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(Prepared by the Scientific and Technical Advisory Panel)

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ПРОГРАММА ОРГАНИЗАЦИИ ОБЪЕДИНЕННЫХ НАЦИЙ ПО ОКРУЖАЮЩЕЙ СРЕДЕ

Report of the GEF-STAP Workshop on

Liquid Biofuels

Version amended and adopted by STAP4

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Prepared by the Scientific and Technical Advisory Panel (STAP)
of the Global Environment Facility (GEF)

Preface

I am pleased to submit this report of the GEF-STAP Workshop on Liquid Biofuels, which was commissioned by the Scientific and Technical Advisory Panel (STAP) of the GEF. The workshop report is based on extensive debates in the panel and with leading bioenergy experts.

It focuses primarily on the GHG benefits of biofuels and on the technology aspects, and examined overall benefits of biofuels and later focused on the context of the transport sector.

The workshop examined the extent to which biofuels can contribute to GHG reductions when substituted for fossil fuels, and the case for sustainability safeguards regarding environmentally compatible and land efficient bioenergy crops. The energy relationship between growing energy crops and converting them into fuels was considered, as well as the overall efficiency of conversion.

The report also draws attention to potential impacts on food security and considers whether biodiesel or bioethanol can replace petroleum without impacting on food supplies.

In the section on the transport sector the overall contribution of biofuels to GHG emission reduction in the transport sector was compared to mitigation achieved through vehicle efficiency. GHG abatement potentials for stationary energy biomass utilization were also considered, in relation to the taking of strategic decisions on country and regional levels concerning land availability when large quantities of biomass are desired.

The conclusions from the workshop adopted by STAP, together with STAP's recommendations to the GEF are published separately.

This report is based on a workshop convened by the Scientific and Technical Advisory Panel of the GEF, led by Dr. Anjali Shanker, STAP-3 Panel member, in September 2005.

Yolanda Kakabadse
STAP Chair

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Note on this Report

The GEF-STAP (Global Environment Facility Scientific and Technical Advisory Panel) commissioned a report from Öko-Institut (Institute for Applied Ecology) on its “Liquid Biofuels Workshop” held during August 30 through September 1, 2005 in New Delhi, India.

This report was to be based on a draft report on the Liquid Biofuels Workshop which was prepared by STAP. Due to the overall interest in the workshop report, Öko-Institut was asked to work further on the report.

In doing so, Öko-Institut was to reflect on the materials presented, views expressed in the plenary and in working group discussions, and relevant referenced papers. In addition, the results of ongoing work of Öko-Institut in the area of sustainable biomass, biofuels, and transport were taken into account.

The author, Uwe Fritsche, wishes to express his gratitude to all contributors for their valuable comments, critique and helpful hints. He would especially like to thank Suani Teixeira Coelho and José Goldemberg (Brazil) and Jorge Antonio Hilbert (Argentina) for their input and detailed review, and the GEF-STAP team and secretariat for excellent contributions.

1 Introduction

The Global Environment Facility (GEF) has received a number of project proposals to support biofuels in developing countries and countries with economies in transition.

In order to clarify the potential of biofuels to reduce emissions of greenhouse gases (GHG) in the transport sector, and define selection criteria for environmentally, socially and economically sustainable projects, the GEF has requested advice from the Scientific and Technical Advisory Panel (STAP) on liquid biofuels.

More specifically, STAP was asked to examine GHG emission reductions and other environmental benefits of biofuels, as well as to evaluate the potential impact of biofuels on biodiversity, land degradation, water and food production, job creation, and to provide guidance to the GEF on biofuels.

In response, STAP convened a workshop on August 29 to September 1, 2005 in New Delhi, India. The primary focus was the transport sector, but the workshop also looked briefly at the production and use of liquid biofuels for stationary applications.

1.1 Scope of the Workshop

The workshop objectives were to provide GEF with a critical evaluation of biofuels in terms of their GHG emission reduction potential, environmental and cross-sectoral impacts and benefits, and constraints. If possible, a framework for analysis of biofuels projects in terms of their GHG emission reduction potential, environmental and cross-sectoral impacts and benefits, constraints, and economic viability was to be found.

The expected outcome was an orientation paper to set out the potential global environmental benefits and the potential impacts of biofuels on other GEF focal areas, identify gaps in knowledge and information, propose a framework and criteria for assessing the sustainability and environmental benefits of biofuel projects, as well as providing information on the state of the art of biofuel production technologies, biocrops potential, and the economic viability of biofuels. The criteria would take into account impacts and synergies with land degradation, with biodiversity issues, land and water use as well as local livelihoods and agricultural/food production. In as much as possible, other linkages were to be highlighted.

