The growing role of biofuels - opportunities, challenges and pitfalls

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Abstract

This paper provides an overview of biomass production potentials, and the importance of technological development and perennial crops to utilize this potential. It examines some of the most critical issues for developing large-scale biomass for energy production, and indicates at the same time how these issues may be avoided or solved. An overview is provided of on-going developments to ensure the 'greenness' of biomass by developing safeguards, e.g. via sustainability criteria and certification schemes for bioenergy. Finally, the importance of sustainable international bioenergy trade as a major driver to develop biomass potentials is highlighted.

El papel creciente de los biocombustibles: Oportunidades y desafíos

Este artículo presenta una visión general sobre el potencial de la biomasa para usos energéticos y el papel que el desarrollo tecnológico puede tener en facilitar la utilización de dichos recursos. Incluye un análisis de los factores más importantes que pueden afectar la utilización de la biomasa para usos energéticos en grande escala, y al mismo tiempo analiza como evitar los aspectos más negativos. Se resumen los factores más importantes que permitan la utilización de la biomasa a gran escala bajo un punto de vista ambiental, por medio del desarrollo de instrumentos adecuados tales como criterios sostenibles y certificación. Finalmente el artículo resalta la necesidad de que el comercio internacional de la bioenergy sea de forma sustentada, que puede ser un factor clave para desarrollar el potencial energético de la biomasa.

Die wachsende Rolle von Biokraftstoffen - Möglichkeiten, Herausforderungen und Fallstricke

Diese Studie bietet eine Übersicht der weltweiten Biomassepotentiale, und beschreibt den Einfluß von Technologieentwicklung und mehrjährigen Nutzpflanzen auf die Nutzbarkeit dieser Potentiale. Es werden einige der kritischen Punkte untersucht, die bei der großflächigen Biomasseproduktion eine Rolle spielen, und gleichzeitig Lösungswege angegeben, wie diese Punkte vermieden oder gelöst werden können. Weiterhin werden derzeitige Entwicklungen beschrieben, die den „grünen" Charakter der Biomasse sichern sollen, zum Beispiel über Nachhaltigkeitskriterien und Zertifizierungssysteme für Bioenergie. Schließlich wird die Bedeutung des nachhaltigen, internationalen Biomassehandels als eine wesentliche Kraft hinter der Entwicklung von Biomassepotentialen hervorgehoben.

What are the perspectives for producing biomass for energy

In principle we categorise biomass into three categories: energy crops on current agricultural land; biomass production on marginal lands; and residues from agriculture and forestry, dung and organic wastes. As we show below, we estimate that globally, these categories may supply 200 EJ, 100 EJ and 100 EJ, respectively. [1 EJ = 10^{18} J]

Clearly, biomass production requires land. The potential for energy crops therefore largely depends on land availability, which must account for growing worldwide demand for food, nature protection, sustainable management of soils and water reserves and a variety of other environmental services. Given that a major part of the future biomass resource for energy and materials depends on these intertwined, uncertain and partially policy dependent factors, it is impossible to present the future biomass potential in one simple figure. A review of the literature on future biomass availability carried out in 2002 (17 studies in total) revealed that no complete integrated scenario assessments were available [Berndes et al., 2003]. These studies include those by IPCC, US EPA, World Energy Council, Shell, and Stockholm Environmental Institute, and arrived at varying conclusions on the possible contribution of biomass to the future global energy supply (e.g., from less than 100 EJ yr^{-1} to above 400 EJ yr^{-1} in 2050). Table 1 provides a summary of the biomass categories and biomass supply ranges as a result of various approaches and methods used by different studies. The major reason for the differences is that the two most crucial parameters – land availability and yield levels – are uncertain, and subject to widely different opinions (e.g., the estimates for 2050 plantation supply ranges from less than 50 EJ yr^{-1} to almost 240 EJ yr^{-1}). In addition, the expectations about future availability of forest wood and of residues from agriculture and forestry vary substantially among the studies.

In theory, with projected technological progress and without jeopardising the world's food supply, energy farming on current agricultural land could contribute over 800 EJ. Organic waste and residues could possibly supply another 40–170 EJ, with uncertain contributions from forest residues and potentially a very significant role for

Table 1. Overview of the global potential of bioenergy supply on the long term for a number of categories and the main pre-conditions and assumptions determining these potentials [1]

Biomass category	Main assumptions and remarks	Potential bioenergy supply up to 2050 (EJ/yr)[2]
Energy farming on current agricultural land	Potential land surplus: 0–4 Gha (Most studies find 1-2 Gha). A large surplus requires intensive agricultural production systems (i.e. modernization of all aspects). When this is not feasible, the bioenergy potential could be reduced to zero. On average higher yields are likely because of better soil quality: 8-12 dry tonne/ha/yr are assumed [3].[1Gha = 10^9 ha]	0–700 (100–300)
Biomass production on marginal lands	On a global scale a maximum of 1.7 Gha could be involved. Low productivity of 2–5 dry tonne/ha/yr [3]. The supply could be low or zero due to poor economics or competition with food production.	0–150 (60–150)
Residues from agriculture	Potential depends on yield/product ratios and the total agricultural land area as well as type of production system. Extensive production systems require re-use of residues for maintaining soil fertility. Intensive systems allow for higher utilisation rates of residues.	15–70
Forest residues	The sustainable energy potential of the world's forests is unclear. Part is natural forest (reserves). Low value: figure for sustainable forest management. High value: technical potential. Figures include processing residues.	0–150 (30–150)
Dung	Use of dried dung. Low estimate based on global current use. High estimate: technical potential. Utilisation (collection) on longer term is uncertain[i].	(0)5–55 EJ
Organic wastes	Estimate on basis of literature values. Strongly dependent on economic development, consumption and the use of bio-materials. Figures include the organic fraction of MSW and waste wood. Higher values possible by more intensive use of bio-materials.	5 – 50 +[5]
Total	Most pessimistic scenario: no land available for energy farming; only utilisation of residues. Most optimistic scenario: intensive agriculture concentrated on the better quality soils. (In brackets: more average potential in a world aiming for large scale utilisation of bioenergy)	40 – 1100 (250 – 500 EJ)

