I., A. Faaij, 2006. Steps towards the development of a certification system for sustainable bio-energy trade. Biomass and Bioenergy, 30,2.p. 83-104.

Lindberg, P., Park, S., and Melis, A. (2009). Engineering a platform for photosynthetic isoprene production in cyanobacteria, using Synechocystis as the model organism. Metab. Eng. Available at: http://www.ncbi.nlm.nih.gov/pubmed/19833224 [Accessed November 2, 2009].

Liska, A. J. and Richard K Perrin, 2009. Indirect land use emissions in the life cycle of biofuels: regulations vs science, Biofuels, Bioproducts and Biorefining, Volume 3 Issue 3, Pages 318 - 328

Lobell, D. B., Marshall B. Burke, Claudia Tebaldi, Michael D. Mastrandrea, Walter P. Falcon, and Rosamond L. Naylor, 2008. Prioritizing Climate Change Adaptation Needs for Food Security in 2030 (1 February 2008) Science 319 (5863), 607. [DOI: 10.1126/science.1152339

Londo, Marc, Sander Lensink, André Wakker, Günther Fischer, Sylvia Prieler, Harrij van Velthuizen, Marc de Wit, André Faaij, MartinJunginger, Göran Berndes, Julia Hansson, Andrea Egeskog, Henrik Duer, Jeppe Lundbaek, Grzegorz Wisniewski, Adam Kupczyk, Kurt Könighofer, The REFUEL EU road map for biofuels in transport: Application of the project's tools to some short-term policy issues, Biomass and Bioenergy, In Press, Corrected Proof, Available online 13 August 2009.

Lotze-Campen, H., Popp, A., Beringer, T., Müller, C., Bondeau, A., Rost, S., Lucht, W., 2009. Scenarios of global bioenergy production: The trade-offs between agricultural expansion, intensification and trade. Ecological Modelling, doi:10.1016/j.ecolmodel.2009.10.002.

Low, T. and Booth, C., 2007. The Weedy Truth About Biofuels. Invasive Species Council: Melbourne, Australia.

Lundqvist, J., Barron, J., Berndes, G., Berntell, A., Falkenmark, M., Karlberg, L., and Rockström, J. (2007). Water pressure and increases in food & bioenergy demand: implications of economic growth and options for decoupling. In: Scenarios on economic growth and resource demand. Background report to the Swedish Environmental Advisory Council memorandum 2007:1.

Lysen, E. and S. van Egmond, eds (2008). "Assessment of Global Biomass Potentials and their Links to Food, Water, Biodiversity, Energy Demand and Economy." The Netherlands Environmental Assessment Agency, Jun 2008.

Lynn Grooms, 2005. BioFuels Journal. “Sparking CO_2 Interest: KS Oil Field Pilot Project Could Open New Market for Ethanol Plants,” Second Quarter, 2005b, pp. 8-9

Macedo, I.C.; Seabra, J.E.A.2008. in Sugarcane ethanol contribution to climate change mitigation and the environment. P. Zurbier and J. Van de Vooren, Eds., Wageningen Academic Publishers, 2008, 95-111

Mann, M. K.; Spath, P. L. (1997). Life Cycle Assessment of a Biomass Gasification Combined-Cycle System. 159 pp.; NREL Report No. TP-430-23076

Market, Fulton, L, IFQC, European Automotive Fuels Briefing, Paris 21/11/2002, http://www.ifqc.org/

Marland G, Schlamadinger B., 1997. Forests for carbon sequestration or fossil fuel substitution? A sensitivity analysis. Biomass and Bioenergy 13(6): 389-397

Martinelli, L. A.. and S. Filoso, 2007. Polluting effects of Brazil's sugar-ethanol industry. Nature 445: 364.

Masera, O.R. y J. Navia, 1997. Fuel Switching or Multiple Cooking Fuels: Understanding Interfuel Substitution Patterns in rural Mexican Households. Biomass and Bioenergy 12:5 pp. 347-361.

Masera, O.R., B.D. Saatkamp y D.M. Kammen 2000. From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model for Rural Households. World Development 28: 12, pp. 2083-2103.(ISI, FI: 1.565) ISSN 0305-750X þð

Masera, O.R., R. Díaz y V. Berrueta, 2005. From Cookstoves to Cooking Systems: The Integrated Program on Sustainable Household Energy Use in Mexico. Energy for Sustainable Development. Vol 9: 5 pp: 25-36. Reseñado en Contraportada.1[1] ISSN 0973-0826.

Massengale R. 1985 The Missouri charcoal kiln, In Proceeding of Symposium on Forest Products Research International, Achievements and the Future, vol. 5, Pretoria.