1.2 Workshop Participation

The workshop, led by STAP, was attended by experts from developing and developed countries with expertise on agriculture, biodiversity, biomass and biofuels, economics, life-cycle analysis, and transport (for a list of all participants, see Annex).

The experts came from a broad range of institutions, including universities, research institutions, international and national organizations, and NGOs.

In addition, the workshop was attended by representatives of the Implementing Agencies of the GEF, the GEF Secretariat, FAO and UNIDO.

1.3 Workshop Structure

The workshop was held over three days, preceded by a one-day open session with the participation of Government Agencies, Ministries, scientific institutions, NGOs and the private sector of India.

1.4 Technical Background Papers

In preparation for the workshop, STAP commissioned two background papers:

- a synthesis and analysis of available Life Cycle Analysis (LCA) studies related to the GHG emissions of biofuels (Larson 2005), and;
- a state-of–the–art review of feedstock and process technologies for biofuels production (Girard/Fallot 2006a).

These papers were made available to the workshop participants as drafts, and have been finalized meanwhile, and are available through the STAP website.

1.5 Availability of Workshop Material

The presentations made at the workshop, as well as the background papers are available on the STAP web site[1]. Furthermore, articles of workshop contributors can be found in a special issue of *Energy for Sustainable Development* as well[2].

1.6 Structure of this Report

In addition to the introduction, this report consists of the following parts:

- The overall background for biomass, bioenergy, and biofuels, as well as more general issues are presented in Section 2.
- The key technology issues for biofuels, the status of the respective conversion technologies, and their prospects, are discussed in Section 3
- The results of existing life-cycle analysis of biofuels can be found in Section 4, while overall environmental implications of biofuels, and a brief discussion on environmental assessment of biofuels are given in Section 5
- The economics of biofuels are discussed in Section 6
- Open questions and controversial issues are highlighted in Section 7.
- Workshop conclusions and recommendations to the GEF are given in a separate report, adopted by the members of STAP4 and referred to in Section 8.

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[1] see http://stapgef.unep.org/activities/technicalworkshops/biofuels

[2] see Coelho et al. 2006; Fallot et al. 2006; Girard/Fallot 2006b; Kojima/Johnson 2006; Lal 2006; Larson 2006; Shanker/Fallot 2006

This report closes with the references, a list of acronyms, and an Appendix with the workshop participants.

2 Background: Why Biofuels?

Biomass and bioenergy – and more specifically: *liquid biofuels* – have been the stepchild of the renewables family for long decades: who would be interested in labor-intense and smelly cooking stoves burning wood[3], or inefficient "woodspirit" trucks, if cheap and more convenient (though fossil) alternatives are available? In brief periods after the oil price shocks of the late 1970ies and the 1980ies, bioenergy and biofuels gained some interest, but just to be neglected once oil prices went down again. In the shadow of "hi-tech" prospects of solar and wind, bioenergy played a niche role[4].

The first years of the 21st century changed that due to four key issues:

- Industrialized countries are challenged to reduce agricultural subsidies, in parallel to global trade arrangements calling for an opening of their agricultural markets. Thus, non-food products like bioenergy/biofuels are seen as options to shift subsidies for farmers to less disputed areas.
- In developing and industrialized countries, the recent rise of oil prices brings back interest not only in coal, but also in renewables in general, and biomass in particular, as the latter is a potential source for baseload electricity, heating, and transport fuels available at fuel costs close to those of oil products[5]. For developing countries lacking oil resources, the oil price rise further worsened their foreign exchange burdens, and reduced affordability of modern energy for the poor even more.
- In developing and industrialized countries, security of supply became an issue: far more substantial than the debate on "peak oil", the surge of oil demand in South East Asia, and the political instability of major supply regions like the Middle East not only cause spot market turmoil which affects prices, but also concerns on the *plain availability* of oil[6]. In that respect, both domestic biomass resources, and imports of bioenergy became attractive, the latter especially from countries like Brazil.

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[3] Clearly, those who cannot afford "modern" energy carriers are tied to traditional biomass (Karekezi 2004)

[4] There are exceptions: Biogas technologies developed in the 1970ies were successfully introduced in several countries (e.g., China, Denmark, France, Germany, India), mainly for converting residues into a clean-burning gas for cooking and electricity generation. Also, efficient wood stoves are a success in various countries. Biofuels – especially bioethanol – vanished more or less until the early 2000ies, with the sole exception of Brazil.