[1] The overview is based on review of 17 studies and [Faaij et al., 2000], [Smeets et al., 2004] and [Hoogwijk et al., 2005]. Where two ranges are given, numbers between brackets give the range of average potential in a world aiming for large-scale utilisation of biomass. A lower limit of zero implies that potential availability could be zero, e.g. if we fail to modernize agriculture so that more land is needed to feed the world.

[2] Where two ranges are given, numbers between brackets give the range of average potential in a world aiming for large-scale utilisation of biomass. A lower limit of zero implies that potential availability could be zero, e.g. if we fail to modernize agriculture so that more land is needed to feed the world.

[3] Heating value: 19 GJ/tonne dry matter.

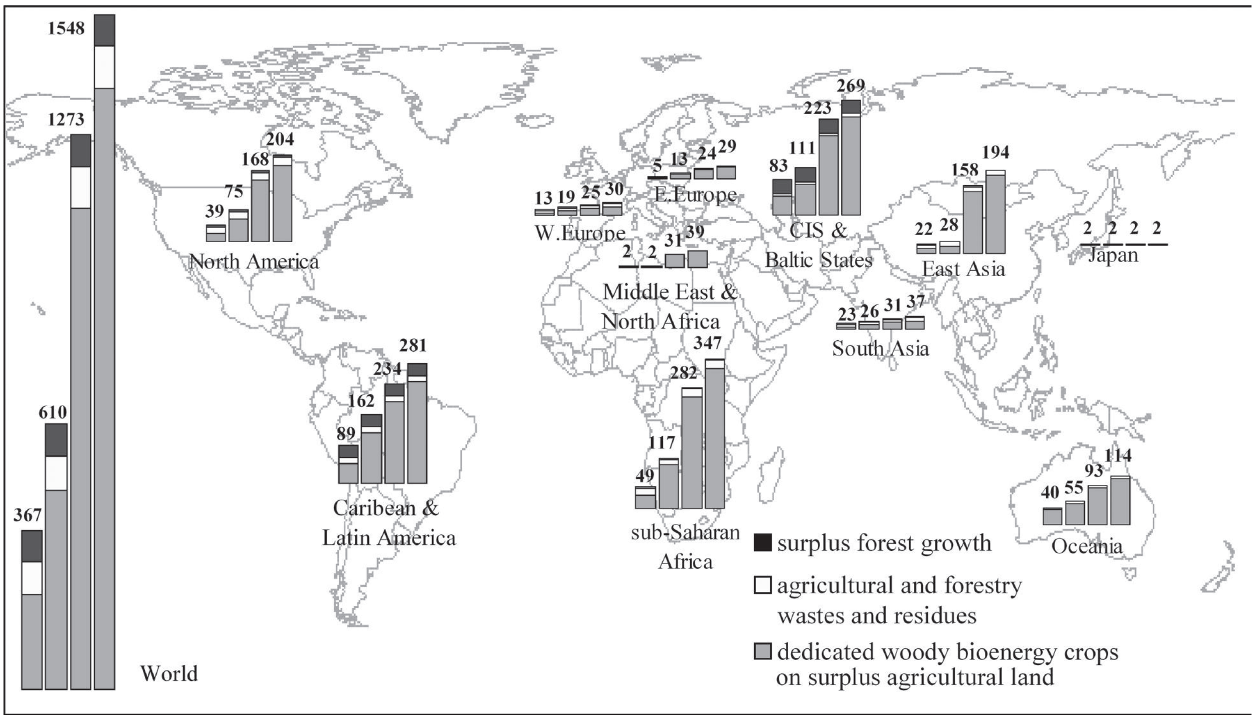
[4] Note that traditional use of dung as fuel should be discouraged. The dung potentials shown here mainly stem from intensive agriculture, which offers opportunities for fermentation and production of biogas.

[5] The energy supply of bio-materials ending up as waste can vary between 20-55 EJ (or 1100-2900 Mt dry matter) per year. This range excludes cascading and does not take into account the time delay between production of the material and 'release' as (organic) waste.

organic waste, especially when bio-materials are used on a larger scale[ii]. In total, the upper limit of the bioenergy potential could be over 1000 EJ annually. This is considerably more than the current global energy use of about 430 EJ.

How do these bottom-up potentials compare to top-down calculations on how much biomass could be produced? In the 1980s and 1990s, the late Prof. DO Hall (at the time the world's leading expert on photosynthesis), and others showed that man already appropriates c. 10% of the global net primary production (NPP) of biomass through agriculture and forestry activities. Dukes [2003] takes this analysis further and extrapolates it to say that the energy fixed through photosynthesis into biomass by this 10% appropriation is approximately equal to current global primary energy demand. Hence, by simple extrapolation, mankind would need to appropriate another 10% of the global NPP to meet a 430 EJ demand solely from bioenergy. In this discussion, it is important to point out that global photosynthetic capacity and therefore NPP is not fixed because limiting factors such as plant nutrients, water and pest and diseases can

Figure 1. Total bioenergy production potential in 2050, agricultural production systems scenarios 1 to 4. The numbers above the bars are EJ/yr. For more background information, see Table 2 and Smeets [2004].



be managed by farmers and foresters[iii].