Mc Laughlin, S.B., D.G. De la Torre Ugarte, C.T. Garten, L.R. Lynd, M.A. Sanderson, V.R. Tolbert and D.D. Wolf, 2002. 'High-value renewable energy from prairie grasses', Environmental Science and Technology, 36, 10, p. 2122-2129.

McAloon, A., T.F., W. Lee, K. Ibsen, and R. Wooley, 2000. Determining the cost of producing ethanol from corn starch and lignocellulosic feedstocks. Technical Report of National Renewable Energy Laboratory (NREL), NREL/TP-580-28893. Golden, CO: National Renewable Energy Laboratory. October, 2000

Melillo et al. Indirect emissions from biofuels: how imprtant? Science Oct 2009

Menichetti, E. and M. Otto, 2009. Energy balance and greenhouse gas emissions of biofuels from a product life-cycle perspective. In R.W. Howarth and S.Bringezu (eds) Biofuels: Environmental Consequences and Interactions with Changing Land Use. Proceedings of the Scientific Committee on Problems of the Environment (SCOPE) International Biofuels Project Rapid Assessment, 22-25 September 2008, Gummersbach Germany. Cornell University, Ithaca NY, USA. (http:// cip.cornell.edu/biofuels/).

Millennium Ecosystem Assessment, 2005. Ecosystems and human well-being: Island Press: Washington, Covelo, London.

Mishra V., 2004. Effect of indoor air pollution from biomass combustion on prevalence of asthma in the elderly. Environ Health Perspect 2003;111:71–78.

Molden, D., K. Frenken, Ch. De Fraiture, R. Barker, B. Mati, M. Svendsen, C.Sadoff, C.M. Finlayson, 2007. Trends in water and agricultural development, In: David Molden (ed.) Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. London: Earthscan, 57-89.

Molina Grima, E., Belarbi, E. -., Acién Fernández, F. G., Robles Medina, A., and Chisti, Y. (2003). Recovery of microalgal biomass and metabolites: process options and economics. Biotechnology Advances 20, 491-515.

Mollersten K., Yan J., Moreira J.R., 2003. Potential market niches for biomass energy with CO_2 capture and storage—opportunities for energy supply with negative CO_2 emissions. Biomass Bioenergy 25(3):273–285.

Muller, Christian., 2007. Anaerobic Digestion of Biodegradable Solid Waste in Low- and Middle-Income Countries - Overview over existing technologies and relevant case studies, Dübendorf, May 2007, http://www.eawag.ch/organisation/abteilungen/sandec/publikationen/publications_swm/downloads_swm/Anaerobic_Digestion_low_resolution.pdf, see also http://www.hedon.info/PhilipsWoodStove

Muller, C., Eickhout, B., Zaehle, S., Bondeau, A., Cramer, W., and Lucht, W.: Effects of changes in CO_2, climate, and land use on the carbon balance of the land biosphere during the 21st 30 century, J. Geophys. Res.-Biogeosciences, 112, G02032, doi:10.01029/02006JG000388, G02032, 2007.

Nabuurs, G J, Masera, O, Andrasko, K, Benitez-Ponce, P, Boer, R, Dutschke, M, Elsiddig, E, Ford-Robertson, J, Frumhoff, P, Karjalainen, T, Krankina, O, Kurz, W A, Matsumoto, M, Oyhantcabal, W, Ravindranath, N H, Sanz Sanchez, M J and Zhang, X (2007) Forestry. In Intergovernmental Panel on Climate Change (IPCC) (ed) Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the IntergovernmentalPanel on Climate Change. Cambridge University Press, Cambridge, New York, pp541-84.

Nagatomi, Yu, Hiromi Yamamoto, Kenji Yamaji, Hiroshi Iwasaki and Koichi Yamada, A system analysis of energy utilization and competing technology using oil palm residue in Malaysia. Journal of Japan Society of Energy and Resources, Vol. 29, No. 5, 1-7, 2008.

Näslund-Eriksson, L., Gustavsson, L. Biofuels from stumps and small roundwood – costs and CO_2 benefits. Biomass and Bioenergy 10 (2008): 897-902

Ndong, R.; Montrejaud-Vignoles, M.; Saint-Girons, O.; Gabrielle, B.; Pirot, R. & Sablayrolles, C., 2009. Life cycle assessment of biofuels from Jatropha curcas in West Africa: a field study Global Change Biology Bioenergy, 2009 (in press).

Nelson DE, Repetti PP, Adams TR, Creelman RA, Wu J, Warner DC, Anstrom DC, Bensen RJ, Castiglioni PP, Donnarummo MG, et al. Plant nuclear factor Y (NF-Y) B subunits confer drought tolerance and lead to improved corn yields on water-limited acres. PNAS 104 (2007): 16450–16455

Nishii, T., M. Konishi, H. Hasebe, An autonomous decentralized supply chain planning system for multi-stage production processes, Journal of Intelligent Manufacturing, 16, 259–275, 2005

Nobles, D., and Brown, R. (2008). Transgenic expression of Gluconacetobacter xylinus strain ATCC 53582 cellulose synthase genes in the cyanobacterium Synechococcus leopoliensis strain UTCC 100. Cellulose 15, 691-701.