[5] This is valid for biomass fuels for electricity generation, and heating. Biofuels for transport are usually more costly, with sugarcane-based ethanol in Brazil being a noteworthy exception.

[6] European countries were forced in late 2005 to acknowledge that security of supply is also an issue for their natural gas imports from Russia.

- Last but not least, global warming concerns call upon industrialized countries to significantly reduce their greenhouse-gas (GHG) emissions, and the flexible mechanisms of the Kyoto Protocol allow for the inclusion of developing countries in GHG reduction projects. CO_2 Emission trading in EU countries further stipulates the interest in low-GHG technologies. Bioenergy, and biofuels, are seen as prominent CO_2-neutral options in that context[7].

As a result, there is a renewed and growing interest in biomass as a renewable energy source in general, and in biofuels to substitute for petroleum-derived products in the transport sector.

2.1 Bioenergy: Where From?

The principle sources of biomass provision are the two primary economic sectors: agriculture and forestry[8]. The direct and indirect flows of biomass from these sources to the energy sector are illustrated in the following figure.

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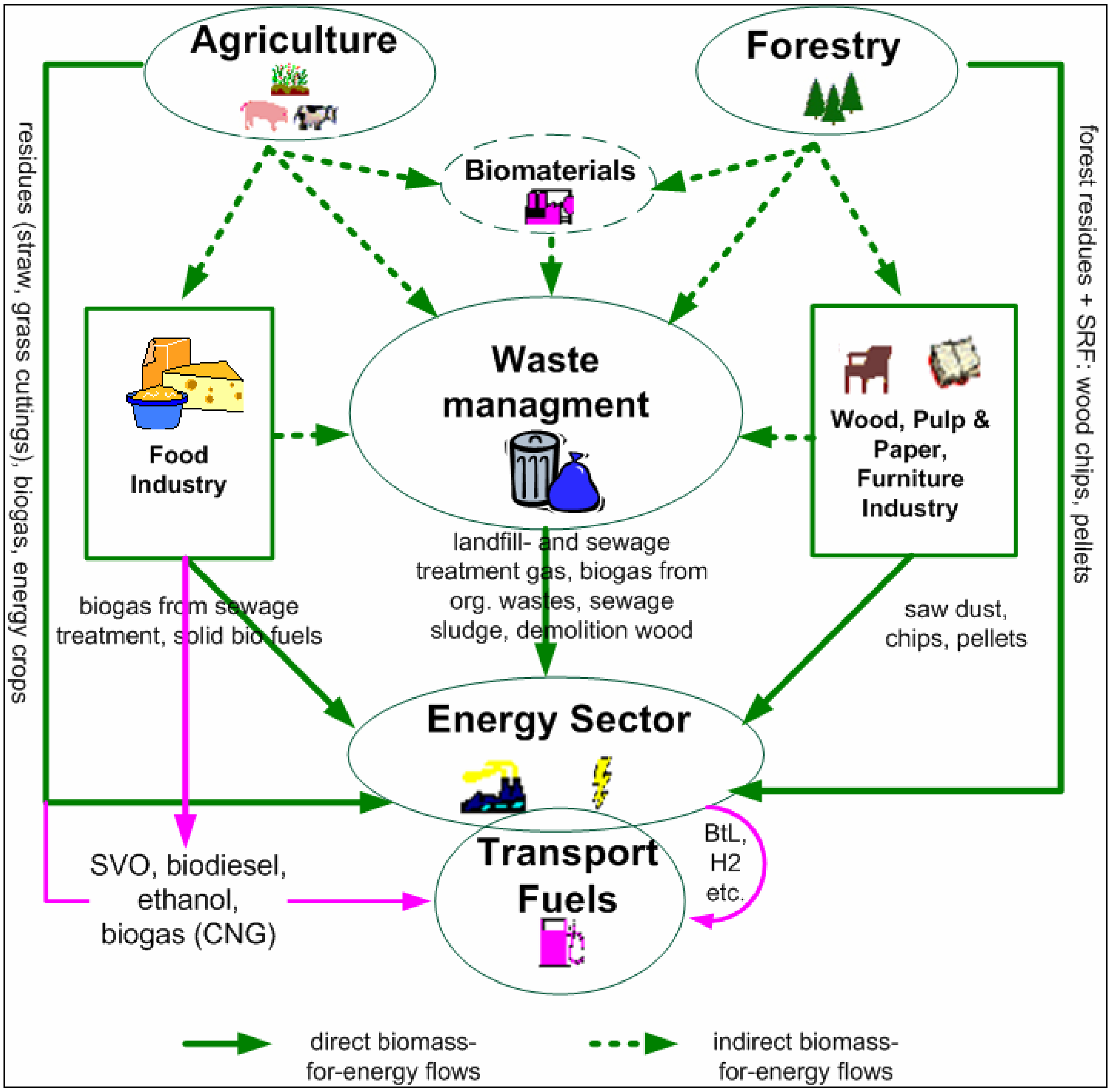
[7] Furthermore, biomass could help sequestering carbon (see Lal 2006; Smith 2004).