However, the question of how an expanding bioenergy sector would interact with other land uses, such as food production, biodiversity, soil and nature conservation, and carbon sequestration has been insufficiently analyzed in these studies. A refined model of interactions between different uses and bioenergy, food and materials production, would facilitate an improved understanding of the prospects for large-scale bioenergy in the future. Recently, these issues were addressed in several studies. One approach is reported in Smeets et al. [2004] where bottom-up information was used on land-use, agricultural management systems on a country-by-country basis, projections for demand for food and information on possible improvements in agricultural management (both for crops and production of meat and diary products). Figure 1 shows the possible variation in the technical potential, assuming four different agricultural production systems (see also Table 2). In all scenarios, no food shortages occur. Scenarios 1 to 3 have in common that they are based on medium growth assumptions between 1998 and 2050 for global human population (from 5.9 to 8.8 billion people) and per capita food consumption (from 2.8 to 3.2 Mcal per person day), a high plantation establishment scenario (from 123 to 284 Mha) and a high technological level for the production of bioenergy crops. Scenario 4 is based on the assumption that research and development efforts may increase yields above the existing level of technology used in this study as e.g. in scenario 3. In scenario 4 crop yields are 25% higher than in scenario 3 due to additional technological improvements. For further details, see Smeets et al. [2004].

Other studies carried out by Hoogwijk [Hoogwijk et al., 2005], [Hoogwijk, 2004] used integrated assessment modelling to evaluate future biomass potentials for different SRES scenario's. In these analyses, Latin America, Sub-Saharan Africa and Eastern Europe are the most promising regions; Oceania and East and NE Asia also show significant potential in biomass production areas under some scenarios in the longer term. The latter can be explained by the projected demographic developments (possibly declining population in China after 2030) and fast technological progress in agriculture, leading to substantial productivity increases. These analyses also show that a large part of the technical potential for biomass production may be developed at low production costs of about 2 U$/GJ [Hoogwijk, 2004], [Rogner et al., 2000].

Technology development

While the main efficiency gains are to be found in agricultural productivity, technological developments can dramatically also improve competitiveness and the efficiency of bioenergy. These gains encompass two major components: conversion of primary biomass to final energy carriers and long distance biomass supply chains (i.e. intercontinental transport of biomass derived energy carriers) [Faaij, 2006], [Hamelinck et al., 2004]. Regarding the first component, current production of biofuels for transport is inefficient, from the perspective of the energy balance and the production per hectare. With the exception of ethanol from sugar cane, 'first generation' biofuels, such as ethanol from corn, sugar beet or wheat, or biodiesel from oil seed crops such as rape seed, typically only reach 20%–50% well-to-wheel GHG emissions reductions compared to gasoline (for ethanol) and diesel (for biodiesel) [IEA, 2004][iv]. Also, such schemes are fairly inefficient on a GJ/ha basis, and far from competitive, even with current oil prices. However, there are several 'second generation' technologies in the pipeline, such as ethanol production from lignocellulosic feedstocks, and production of biodiesel using the Fischer-Tropsch process.

These technologies can achieve higher GHG reduction rates and higher yields per hectare. Also, they will be able to convert a larger diversity of biomass feedstocks than the current first generation technologies, in particular, low cost residues. It is expected that these second generation technologies will be commercially available within the next one or two decades, i.e. in the time frame in which truly large-scale production of biofuels could take off. These aspects have to be taken into account when calculating future land-requirements. Thus, we deem calculations, such as how much the EU's land area would be needed to cover its domestic demand for e.g. biodiesel based on current rape seed yields and conversion technologies, rather misleading. Regarding the second component of bioenergy logistics, development technologies which convert low-density (both in terms of mass and energy per volume) primary biomass to high-density, high value energy carriers such as wood pellets, torrefied pellets, pyrolysis oil or even directly produced transportation fuels such as ethanol and biodiesel, will widen the possibilities of long-distance bioenergy trade and increase the competitiveness of biofuels.

Perennial crops – the way forward

Regarding the feedstock production, second-generation technologies will favor the production of perennial crops (such as eucalyptus, poplar, grasses such as miscanthus and sugar cane), as they are better than the current annual agricultural crops, economically and environmentally. Next to their better GHG performance, soil carbon improvements can be realized, while fertilizer and pesticide inputs are generally lower. In addition, a recently published article in Nature shows that actual biomass yields can be higher if a large biodiversity of perennial crops is maintained [Tilman, 2006a, 2006b]. If designed and managed wisely, biomass plantations can be multifunctional and may generate local environmental benefits. For example, willow plantations in Sweden may be used for soil carbon accumulation, increased soil fertility, reduced nutrient leaching, shelter belts for the prevention of soil erosion, plantations for the removal of cadmium from contaminated arable land (phyto-remediation), and vegetation filters for the treatment of nutrient-rich, polluted water [Börjesson and Berndes, 2006].

Short rotation woody crops (SRC) in general require fewer inputs of herbicides and pesticides. Rich et al (2001) suggest SRC plantations are generally better for a wide variety of wildlife than existing adjacent farmland around the (former) ARBRE project area (UK). When established on agricultural land an increase in biodiversity usually result, e.g. in some cases an increase in species richness occurs. SRC is generally regarded as environmentally friendly and many environmental groups view the technology favourably. Also, in the UK, large scale SRC monoculture is unlikely given the nature of land tenure. Rather, the most likely scenario may be a large number of small plots scattered over large areas.

So what are the main critical issues regarding the large-scale production of biomass for energy?