Novozymes, 2008. http://www.novozymes.com/en/MainStructure/AboutUs/Positions/Enzymes+produced+by+GMMs.htm

NRC 2009 “Liquid Transportation Fuels from Coal and Biomass Technological Status, Costs, and Environmental Impacts” America's Energy Future Panel on Alternative Liquid Transportation Fuels; National Academy of Sciences; National Academy of Engineering; National Research Council, ISBN: 0-309-13713-6, 300 pages, 6 x 9, (2009); http://www.nap.edu/catalog/12620.html

NSF. 2008. Breaking the Chemical and Engineering Barriers to Lignocellulosic Biofuels: Next Generation Hydrocarbon Biorefineries. Ed. George W. Huber, University of Massachusetts

Amherst. National Science Foundation. Chemical, Bioengineering, Environmental, and Transport Systems Division. Washington D.C. 180 p. http://www.ecs.umass.edu/biofuels/Images/Roadmap2-08.pdf

Obersteiner M, Azar C, Kauppi P, Mollersten K, Moreira J, Nilsson S, Read P, Riahi K, Schlamadinger B, Yamagata Y, Yan J, van Ypersele J.-P., 2001. Managing climate risk. Science 294(5543):786–787

OECD/FAO, 2008. (Organization for Economic Co-operation & Development/ Food and Agriculture Organization of the United Nations). 2008. Agricultural outlook 2008-2017. OECD Publishing, Paris.

O'Hare, M. R J Plevin, J I Martin, A D Jones, A Kendall and E Hopson, 2009. Proper accounting for time increases crop-based biofuels' greenhouse gas deficit versus petroleum, Environ. Res. Lett. 4 024001 (7pp) doi: 10.1088/1748-9326/4/2/024001

Openshaw, K., 2000. A review of Jatropha curcas: an oil plant of unfulfilled promise. Biomass and Bioenergy, 19 pp 1 - 15.

P.T. Pienkos and A. Darzins, The promise and challenges of microalgal-derived biofuels. Biofuels, Bioprod. Bioref. (2009):431-440

Pacca, S. and J. R. Moreira, 2009. Historical carbon budget of the Brazilian ethanol program, Energy Policy 37, p 4853-4873.

Pate, R., M. Hightower, C. Cameron, W. Finfield, 2007. Overview of energy-water interdependencies and the emerging energy demands on water resources, Los Alamos, Sandia National Laboratoty

Paustian, Keith, John M. Antle, John Sheehan, and Eldor A. Paul, 2006. Agriculture's Role in Greenhouse Gas Mitigation, Prepared for the Pew Center on Global Climate Change, September 2006

PERES, Frederico ; Moreira, J. C. ; Rodrigues, karla ; Lerner, R. ; Claudio, Luz . El uso de pesticidas en la agricultura y la salud del trabajador rural en Brasil. Ciencia & Trabajo, v. 9, p. 158-163, 2007.

Perlack, R.D., L.L. Wright, A. Turhollow, R.L. Graham, B. Stokes, and D. Erbach, 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Energy U.S.D.o. and U.S.D.o. Agriculture. Editors. ORNL/TM-2005/66. Oak Ridge, TN: Oak Ridge National Laboratory. http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf, p. 60

Phillips, S., A.Aden, J.Jechura, D.Dayton, and T.Eggeman. 2007. Thermochemical Ethanol via Indirect Gasification and Mixed Alcohol Synthesis of Lignocellulosic Biomass. Technical Report NREL/TP-510-41168. Golden, CO: National Renewable Energy Laboratory.

Pienkos, P. T. and A. Darzins, The promise and challenges of microalgal-derived biofuels. Biofuels, Bioprod. Bioref. (2009):431-440

Pimentel D, McNair S, Janecka J, Wightman J, Simmonds C, O'Connell C, Wong E, Russel L, Zern J, Aquino T, Tsomondo T (2001) Economic and environmental threats of alien plant, animal, and microbe invasions. Agric Ecosyst Environ 84:1–20

Pingali, P. L. and P. W. Heisey. 1999. Cereal Crop Productivity in Developing Counties: Past Trends and Future Prospects. Economics Working Paper 99-03, CIMMYT, Mexico D.F.

Practical Action Consulting (2009). Small-Scale Bioenergy Initiatives: Brief description and preliminary lessons on livelihood impacts from case studies in Asia, Latin America and Africa. Prepared for PISCES and FAO by Practical Action Consulting, January 2009

Purdon, M., Bailey-Stamler,s; and Samson,R. 2009. Better bioenergy: Rather than picking bioenergy "winners," effective policy should let a lifecycle analysis decide. Alternatives Journal 35:23-29.