[8] If marine biomass would be included, the fishery sector would have to be taken into account as well.

Figure 1 Flowchart of Biomass for Energy (and Materials)



Source: Öko-Institut

The major share of today's human "appropriation" of biomass is dedicated to the provision of food, fodder, and fiber – currently, only some 10 percent of the biomass is *directly* used for energy purposes, but *residues* from agriculture and forestry and their downstream processing find their way into cooking stoves, furnaces, and powerplants.

One has to keep these figures in mind when considering the sustainability of bioenergy: *First and foremost*, the pressure on land, biodiversity, soil etc. results from *non-energy* biomass supply, i.e. (non-sustainable) agriculture, and (again non-sustainable) forestry[9].

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[9] It should be noted that about half of the global forestry products are for firewood, though (FAO 2000). Furthermore, bioenergy supply could *grow far more rapid* than traditional agriculture, or forestry – especially if fossil energy prices remain high or rise further, and revenues for agricultural and forest products continue to decrease.

2.2 Bioenergy: How Much?

Today, all forms of *bioenergy* (biomass used for energy, including biofuels) supply approx. 10 percent of the world primary energy demand, representing about 90 percent of the global contribution of *all* renewable energies (REN21 2006). While bioenergy's share *de*creased in OECD energy supply over the last decades[10], biomass is an important energy source in developing countries[11] (see following table).

Table 1 Primary Energy Demand, Renewables and Biomass in Selected Regions

Region	**total primary energy**	**total renewables**	**total biomass**	**biomass share of primary energy**
Africa	21.5	10.8	10.5	49%
Latin America	18.8	5.3	3.3	18%
Asia w/o China	48.2	16.1	15.0	31%
China	48.4	10.0	9.0	19%
Middle East	16.3	0.1	0.0	0%
CIS + Central Europe	43.7	1.7	0.6	1%
OECD	223.3	12.7	6.8	3%
World	**420.3**	**56.7**	**45.2**	**11%**

Source: OEKO (2005a), based on IEA data for the year 2000; data given in EJ/year

The major share of today's bioenergy comes from *organic wastes,* and - in a few but relevant regions – from unsustainable use of forests, and bushland, respectively.

As can be seen from the table above, most of the bioenergy today is, however, used in developing countries – and that in inefficient and polluting ways (Karekezi 2004).

Without doubt, there is a need to modernize the "traditional" use of bioenergy, and this will be facilitated by its conversion to modern energy carriers, such as liquid or gaseous biofuels, efficiently supplied heat, and combined heat & power (CHP) generation.

Given the rise in oil prices, the concern on global climate change and the relatively low commodity prices for agricultural and forestry mass products, there is no questioning that bioenergy supply and use will rise accordingly.

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[10] There are some exceptions to this trend, e.g., Austria, Denmark, Finland, and Sweden. Also in Germany, drastically higher shares of bioenergy are expected in the future (Fritsche et al. 2004).

[11] In developing countries, some 35% of primary energy comes from biomass (on average); in some African countries, even up to 90%. The energy supply of approx. 2 billion people depends nearly exclusively on "traditional" biomass (wood, manure), especially for cooking (Karekezi 2004).

2.3 Global Potential of Bioenergy

Various studies on the global bioenergy potential give a corridor of some 50 to more than 1,000 EJ – depending on assumptions for agriculture, yields, population, etc. (Hoogwijk 2004; Lal 2006; MNP 2005; WBGU 2003; WWI/gtz 2006).

Clearly, tropical regions in Latin America and Africa could become a "green eldorado" for bioenergy, as they are already for traditional agricultural products (Fallot et al. 2006a+b*)*. But also other regions of the world could grow substantial amounts of bioenergy, in addition to the potentials of bioenergy from residues and wastes.