The (sustainable) use of different types of land (marginal and degraded, as well as good quality agricultural and pasture land) depends on the success of accelerating the improvements in current agricultural management practices, and integrating biomass production in a sustainable way into current land-use patterns. Our understanding of how this can be achieved from region to region is often limited. Current experiences with energy crops such as willow, miscanthus and switchgrass, is limited but can point to how biomass production can gradually be introduced in agriculture and forestry. In developing countries (e.g. in sub-Saharan Africa) very large improvements can be made in agricultural productivity[v]. However, better and more efficient agricultural methods cannot not be implemented without investments, proper capacity building and infrastructure improvements and political stability. Much more experience is needed with such schemes, in which the introduction of bioenergy can play a pivotal role to create more income for rural regions by additional bioenergy production. Financial resources generated could then accelerate investment in conventional agriculture and infrastructure and also lead to improved management of agricultural land. Critical issues that require further research and especially more regional demonstrations and experience with biomass production are:

Competition for water

Water is a critical resource for both food and biomass production and in short supply in many regions. Water scarcity in relation to additional biomass production has been addressed to a limited extent. Berndes [2002] explains that 'large-scale expansion of energy crop production would lead to a large increase in evapotranspiration appropriation for human uses, potentially as large as the present evapotranspiration from global cropland. In some countries this could exacerbate an already stressed water situation. But there are other countries where such impacts are less likely to occur. One major conclusion for future research is that assessments of bioenergy potentials need to consider restrictions from competing demand for water resources. Improved agricultural practices must enhance water-use efficiency (e.g. through breeding for drought tolerance and by using drip instead of overhead irrigation).

Availability of fertilizers and pest control

Raising agricultural productivity can only be achieved when better management and higher productivities are achieved. This implies better plant nutrition and pest control methods. Sound agricultural methods (agroforestry, precision farming, biological pest control, etc.) exist that can achieve major increases in productivity with neutral or even positive environmental impacts. However, such practices must be secured by sufficient knowledge, funds and human capacity.

Land-use planning taking biodiversity and soil quality into account

Criticism is raised by various recent studies (e.g. by the MNP [ten Brink et al., 2006] and the European Environment Agency [EEA, 2006]) that further intensification of agriculture and large scale production of biomass energy crops may result in a losses of biodiversity compared to current land-use, even when international standards for nature protection (10–20% of land reserved for nature) are respected [Smeets et al., 2004]. Perennial crops have a better ecological profile than annual crops and the benefits with respect to biodiversity can be achieved when perennial crops are displaced. However, insights into how biodiversity can be optimised and improved compared to current land-use, when sound landscape planning is introduced, are limited and urgently require R&D. Overall, experience from Sweden and the UK with integration of willow production on landscape level, indicate there is a positive effect. Sao Paulo State has strict standards for sugar cane production areas and which appear to ensure that its production does not necessarily lead to a loss in biodiversity. More regional efforts, experience and site-specific solutions are needed. Regarding improvement of soil quality, Lal [2006] shows how some biofuel plantations e.g. Jatropha, Pongamia, can contribute to restore degraded soil and sequester carbon in biota and soil.

The use and conversion of pasture land

As discussed above, much land can be released when production of meat and dairy products is done in more intensively (including partial zero-grazing). This would allow grassland currently used as pasture to be used more efficiently. Grasslands could then be used for production of energy grasses or partly be converted to woodlands. Such changes in land-use functions have been poorly studied. The impacts of such changes should be closely evaluated.

Socio-economic impacts

Large scale production of modern biofuels, could provide a major opportunity for many rural regions around the world to generate income and employment. Given the size of the global market for transport fuels, the benefits could be vast, e.g. by reducing oil imports and exporting biofuels. Nevertheless, it is far from certain that those benefits will accrue to the rural populations and smallholder farmers. Also, the net impacts for a region as whole, including possible changes and improvements in agricultural production

Table 2. Overview of assumptions for agricultural production system scenarios used by Smeets [2004]

Agricultural production system scenarios	1	2	3	4
Animal production system used (pastoral, mixed, landless)	Mixed	Mixed	Landless	Landless
Feed conversion efficiency	High	High	High	High
Level of technology for crop production[1]	Very high	Very high	Very high	Super-high
Water supply for agriculture	Rain-fed	Irrigated	Irrigated	Irrigated

[1] Scenarios are based on a plausible combination of technologies e.g. a scenario based on a high level of technology for the production of food crops and a low level of technology used in the animal production system (low feed conversion efficiencies) is considered illogical. Going from scenario 1 to 4, the efficiency of food production (expressed in hectares cropland required to meet the projected increase in consumption) increases, thus the area agricultural land claimed for food production decreases.

methods, should be kept in mind when developing biomass and biofuel production capacity. New biofuel production schemes should ensure the involvement of the regional stakeholders, in particular the farmers. Worldwide experience with such schemes needs to be developed.

Macro-economic impacts of changes in land-use patterns

Although the analyses discussed indicate that both world food demand and additional biomass production can be reconciled, more intensive / efficient land-use and additional land-use for biomass production may lead to macro-economic effects on land and food prices. Although this is not necessarily a bad outcome as it could be vital for farmers to enable investment in current production methods, the possible implications on macro-economic level are poorly understood. Again, more work is needed to identify the speed at which changes should be implemented to avoid undesired economic effects[vi].