R&D issues, ECN Biomass, w.ecn.nl/library/reports/2001e/rx01011.html

Rai, Saroj. 2006. Biogas Promotion in Nepal, 1st. Meeting of Experts on Domestic Biogas, April 5-6, 2006, Hanoi, Vietnam, . http://www.hedon.info/docs/20060406_Biogas_promotion_Nepal.pdf

Rajagopal, D. and Zilberman, D., 2007. Review of Environmental, Economic and Policy Aspect of Biofuels. Sustainable Rural and Urban Development Division of The World Bank. Policy Research Working Paper 4341.

Ranius, T., Fahrig, L. Targets for maintenance of dead wood for biodiversity conservation based on extinction thresholds. Scandinavian Journal of Forest Research 21/3 (2006) 201-208.

Ravindranath, N. H., P. Balachandraa, S. Dasappaa and K. Usha Rao, 2006. Bioenergy technologies for carbon abatement, Biomass and Bioenergy Volume 30, Issue 10, October 2006, Pages 826-837

Reinhardt, G. (1991). Biofuels: energy and GHG balances: methodology and case study rape seed biodiesel.IFEU – Institute für Energie- und Umweltforschung Heidelberg.

Reith et al., 2002. Co-Production of Bio-ethanol, Electricity and Heat from Biomass Waste: Potential andR&D issues, ECN Biomass, w.ecn.nl/library/reports/2001e/rx01011.html Riegelhaupt, E., P. Manzanares, M. Balllesteros, S. Coelho, P. Guardabassi, C. S. James and G. Aroca,

Risø Energy Report 2, 2009. New and emerging bioenergy technologies, edt. Edited by Hans Larsen, Jens Kossmann and Leif Sønderberg Petersen, Riso Laboratory, Denmark

Rendleman, C. M. and H. Shapouri, 2007. New Technologies in Ethanol Production, Agricultural Economic Report Number 842, Office of the Chief Economist, Office of Energy Policy and New Uses, USDA

Rentizelas A. A ., Tolis A. J., and Tatsiopoulos I. P. 2009. Logistics issues of biomass : The storage problem and the multi - biomass supply chain. Renewable and Sustainable Energy Reviews 13 (4) 887-894

Rhodes, James S. and David W. Keith, 2007. Biomass with capture: negative emissions within social and environmental constraints: an editorial comment, Climatic Change DOI 10.1007/s10584-007-9387-4

Roden, C. A., T. C. Bond, et al. (2009). "Laboratory and field investigations of particulate and carbon monoxide emissions from traditional and improved cookstoves." Atmospheric Environment 43(6): 1170-1181

Romero .J & Elder M CDM and Biofuels in Proceedings of 6th International Biofuel Conference 4-5 March 2009 p31-38

Romieu, I., H. Riojas-Rodriguez; A. Teresa Marrón-Mares, A. Schilmann, R. Perez-Padilla y O. Masera, 2009. Improved biomass stove intervention in rural Mexico: Impact on the respiratory health of women. American Journal of Respiratory and Critical Care Medicine. 180: 649-656.

Rosegrant, Mark W. & Cai, Ximing & Cline, Sarah A. & Nakagawa, Naoko, 2002. "The role of rainfed agriculture in the future of global food production:," EPTD discussion papers 90, International Food Policy Research Institute (IFPRI).

Rost, S., Gerten,D., Hoff, H., Lucht, W., Falkenmark, M., Rockström, J. Global potential to increase crop production through water management in rainfed agriculture. Environ. Res. Lett. 4 (2009) 044002

Rowe,R., Whitaker, J., Chapman, J., Howard,D., Taylor, G., 2008. Life-Cycle Assessment in Bioenergy Sector: Developing a Systematic Review Working Paper. UKERC / IUP / FSE / 2008 / 002

Sanchez, Pedro A, , Sonya Ahamed, Florence Carré, Alfred E. Hartemink, Jonathan Hempel, Jeroen Huising, Philippe Lagacherie, Alex B. McBratney, Neil J. McKenzie, Maria de Lourdes Mendonça-Santos, Budiman Minasny, Luca Montanarella, Peter Okoth, Cheryl A. Palm,1 Jeffrey D. Sachs,1 Keith D. Shepherd,10 Tor-Gunnar Vågen, Bernard Vanlauwe, Markus G. Walsh, Leigh A. Winowiecki,1 Gan-Lin Zhang, 2009. Digital soil map of the world. Science 325 (2009): no 5941, pp. 680 - 681

(S&T)2 Consultants Inc., 2009. An examination of the potential for improving carbon/energy balance of Bioethanol IEA Task 39 Report T39-TR1, 72 pp., Delta, Canada.