The following table indicates the potential of biomass in year 2050. In the *most optimistic* scenario, bioenergy could supply about twice the current global energy demand, *without* violating food production, forest protection, and biodiversity. In the *least favorable* scenario however, bioenergy supply could perhaps be *even less* than today.

Table 2 Bioenergy Production Potentials for Selected Biomass Types in 2050

	Potential (EJ)	**Main Assumptions and Remarks**
Agricultural Residues	15–70	Based on estimates from various studies. Potential depends on yield/product ratios, total agricultural land area, type of production system. Extensive production systems require leaving of residues to maintain soil fertility; intensive systems allow for higher rates of residue energy use.
Organic Wastes	5–50	Based on estimates from various studies. Includes the organic fraction of MSW and waste wood. Strongly dependent on economic development and consumption, and as well as use for biomaterials. Higher values possible by more intensive biomaterials use.
Forest Residues	30–150	Figures include processing residues. Part is natural forest (reserves). The (sustainable) energy potential of world forests is unclear. Low range value based on sustainable forest management; high value reflects technical potential.
Energy Crops (agricultural land)	0–700	Potential land availability 0 - 4 million hectares, though 1–2 is more average. Based on productivity of 8–12 dry tonne/ha/yr (higher yields are likely with better soil quality). If adaptation of intensive agricultural production systems is not feasible, bioenergy supply could be zero.
Energy Crops (marginal land)	60–150	Potential maximum land area of 1.7 million ha. Low productivity is 2–5 dry tonne/ha/yr. Bioenergy supply could be low or zero due to poor economics or competition with food production.
Total	**40–1,100** **(100 –500)**	Pessimistic scenario assumes no land for energy farming, only use of residues; optimistic scenario assumes intensive agriculture on better quality soils. ( ) = most realistic for large-scale bioenergy use.

Source: adapted from WWI/gtz (2006)

The potential for sustainable bioenergy supply is in the order 5 to 10 times the present global bioenergy use, with about ¼ to ⅓ of that coming from biogenic residues, and wastes, respectively. This means that the future potential of bioenergy will be *dominated by dedicated bioenergy crops*, so that land use policies, crop variety, and farming systems and practices will be the *decisive factors* of the bioenergy's sustainability.

2.4 Global Biomass Trade

Today, biofuels developments are a result of national policies favoring *domestic* biofuels, aiming to replace oil imports, and to shift agricultural subsidies. Yet, as a consequence of the energy price and supply security developments, interest in global trade of biofuels is spreading. Brazil, in particular, could extend its ethanol exports significantly, and palmoil-producing countries are interested in biofuels exports as well.

The failure of the WTO Doha Round in opening agricultural markets of many OECD countries (as well as to restrict subsidized agricultural exports) shifts the focus of traditional farming for cash crops to dedicated bioenergy crops which have the prospect of higher revenues on international markets if converted into biofuels. IEA Bioenergy Task 40 projects a significant increase in global shipping of bioenergy for the future[12], similar to recent analysis in UNCTAD (2006).

2.5 Sustainability Issues of Bioenergy Development

Biomass for energy is seen as a major option to reduce poverty (FAO 2006), to increase income in rural regions (UNCTAD 2005), and to contribute to GHG reduction (UNDP 2005). On the other hand, serious concerns on the sustainability of future bioenergy development are raised internationally (see Section 5). As UN agencies are dedicated to sustainable development principles as expressed in e.g., the Millennium Development Goals, the UN Conventions on Biodiversity, and Climate Change, potential environment and social problems of bioenergy development need consideration by GEF. This is even more so as the various UN bodies have been called upon to "deliver as one", and to strengthen the coherence of UN activities with respect to global development goals (UN 2006).

Bioenergy offers significant *opportunities to support* sustainable development, especially in rural areas, and that bioenergy could - in comparison to fossil fuels - *reduce* GHG and air emissions if managed adequately (UNEP/DaimlerChrysler 2005).

Research in sustainable bioenergy systems is a very recent issue, though, with most studies focusing Europe and North America, and even less empirical data available. This is even more so for sustainability issues of bioenergy in developing – mostly Southern – countries where semi-arid and arid as well as tropical climates restrict the application of results from Northern countries which have different soils, climates, and use different farming and cropping systems.

To safeguard against negative social and environmental impacts of future bioenergy developments, *sustainability standards* are getting more attention. A variety of voluntary schemes like product labeling and certification, but also suggestions for internationally binding regulation, and conditionalities for (governmental) support schemes (e.g., subsidies or preferential treatment of certified products) are researched and discussed widely (OEKO 2006b).