Net GHG emissions – including indirect land-use effects

Connected to the previous issue are impacts on overall GHG emission rates related to (biomass-induced and general) changes in land-use. As pointed out previously by Cameron[vii], the pressure on land is often huge in many developing countries such as Malaysia and Indonesia, and to a lesser extent Brazil. In these cases, increasing production of palm oil and soya are one of the main drivers of deforestation, and GHG emissions arising from forest clearance by fire, and changing soil carbon stocks with different types of land use. If biomass energy crops increase pressure on land, these problems could be exacerbated, both directly and indirectly. For the direct cases, more research is required on GHG balances when perennial energy crops replace pastures, (degraded) farm land or forests – the choice of the right cropping system is crucial. Regarding the induced impacts, it is clear that land-use change patterns are complex, and that whole-system GHG emissions have to be assessed.

Tackling the issues – development criteria for sustainable biomass production

With the increasing international trade in biomass resources, concerns have been growing about whether all imported biomass streams can be considered sustainable. The production and removal of biomass can have negative impacts on ecology and land-use, as well as socio-economic impacts and GHG emissions. Recently, these aspects have been recognized by policy makers, scientists and the industry. Various preliminary efforts have been undertaken to move towards certification and track-and-trace systems for imported biomass. Examples include the development of the Green-Gold-Label, a biomass tracking system developed by Essent [CU, 2006], the FairBiotrade research project carried out by Copernicus UU (see e.g. Lewandowski et al, 2005, Damen and Faaij, 2004 and Smeets and Faaij, 2006), and various other studies on sustainability and certification of biomass (see e.g. Tipper et al., 2006; WWI, 2006; WWF, 2006 Hamelinck, 2004). Furthermore, the initiatives such as the IEA Bioenergy Task 40 on International Sustainable Bioenergy Trade (see www.bioenergytrade.org), the FAO International Bioenergy platform (IBEP) or the UNCTAD Biofuels initiative demonstrate the

Table 3. Summary of sustainability criteria, indicators/procedures and suggested levels for 2007 and 2011 [Cramer et al., 2006]. For criteria 2-6 a dialog with national and local stakeholders is required

Criterion and level	Indicator/procedure 2007	2011
1. GHG balance , net emission reduction by >=30% in 2007 and >= 50% in 2011	Use of developed methodology Use of reference values for specific steps in logistic chain	As 2007
2. Competition with food supply, local energy supply, medicines and building materials Supply is not allowed to decrease	Footnote a	Footnote b
3. Biodiversity, No decline of protected areas or valuable ecosystems in 2007, also active protection of local eco-systems in 2011	No plantations near gazetted protected areas or high conservation value areas max. 5% conversion of forest to plantations within 5 years Footnote a	As 2007 Additional obligatory management plan for active protection of local ecosystems As 2007 Footnote b
4. Wealth, no negative effects on regional and national economy in 2007, and active contribution to increase of local wealth in 2011	Footnote a, based on Economic Performance indicators of the global reporting initiative	Footnote b
5. Welfare, including		
5.a Labour conditions	Compliance with Social Acountability 8000 and other treaties	As 2007
5.b Human rights	Compliance with universal declaration of HR	As 2007
5.c Property and use rights	Three criteria from existing systems (RSPO 2.3, FSC 2, FSC 3)	As 2007
5.d Social conditions of local population	Footnote a	Footnote b
5.e Integrity	Compliance with Business principles of countering bribery	As 2007
6. Environment, including		
6.a Waste management	Compliance with local & national laws	
GAP	As 2007	
6.b use of agro-chemicals (incl. Fertilizers)	Compliance with local & national laws	As 2007 & EU legislation
6.c prevention of soil erosion and nutrient depletion Avoid plantations on marginal or vulnerable soils, or with high declivity Monitoring soil quality Nutrient balance	Erosion management plan Footnote b	
6.d Preservation of quality and quantity of surface water and ground water	Footnote a, special attention for water use and treatment	Footnote b
6.e Airborne emissions	Comply with national laws	Comply with EU laws

a For this criterion a reporting obligation applies. A protocol for reporting will be developed.
b New performance indicators will be developed for this criterion between 2007-2011

increased attention to global biomass trade and sustainability.