Sax, D.F., Gaines, S. D., 2008. Species invasion and extinction:The future of native biodiversity on islands. PNAS 105 pp. 11490-11497

SCBD, 2006. Secretariat of the Convention on Biological Diversity (SCBD). (2006). Global Biodiversity Outlook 2. SCBD: Montreal.

Scharlemann J, Laurance W., 2008. How Green Are Biofuels? Science 319: 43.

Schei MA, Hessen JO, Smith KR, Bruce N, McCracken J, Lopez V., 2004. Childhood asthma and indoor woodsmoke from cooking in Guatemala. J Expo Anal Environ Epidemiol 2004;14: Suppl. 1 s110–s117.

Schlamadinger, B. , R. Edwards, K. A. Byrne, A. Cowie, A. Faaij, C. Green, S. Fijan-Parlov, L. Gustavsson, T. Hatton, N. Heding, K. Kwant, K. Pingoud, M. Ringer, K. Robertson, B. Solberg, S. Soimakallio, and S. Woess-Gallasch. 2005. Optimizing the greenhouse gas benefits of bioenergy systems. 14th European Biomass Conference, 17-21 October 2005, Paris, France. Proceedings of the 14th European Biomass Conference. Biomass for Energy, Industry and Climate Protection. 2029-2032.

Schlamadinger, B., Apps, M., Bohlin, F., Gustavsson, L., Jungmeier, G., Marland, G., Pingoud, K., Savolainen, I. 1997: Towards a standard methodology for greenhouse gas balances of bioenergy systems in comparison with fossil energy systems. Biomass and Bioenergy, Vol. 13, No.6, pp. 359 - 375, 1997.

Schlamadinger, B., Grubb, M., Azar, C., Bauen, A. and Berndes, G., 2001. “Carbon sinks and the CDM: could a bioenergy linkage offer a constructive compromise?” Climate Policy 1: 411-417.

Schlamadinger, B.; Marland, G. The role of forest and bioenergy strategies in the global carbon cycle. Biomass Bioenergy 1996, 10, 275–300

Scolforo, J. R., 2008. Mundo Eucalipto - Os Fatos E Mitos De Sua Cultura, ed. Mar de Ideias, Brazil, ISBN: 8560458042

Searchinger, T, Heimlich, R,. Houghton, R. A., Dong, F. Elobeid, A., Fabiosa, J., Tokgoz, T., Hayes, D., and Yu, T., 2008. Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land Use Change. Science 319: 1238.

Semere, T. & Slater, F. M., 2007. Ground flora, small mammal and bird species diversity in miscanthus (Miscanthus giganteus) and reed canary-grass (Phalaris arundinacea) fields Biomass and Bioenergy, 2007, 31, 20–29.

Sheehan, J., A. Aden, C. Riley, K. Paustian, K. Killian, J. Brenner, D. Lightle, M. Walsh, J. Cushman, and R. Nelson, 2002. Is biomass from corn stover sustainable? Draft Report. Golden, CO: National Renewable Energy Laboratory.

Sheehan, J., Dunahay, T., Benemann, R., Roessler, G., and Weissman, C. (1998). A Look Back at the U.S. Department of Energy's Aquatic Species Program: Biodiesel from Algae.Rowe,R. (ed.)

Simpson, T. W., R. W. Howarth, H. W. Paerl, A. Sharpley, and K. Mankin, 2008. The new gold rush: Fueling ethanol production while protecting water quality. Journal of Environmental Quality 37: 318-324

Sims, Ralph., Michael Taylor, Jack Saddler, and Warren Mabee, 2008. From 1st- to 2nd-Generation Biofuel Technologies - An overview of current industry and RD&D activities, OECD/IEA, November 2008

Singh N.P., 2007. 25 years of Renewable energy in India Published in Akshay Urja GOI publication Vol 1 Issue 2 Sep –Oct 2007 p16-21.

Smeets, E., A. Faaij, I. Lewandowski, 2005. The impact of sustainability criteria on the costs and potentials of bioenergy production. An exploration of the implementation of sustainability criteria on the costs and potential of bioenergy production applied for case studies in Brazil and Ukraine, Utrecht University, Utrecht, the Netherlands, p.73+ Appendices

Smeets, E., Bouwman, L., Stehfest, E., van Vuuren, D., Posthuma, A. (2008). Contribution of N2O to the greenhouse gas balance of first-generation biofuels. Global Change Biology (2008) 14, 1–23

Smeets, E., Faaij, A., 2007. Bioenergy potentials from forestry 2050: An assessment of the drivers that determine the potentials. Climatic Change 81 (2007): 353-390.