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[12] Since the mid-1990s, biomass-related trade flows have been increasing rapidly. Many trade flows are between neighboring countries, but increasingly, long- distance trade also occurring. Examples are export of ethanol from Brazil to Japan and the EU, palm kernel shells (a residue of the palm oil production process) from Malaysia to the Netherlands, wood pellets from Canada to Sweden. For details, see http://www.bioenergytrade.org

The *financial sector* has started to look into this issue as well (DB 2005; UBS 2006), and some call for caution when considering investments in biofuels (Sarasin 2006).

2.6 The Broader Context

Before going into a more refined discussion on the biofuels technologies (Section 3), their environmental profiles (Sections 4 + 5) and economics (Section 6), two more general issues need to be addressed first:

- the theoretical competition of end-uses for biomass, and;
- the potential role of biofuels in the transport sector.

2.6.1 Biomaterials, Bioenergy, and Biofuels: Which is best for what?

As biomass is – due to its land use and competing options for using biomass – a "scarce" resource even if it is renewable, and potentials are large, its use should be *as efficient as possible*[13]. But efficiency means a ratio, so it must be defined against what biomass use is measured.

In general, efficiency of biomass use is considered in terms of overall output (of a service) against the land used for biomass supply, i.e., liters of biofuels per hectare, tonnes of biopolymers, or MegaJoules of bioenergy per hectare.

A liter of biodiesel or a ton of bioplastic can be converted into MegaJoules based on the respective heating values, but their value is not measured in energy terms, as they deliver different services, i.e. packaging, or mobility, which are different from energy services like heating, or electricity for various applications.

Therefore, the efficiency of biomass use should be measured based on terms which are comparable, disregarding the respective uses. Such terms are e.g., the reduction of GHG emissions per hectare, and the avoided units of fossil oil per hectare.

One can also use the costs of GHG or fossil oil savings, as low costs per service is an overall objective of societies. For this, combining GHG balances (Section 4) with economic performance (Section 6) of biofuels gives specific GHG reduction costs which can be a suitable efficiency criterion to compare biomass use across sectors, and applications[14].

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[13] As indicated in Section 2.3, the major share of the global biomass potential comes from dedicated energy crops, so that only those are considered here. But in principle, the argumentation holds true also for biomass residues, and wastes, respectively, where the reference would not be a hectare of biomass production, but a tonne of residues or wastes used.

[14] During the GEF-STAP Liquid Biofuels Workshop, some data was given for the GHG reduction costs in the transport sector, which included data for biofuels in comparison to other GHG reduction options (Friedrich 2005). Similarly, ongoing research for the EU-25 countries (ISI/EEG 2006) and for Germany (Fritsche 2004 + 2006) is concerned with the "optimal allocation" of biomass to the electricity, heat, and transport sectors. As this is data for the circumstances in industrialized countries, but the GEF interest is on developing countries, it is not included in this report. Interested parties are referred to the indicated literature.

Such comparisons are helpful, as they give a *first orientation* on the relative attractiveness of the various biomass use options, but they are *insufficient for policy decisions*, as biomass uses have far more implications that GHG reductions, and cost balances: The potential positive trade-offs like e.g., reduced air emissions (especially SO_2), job creation, and rural development etc. must be considered as well as potential negative impacts (see Section 5).

Only *integrated analyses of multiple biomass uses* which factors in cross-sectoral implications, and which consider *interlinkages* between e.g., air pollution, biodiversity, climate change, economics, land and water use, social development, soil conservation etc. would be a sufficient base for decision-making on the policy level (Fritsche 2005).

From a more pragmatic point of view, decision-makers will consider also that

- biomaterials in principle *do not compete* with bioenergy/biofuel use, as their heating value can be "recycled" at the end of the product life[15],
- "next" generation biofuel technologies (see Section 3.2), and advanced stationary biomass conversion might well "co-develop" into hybrid schemes (see Section 3.3), and, finally,
- the "scarcity" of biomass resources is an *anticipated*, not a current issue. Therefore, in the next years one can develop *all biomass uses in parallel*.

2.6.2 The Potential Role of Biofuels in the Transport Sector

The transport sector is expected to cause the major share of future increases in oil demand, with the largest growth from non-OECD developing countries (see figure below).