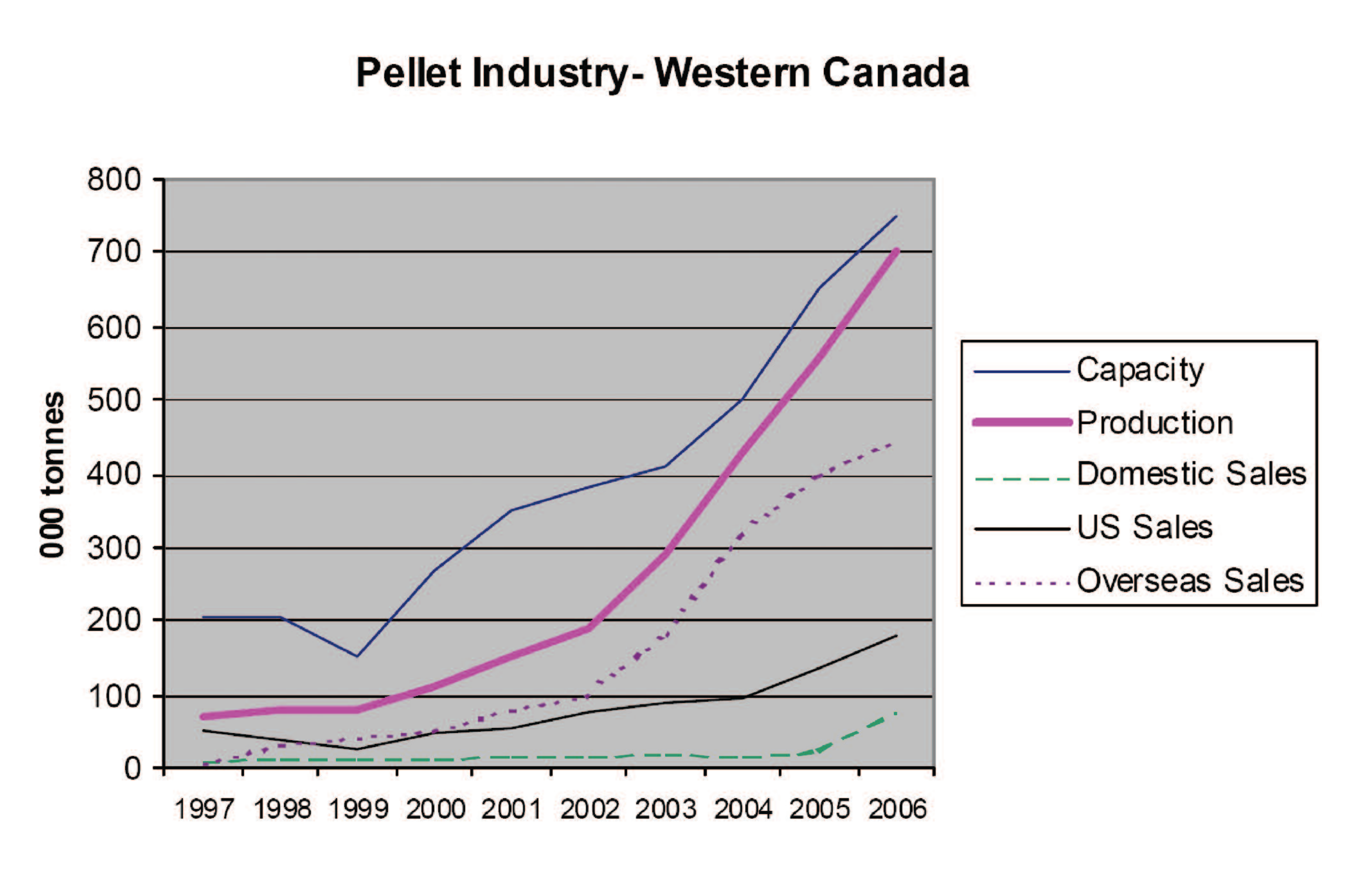
The need for biomass sustainability criteria has also been recognized in several EU countries and by different international bodies. Current examples are:

• Ongoing development of GHG and sustainability criteria for biomass transportation fuels under the renewable transport fuel obligation (RTFO) in the UK [Archer, 2006].

• Existing regulations energy/CO_2 balances and sustainability criteria for Belgian biomass for co-firing [Ryckmans, 2006]

• The EU strategy for biofuels [EC, 2006], in which standards to ensure the sustainability of biofuel feedstocks are explicitly mentioned

Figure 2. Pellet production and export in Western Canada [Bradley, 2006]



• More in general, the issues surrounding the production of palm oil in Southeast Asia and soya beans in South America have triggered the establishment of round tables where all stakeholders in the chain are represented.

The Dutch government has one of the most advanced policies for developing sustainability criteria for biomass. In the autumn of 2005, awareness regarding the necessity of biomass sustainability criteria increased when environmental NGOs condemned the use of palm oil for green electricity production in natural gas-fired power plants. While the short-term policy reaction was to reduce feed-in tariffs for palm oil, the urgent need for biomass sustainability criteria was recognized by the Dutch parliament. Thus, a commission was established in January 2006 to develop a system for biomass sustainability criteria for the Netherlands.

The main starting points of the commission were [Cramer et al., 2006]:

• Development of a long-term vision about biomass sustainability (2020-2040)

• Based on this vision, development of concrete, measurable biomass sustainability criteria in the short term

• Development of a universal framework of sustainability criteria, with the emphasis on non-food applications (chemical industry, fuels, energy production). The sustainability criteria and indicators developed could also be of importance to judge food production on sustainability aspects. It is acknowledged that biomass, feed, fuel and fodder can barely be regarded separately.

• Compliance with international treaties, EU regulations, WTO rules etc.