Smeets, E., Faaij, A., Lewandowski, I., Turkenburg, W. A bottom-up assessment and review of global bio-energy potentials to 2050. Progress in Energy and Combustion Science, 33 (2007). 56-106

Smeets, E.M.W., A.P.C. Faaij, I.M. Lewandowski and W.C. Turkenburg, 2007. A bottom-up assessment and review of global bio-energy potentials to 2050, Progress in Energy and Combustion Science, 33(1), 56-106.

Smith, K. R. 1987. Biofuels, Air Pollution, and Health: A Global Review. New York: Plenum Press.

Smith, K.R. and E. Haigler, 2008. Co-Benefits of Climate Mitigation and Health Protection in Energy Systems: Scoping Methods, Annual Review of Public Health, Vol 29, April 2008

Soimakallio, S., Mäkinen, T., Ekholm, T., Pahkala, K., Mikkola, H. & Paappanen, T. 2009.Greenhouse gas balances of transportation biofuels, electricity and heat generation in Finland. Dealing with the uncertainties. Energy Policy 37(1), pp. 80-90.

Sparovek, G., Berndes, G., Egeskog, A., Luiz Mazzaro de Freitas, F., Gustafsson, S., Hansson, J. (2007). Sugarcane ethanol production in Brazil: An expansion model sensitive to socio-economic and environmental concerns. Biofuels, Bioproducts and Biorefining, 1: 270-282

Sparovek, G, Barretto A, Berndes, G., Martins, S.P., Maule, R.F. (2009). Environmental, land-use and economic implications of Brazilian sugarcane expansion 1996-2006. Mitigation and Adaptation Strategies for Global Change 14:285-298. DOI 10.1007/s11027-008-9164-3

Squizato, R., 2008. New approaches could increase biofuel output. Bioenergy Business, 2(2): 17 March.

Steenblik, R. 2007. Biofuels at What Cost: Government Support for Ethanol and Biodiesel in Selected OECD Countries. Global Subsidies Initiative, Geneva

Steierer F, Fischer-Ankern A, Francoeur M, Wall J, Prins K. (2007): Wood energy in Europe and North America:

Strengers et al., Geojournal 61, 381 (2004)

Sustainable Transportation Solutions, Ltd., 2006: "Biogas as a Road Transport Fuel: An assessment of the potential role of biogas as a renewable transport fuel". Research performed and report written for the National Society for Clean Air and Environmental Protection (NSCA). United Kingdom. http://www.environmental-protection.org.uk/assets/library/documents/biogas_as_transport_fuel_june06.pdf

Tang, WL, Zhao, H. 2009. Industrial biotechnology: Tools and applications. Biotechnol J. 2009 Oct 20. US: http://dx.doi.org/10.1002/biot.200900127

Tao, L.; Aden, A. The economics of current and future biofuels. In Vitro Cell. Dev. Biol.-Plant 2009, 45:199-217

The Royal Society, 2008. Sustainable biofuels: prospects and challenges. Policy document 01/08, January 2008. The Royal Society 6–9 Carlton House Terrace London.

Thorn J, Brisman J, Toren K., 2001. Adult-onset asthma is associated with self-reported mold or environmental tobacco smoke exposures in the home. Allergy 2001;56:287–292.

Tilman, D. Hill, J. and Lehman, C., 2006. Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass, Science 314 (5805), 1598-1600.

Tilman, D., K.G. Cassman, P.A. Matson, R. Naylor and S. Polasky, 2002. Agricultural sustainability and intensive production practices, Nature 418, 671-677.

Tilman, D., Reich, P. & Knops, J., 2006. Biodiversity and ecosystem stability in a decade-long grassland experiment Nature, 2006, 441, 629-632.

Tran, N., Bartlett, J., Kannangara, G., Milev, A., Volk, H., and Wilson, M. (2010). Catalytic upgrading of biorefinery oil from micro-algae. Fuel 89: 265-274.

UK,DFT - Department for Transport, 2009. International resource costs of biodiesel and bioethanol, http://www.dft.gov.uk/print/pgr/roads/environment/research/cqvcf/internationalresourcecost

UNEP Year Book, 2008. An Overview of Our Changing Environment. Division of Early Warning and Assessment (DEWA), United Nations Environment Programme, Nairobi, Kenya.

UNEP, 2007. United Nations Environment Programme (UNEP). (2007). Global Environment Outlook 4: Environment for Development. United Nations Environment Programme.

United Nations, 2007. The potential impacts of biofuels on biodiversity, Notes by the executive secretary, Conference of the parties to the convention on biological diversity, Ninth meeting, Bonn, 19-30 May 2008

U.S. Cellulosic, 2009. www.ethanolrfa.org/resource/cellulosic/documents/CurrentCellulosicEthanolProjects-January2009.pdf

USEPA, 2006. U.S. Environmental Protection Agency (USEPA), 2006. Inventory of U.S. greenhouse gas emissions and sinks: 1990–2004. Washington, DC: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, in press. EPA 430-R-05-003.