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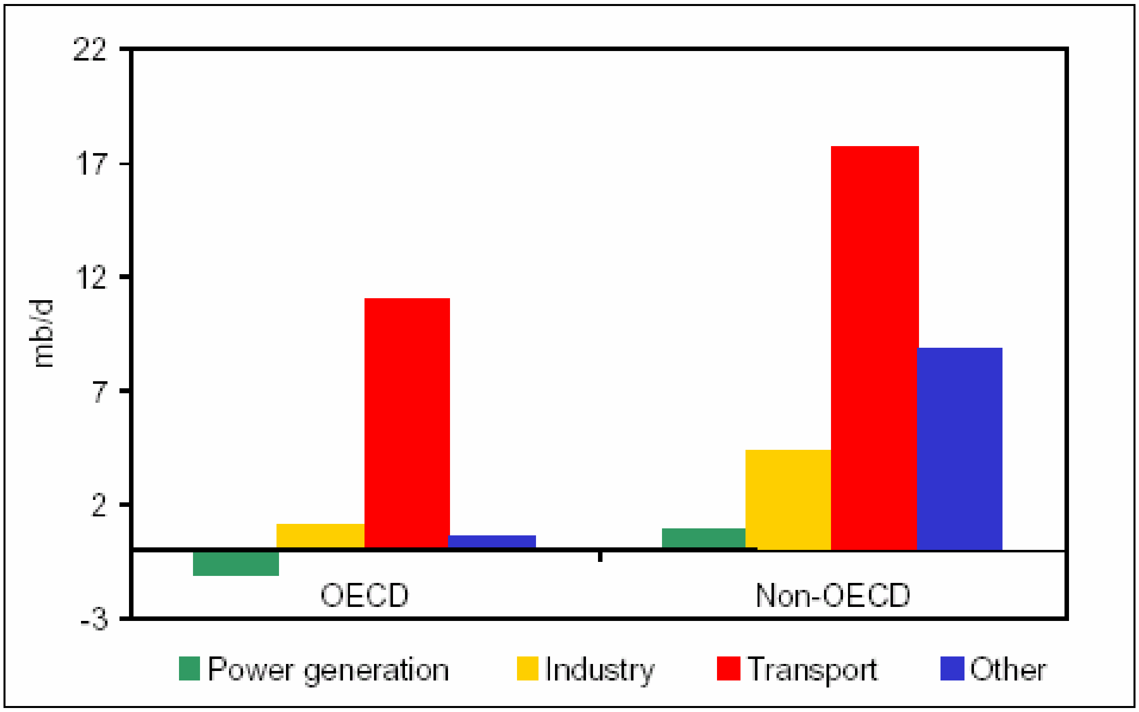
[15] This is valid for *non*-dissipative biomaterial use, i.e., for uses where biomaterial is available in a physically concentrated ("bulk") form. This is the case for most uses (bioplastics, construction materials, furniture, paper, etc.). Only few applications (e.g., biolubricants, detergents) are dissipative so that the biomass of the material cannot be recycled.

Figure 2 Increase in World Oil Demand, 2002 – 2030



Source: Girard/Fallot (2006a), figure taken from IEA (2004)

As security of supply concerns focus on oil, the transport sector is a key area of potential oil reductions, and near-term alternative fuel options are few[16].

If the IEA projections would become reality, though, the transport sector may become responsible for almost ⅓ of the *future growth* in global GHG emissions (see next figure).