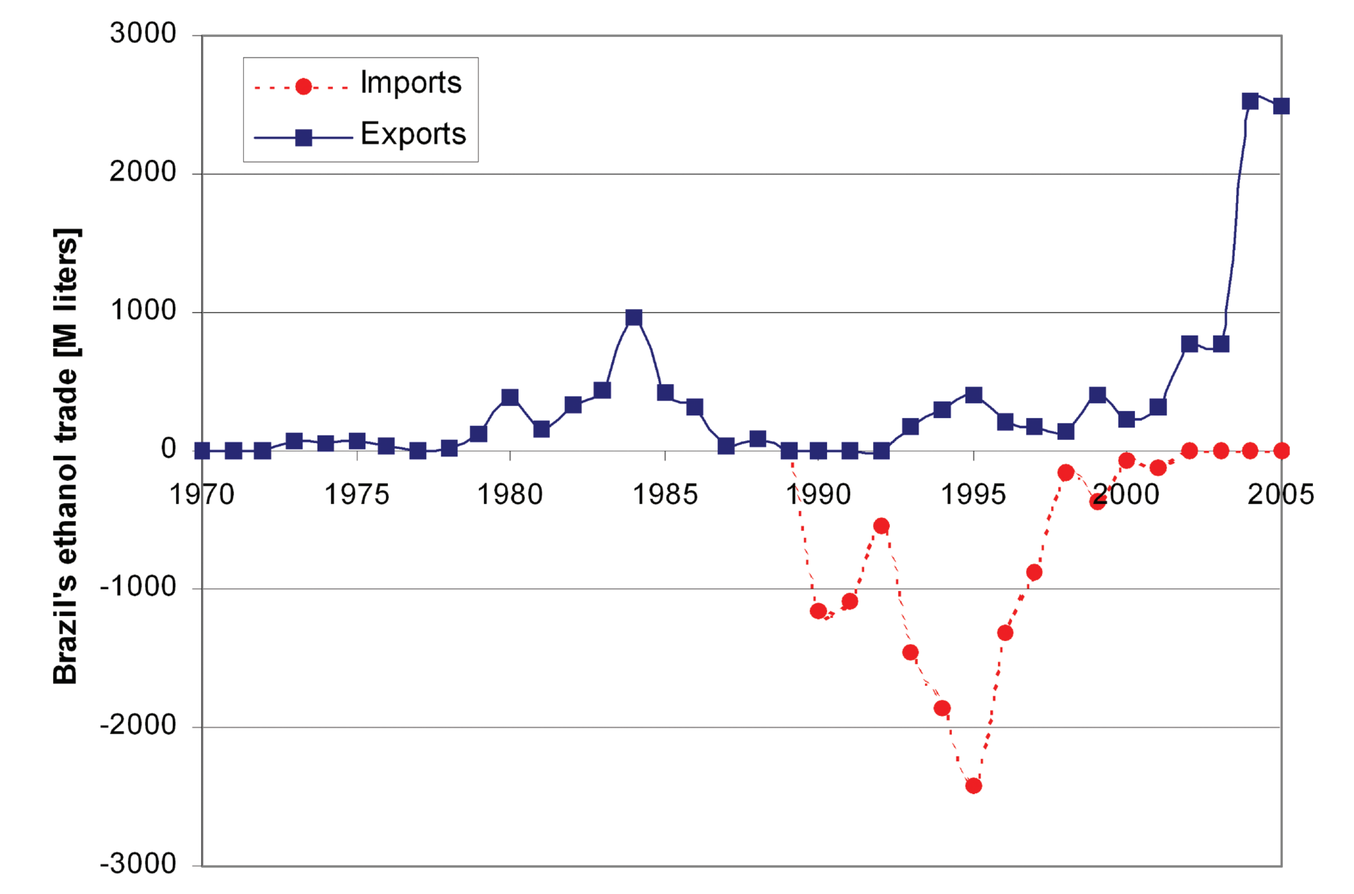
• Development of short term minimum sustainability demands and stricter criteria in the longer term

• Sustainability criteria are valid for both biomass energy crops and biomass crops, and both applicable for imported biomass and domestic biomass

Based on these starting points, consultations with Dutch stakeholders and scientific support, the commission developed a number of biomass sustainability criteria and indicators/procedures for the short-term (2007) and the medium term (2011). These included GHG reductions of at least 30% (rising to 50% by 2011), no decline of biodiversity or valuable ecosystems, prevention of soil erosion, preservation of quality and quantity of surface water and ground water increased human welfare and no reduction in food supplies, etc., see Table 3 for more details [Cramer et al., 2006].

While it is clear that for most of such criteria, indicators and procedures still need to be developed, these approaches show promise. What is more important to emphasize is that such criteria cannot be developed overnight. The procedure is to set minimum levels of sustainability criteria now, and use pilot cases to build up experience of how sustainability criteria can be met under diverse conditions. Also, the proposed sustainability goes far beyond many other sectors. This could easily backfire on biotrade if too many restrictions are put in place, making an evaluation period even more important. In addition, some sustainability criteria may actually conflict with each other[viii] and, the costs of meeting the sustainability criteria will have to be evaluated[ix] and if necessary the criteria and indicators can be adapt-

Figure 3. Trade in ethanol in Brazil 1970-2005 [Walter et al., 2006]



ed and improved. This was the approach followed in the Dutch case, and a four-year evaluation period has been established.

Finally, a crucial aspect of such criteria is enforcement. Examples from FSC-certified wood show that such systems are effective but also not flawless. Frequent field visits are vital to ensure compliance with criteria, as is stakeholder participation both during the set-up and monitoring of certification systems.

The role of international bioenergy trade

After discussing the potentials and pitfalls of global bioenergy production we want to emphasize, be it briefly, the importance of international bioenergy trade as one of the main drivers behind development of the major transitions required. As can be seen e.g. in figure 1, main supply regions are generally not situated in densely populated and highly developed areas where demand is/can be large. Bioenergy trade is developing rapidly and is already proving to be substantial as highlighted through these three brief examples:

Pellet exports from Canada to European countries and the USA. The export of wood pellets from Canada has grown exponentially in the past several years (see figure 2), primarily from the west coast. There are at least 11 pellet plants in Canada, exporting to Europe and the US [Bradley, 2006]. Expectations are that production will exceed one million tonnes in 2006.

Ethanol exports from Brazil to Japan, the USA and Europe: Figure 3 shows Brazil's ethanol trade since 1970. Market opportunities and constraints have determined exports and imports. A substantial amount of ethanol was imported during the 1990s, first during the supply shortage of ethanol (1990-1991) and second when international sugar markets were favorable for exports (1993-1997). Traditionally, Brazilian exports of ethanol have been oriented for beverage production and industrial purposes but, recently, trade for fuel purposes has increased significantly, as illustrated in Figure 3,. In 2004 exports reached 2.5 billion liters and it is estimated that almost the same amount was exported in 2005 [Walter et al., 2006].

Palm oil and palm kernel shell exports from Malaysia and Indonesia to Europe: over the last years, increasing amounts of palm kernel shells and palm oil have been co-fired in European power plants. While no exact statistics are available, substantial imports have been occurring in the UK and the Netherlands [Junginger et al. 2006, Rosillo-Calle and Perry, 2006].