USEPA, 2008. Biofuel Technologies' Contribution to Life Cycle Emissions, V. Dornburg, A. Faaij, B. Meuleman, 2006. Optimising waste treatment systems; Part A: methodology and technological data for optimising energy production and economic performance. Resources, Conservation & Recycling, Volume 49, Issue 1, November 2006, Pages 68-88.

van Dam, J., Faaij, A., Lewandowski, I., Van Zeebroeck, B. Options of biofuel trade from Central and Eastern to Western European countries, Biomass and Bioenergy 33 (2009): 728-744.

van Dam, J., Junginger, M., Faaij, A., Jürgens, I., Best, G., Fritsche, U., 2008. Overview of recent developments in sustainable biomass certification, Biomass and Bioenergy, 32 (8): 749-780.

van Iersel, S., Gamba, L., Rossi, A., Alberici, S., Dehue, B., van de Staaij, J., and Flammini, A. (2009). Algae-Based Biofuels: A Review of Challenges and Opportunities for Developing Countries (FAO and Global Bioenergy Partnership) Available at: ftp://ftp.fao.org/docrep/fao/011/ak333e/ak333e00.pdf.

van Vuuren , D.,van Vliet, J., Stehfest, E. Future bioenergy potentials under various natural constraints. Energy Policy 37 (2009): 4220-4230.

van Vuuren, D.P., M.G.J. den Elzen, P.L. Lucas, B. Eickhout, B.J. Strengers, B. van Ruijven, S. Wonink and R. van Houdt, 2007: Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs, Climatic Change, 81(2), pp. 119-159

Varis, O. 2007. Water demands of bioenergy production. Water Res Devel 23(3): 519535.

Vergara-Fernandez, V. 2008. Evaluation of marine algae as a source of biogas in a two stage anaerobic reactor system. Biomass & Energy, 32(4)/ 338-344.

Vidal, C.J. and Goetschalckx, M., Strategic production-distribution models: A critical review with emphasis on global supply chain models. European Journal of Operational Research, 98, 1–18, 1997.

Virunga National Park, www.gorilla.cd.

VODO, 2001. Source Paper for the VODO International Conference on Globalisation and Sustainable Development, held on November 19-21, 2001 at Antwerp, Brussels, sponsored by Belgian Government, the Flemish Federation of Third-World Organizations and VODO ((Vlaams Overleg Duurzame Ontwikkeling Flemish Network on Sustainable Development), Belgium. AUTHOR: Raymond Myles, Secretary General-cum-Chief Executive, INSEDA, St. Soldier Tower, Vikas Puri, New Delhi-18

von Blottnitz, H. and Curran, M. A., 2006. A Review of assessments conducted on bio-ethanol as a transportational fuel from a net energy greenhouse gas, and environmental life-cycle assessment perspective. Journal of Cleaner Production Vol 15:607 – 619.

von Schirnding, Y., Bruce, N., Smith, K., Ballard-Treemer, G., Ezzati M., Lvovsky, K., 2001. Addressing the Impact of Household Energy and Indoor Air Pollution on the Health of the Poor - Implications for Policy Action and Intervention Measures, Geneva, Commission on Macroeconomics and Health, World Health Organization.

Vonshak, A., and Richmond, A. (1985). Problems in developing the biotechnology of algal biomass production. Plant and Soil 89, 129-135.

Vörösmarty, C.J., E.M. Douglas, P.A. Green, and C. Revenga (2005). Geospatial indicators of emerging water stress: An application to Africa. Ambio. 34: 230-236.

W. W. Wilhelm, Jane M. F. Johnson, Douglas L. Karlen and David T. Lightle. Corn Stover to Sustain Soil Organic Carbon Further Constrains Biomass Supply. Agron J 99:1665-1667 (2007). DOI: 10.2134/agronj2007.0150

Wall-Bake, J.D., M. Junginger, A, Faaij, T. Poot, A. da Silva Walter, 2009. Explaining the experience curve: Cost reductions of Brazilian ethanol from sugarcane, Biomass and Bioenergy, Volume 33, Issue 4, April 2009, Pages 644-658

Walsh M.E., de la Torre Ugarte D.G., Shapouri, H., Slinsky, S.P., 2003. Bioenergy crop production in the United States: potential quantities, land use changes, and economic impacts on the agricultural sector. Environmental Resource Economics 24(4):313–333

Walsh, M. Method to estimate bioenergy crop feedstock supply curves. Biomass and Bioenergy 18 (2000): 283-289

Wang, M., Wu, M., and Huo, H. 2007 "Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types", Environ. Res. Lett. 2 (2) 024001 (13 pp)

Wang, M.; Huo, H.; Arora, S. Methods of Dealing with Co-Products of Biofuels in Life-Cycle Analysis and Consequent Results within the U.S. Context. Energy Policy 2009, In Press