These examples show how international bioenergy trade helps to cover the demand for transport biofuels and for electricity from biomass. The future vision on global bioenergy trade is that it develops over time into a real 'commodity market' which will secure supply and demand in a sustainable way. The development of truly international markets for biomass may become an essential driver to deliver the biomass potentials discussed above and exploit a resource which is currently under-utilized in many world regions. Exporting biomass-derived commodities to supply the world's energy markets could provide a stable and reliable demand for rural communities in many countries, particularly developing ones, thus creating an important incentive for rural investment that is much needed in many areas in the world. Thus, we see trade as an essential prerequisite for viable bioenergy development, with the practical monitoring of sustainability as a key factor for long-term security.

So what can biomass for energy deliver?

The techno-economic potential of biomass resources for energy and industrial materials can be very large. In theory, twice the current global energy demand, but more likely around 400 EJ, without competing with food production, protection of forests and nature. Roughly, one quarter (100 EJ) could be provided by efficiently exploiting residues from agriculture and forestry and from organic waste. Another 100 EJ could stem from the rehabilitation of degraded land. Note that these two potentials do not require additional land. The remaining half could come from dedicated energy crops on current agricultural and pasture lands, corresponding to about 1 billion ha worldwide. This is some 8% of the global land surface and one-fifth of the land currently in use for agricultural production. If the global bioenergy market is to develop to supply 400 EJ per year over this century (compared to 430 EJ current total global energy use), the value of that market assuming US$4/GJ would amount to some $1.6 trillion per year. Logically, not all biomass will be traded on international markets, but such an indicative estimate how important this market could become for rural areas worldwide.

These numbers are impressive, perhaps daunting to some. Major transitions are required to exploit this bioenergy potential, which can only be reached in the second half of this century. Improving agricultural land-use efficiency in developing countries (i.e. increasing crop yields per hectare) is a key factor. It is still uncertain to what extent and how fast such transitions can be realized in different regions. Significant problems are posed by the lack of capital, skills, land tenure, etc., all of which are major impediments to agricultural modernization. Under less favorable conditions, the (regional) bioenergy potential(s) could be quite low.

Biofuels are not the panacea for solving the global energy situation, but should be seen as part of the solution. While bioenergy can, in theory, provide a substantial part to the future global energy supply, realizing these potentials will require profound changes, especially in agriculture. There are potential alternatives to bioenergy that can also play a major and sometimes synergistic role e.g. solar, geothermal, wind, etc. Even though there are a number of critical issues involved with the large-scale production of biofuels, we also see opportunities for many countries e.g. restoring degraded soils using biomass could result in environmental gains and exporting refined biofuels can be high-value export products allowing re-investment in poor rural areas.

Ensuring the sustainability of biomass production is a major challenge, but also a great opportunity. Change means not only threats, but also opportunities. The challenge is to be able to implement the change in intelligent and benign ways. After all, this could be a first large-scale commodity market where there is a considerable scope for implementing sustainability criteria – which, in turn, could have positive impacts on food and fodder commodities. At the same time, global bioenergy trade is growing rapidly, and annual increases of 100% of traded biomass volumes are becoming reality. Therefore, the rapid early development and implementation of sustainability frameworks is crucial.

Certification, preferably starting from an internationally accepted framework but applied and verified at a regional level with strong stakeholder participation, seems to be a feasible way to achieve this. Showing best-practice operations through export-oriented pilot projects in a diversity of developing countries and different rural areas is crucial in the short term. Good examples of successful business models and sound sustainability frameworks can guide market forces in a sustainable direction. If we succeed, we may be looking at the first stages of the Green OPEC (or BIO-PEC) of the future!

Acknowledgements

The authors would like to thank Bo Hektor for valuable comments. While the authors are all members on IEA Bioenergy Task 40, the arguments and visions expressed in this article are not necessarily those of the IEA Bioenergy Agreement. For more information on IEA Task 40, see www.bioenergy-trade.org.
This paper was first published in the September-October 2006 issue of Renewable Energy World (www.renewable-energy-world.com)

Endnotes

i Note that traditional use of dung as fuel should be discouraged. The dung potentials shown here mainly stem from intensive agriculture, which offers opportunities for fermentation and production of biogas.

ii The range of the land area required to meet the potential additional global demand for bio-materials (such as bio-plastics or construction materials) was not included in table 1. The energy supply of bio-materials ending up as waste can vary between 20-55 EJ (or 1100-2900 Mt dry matter) per year. This range excludes cascading and does not take into account the time delay between production of the material and 'release' as (organic) waste.

iii For example, leaving aside (at this point) the wider environmental and social implications, well-managed sugarcane grown in Brazil's cerrados fixes between 20 and 30 oven dry tonnes (odt) of biomass per ha/yr compared to undisturbed 'natural' vegetation which could fix between 0 and 5 odt/ha/yr when mature. Land management is a crucial factor therefore.

iv Note that Brazilian ethanol from sugar cane is the only biofuel currently commercially available, which achieves much higher GHG emission reductions, i.e. 80-90% (IEA, 2004). Also other current biofuels from crops in tropical regions (e.g. biodiesel from jatropha, palm oil etc.) perform better than biofuels from crops grown in temperate regions).

v Current agricultural methods deployed in sub-Saharan Africa are is often subsistence farming, with low yields per hectare.

vi For a more detailed treatment of the biomass vs. fuel debate, see for example the SEI Newsletter [June 2005].

vii See the article of A. Cameron in March/April 2006 edition of Renewable Energy World.

viii For example modernization of agriculture may make the necessity of very hard physical labour obsolete. At the same time greater mechanization will lead to less employment.

ix Examples of other certification system show that depending on the local situation and specific criteria, additional costs may vary widely, e.g. 8-65% (Junginger, 2006).

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