Warner, E.; Heath, G, Mann, M. 2009. Variability in Life Cycle Greenhouse Gas Emissions for Biopower Generation Technologies. Submitted to Publication. See also Heath G, Mann M, Sawyer P, Vorum M, Burkhardt J, Dolan S, O'Donoughue P. 2009. Variability in Life Cycle Greenhouse Gas Emissions for Electricity Generation Technologies. Life Cycle Assessment IX. American Center for Life Cycle Assessment, Boston, MA. September 30, 2009. WBGU, 2009. WBGU – German Advisory Council on Global Change (2009): Earthscan. – see http://www.wbgu.de/wbgu_jg2008_engl.html)

Wicke, B., J. van Eijck, E. Smeets, A. Faaij and H. Watson, 2009. ANNEX 2-3-2: Report on potential contribution to sustainable energy supply Deliverable D2.4 COMPETE - Competence Platform on Energy Crop and Agroforestry Systems for Arid and Semi-arid Ecosystems - Africa, Third Periodic Activity Report (01.01.2009 – 31.12.2009) Dec, 2009, WIP, Sylvensteinstrasse 2, 81369 Munich, Germany.

Williams, R. H., Larson, E. D., Liu, G., and Kreutz, T. G., 2009. Fischer-Tropsch fuels from coal and biomass: Strategic advantages of once-through (polygeneration) configurations. Energy Procedia 1: 4379 – 4386.

Wilkie, A.C., Riedesel, K.J., Owens, J.M., 2000. Stillage character ization and anaerobic treatment of ethanol stillage from conventional and cellulosic feedstocks. Biomass and Bioenergy 19, 63-102

Wirsenius, S., Azar, A., Berndes, G. Preserving natural ecosystems and global biodiversity: How much land can be spared for nature by dietary changes and livestock productivity increases? Agricultural Systems, under review

Wirsenius, S., Azar, C., Berndes, G. Global bioenergy potentials: a new approach using a model-based assessment of biomass flows and land demand in the food and agriculture sector 2030. 2nd World Conference and Technology Exhibition on Biomass for Energy, Industry and Climate Protection, Rome, Italy, 10-14 May 2004.

Wise MA, KV Calvin, AM Thomson, LE Clarke, B Bond-Lamberty, RD Sands, SJ Smith, AC Janetos, JA Edmonds. 2009. "The Implications of Limiting CO_2 Concentrations for Agriculture, Land Use, Land-use Change Emissions and Bioenergy" PNNL -18341 Pacific Northwest National Laboratory, Richland, WA.

Woertz, I., Feffer, A., Lundquist, T., and Nelson, Y. (2009). Algae Grown on Dairy and Municipal Wastewater for Simultaneous Nutrient Removal and Lipid Production for Biofuel Feedstock. J. Envir. Engrg. 135, 1115-1122.

Wolf, J., P.S. Bindraban, J.C. Luijten and L.M. Vleeshouwers, 2003. Exploratory study on the land area required for global food supply and the potential global production of bioenergy, Agricultural systems 76, 841-861.

World Bank, 2009. Global Economic Prospects - Commodities at the Crossroad, 2009 The International Bank for Reconstruction and Development / The World Bank, Washington DC 20433

Wright, L.L., 1994. Production technology status of woody and herbaceous crops. Biomass and Bioenergy 6(3): 191–209.

WWF, 2007. Rain forest for biodiesel? Ecological effects of using palm oil as a source of energy

WWI, 2006. Biofuels for transportation – Global potential and implications for sustainable agriculture and energy in the 21st century. Worldwatch Institute, Washington D.C.

Yokoyama, S., and Matsumura, Y. (ed.), 2008. The Asian Biomass Handbook. A Guide for Biomass Production and Utilization. The Japan Institute of Energy.

Zah, R., Böni, H., Gauch, M., Hischier, R., Lehman, M. and Wäger, P., 2007. Life Cycle Assessment of Energy Products: Environmental Assessment of Biofuels – Executive Summary. Empa, Swiss Federal Institute for Materials Science and Technology, Technology and Society Lab: St. Gallen, Switzerland.

Zemke-White, L., and Ohno, M. (1999). World seaweed utilisation: An end-of-century summary. Journal of Applied Phycology 11, 369-376

Zomer, R. J., Trabucco, A., van Straaten, O. & Bossio, D. A. (2006) Carbon, Land and Water: A Global Analysis of the Hydrologic Dimensions of Climate Change Mitigation through Afforestation/Reforestation, IWMI Research Report 101 (Colombo: International Water Management Institute).

Zuurbier, P. J. P. and J. van de Vooren, 2008. Sugarcane ethanol : contributions to climate change mitigation and the environment, Wageningen Academic Publishers, Wageningen, the Netherland