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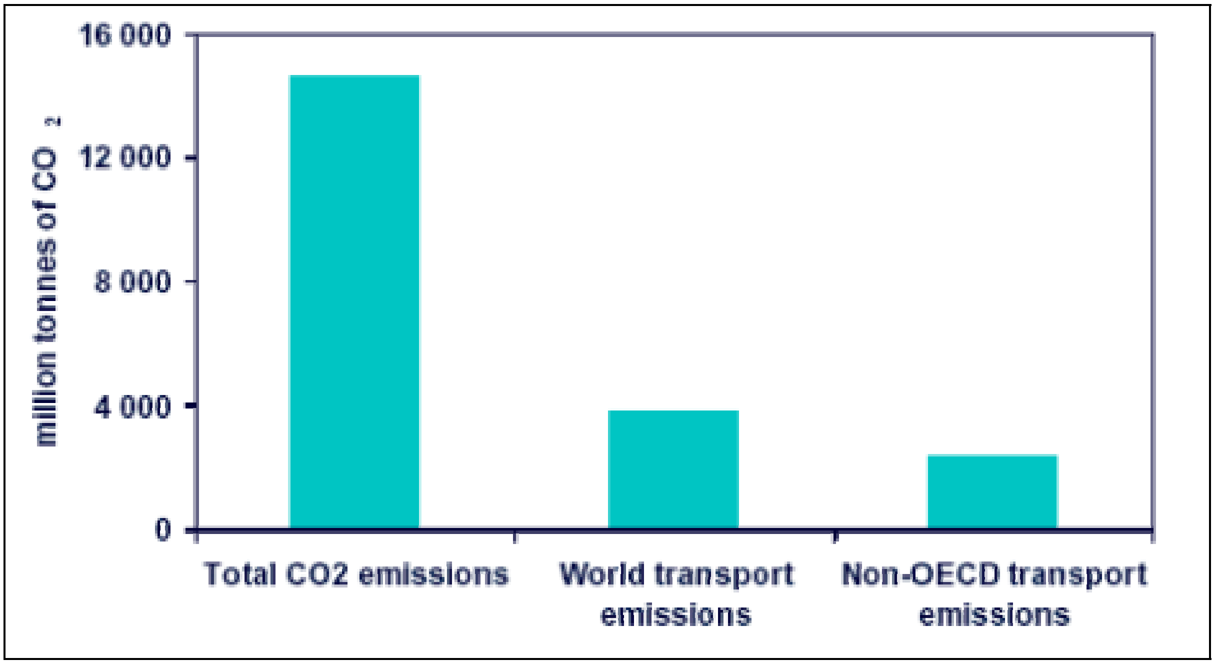
[16] Clearly, fossil oil for gasoline and diesel can be saved as well if less transport fuel is needed, i.e. if more efficient transport modes (fuel-efficient cars) and modal-splits (public transports, etc.) are used, and mobility demand itself might decrease in the longer-term through better spatial planning, home office developments and virtual meetings. Similarly, more efficient logistics and freight transport modes could significantly reduce oil use in the transport sector.

Figure 3 Incremental CO_2 Emissions in the Transport Sector, 2002-2030



Source: Girard/Fallot (2006a), figure taken from IEA (2004)

It is thus critical to explore options for GHG emission reductions in the transport sector.

As a prerequisite for a globally sustainable transport system, the *decoupling* of mobility services from the use of non-renewable resources (e.g. fossil fuels) is needed. From that point of view, GHG emission reduction options in the transport sector include:

- increased end use efficiency in vehicles (airplanes, buses, cars, ships, trains, trucks),
- shifts towards low-emission transport modes (high-occupancy vehicles, efficient logistics, public transport),
- use of sustainable biofuels, and
- use of fossil-fuel derived synfuels and/or electricity from systems using CCS[17].

Scenario analyses for industrialized countries show that raising fuel efficiency far beyond a business-as-usual path is the most cost-effective option to reduce GHG emissions in the transportation sector, followed by a gradual raise in alternative fuels (i.e., biofuels, de-carbonized synfuels).

The relative contribution of all options depends on whether they can successfully be implemented, i.e., to the extent that efficiency strategies fail to deliver, and fuel substitution becomes more important.

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[17] CCS = carbon capture and storage which is under developments. CCS could be applied also to sequester C from biomass.

Among the biofuels options, 2nd generation biofuels may become highly interesting within a 10-15 year time horizon.

GHG emission reductions from biomass use e.g. in stationary energy systems (e.g. combined heat and power) might offer higher and more cost-effective GHG abatement potentials than biofuels.

Still, in the 5-10 year time horizon, the energy uses of biomass will predominantly remain in the areas of co-firing and cogeneration which will be based mainly on low-cost biomass resources (i.e., residues and wastes) which *cannot* be converted to biofuels with 1st generation technologies.

Furthermore, as with the case of bioethanol in Brazil, the GHG reduction cost in the transport sector could become zero or even negative.

The GEF-STAP report for the Third GEF Assembly in 2006 concluded in that respect:

Given the tremendous growth in demand for energy services, in all sectors (transport, buildings, and industry) it is essential to focus on energy efficiency, as much if not more on clean production (…)
Modernization of biomass (its conversion to modern energy carriers such as electricity and liquid/gaseous fuels) emerged as a theme of very high potential and requiring more effort, through its many different applications – biofuels, electricity, but also as an input for heating applications. Resource productivity can thus be increased and risks reduced, for example import dependency, and resource conflicts in the oil and gas markets" (GEF-STAP 2006).

It seems reasonable to consider efficiency in the transport sector, and biofuel development *not* as competing either-or options, but as key elements of a sustainable transport strategy which must be implemented *both* (WWI/gtz 2006).

3 Biofuels: From Ethanol to BtL?

In the following, the status of technologies to convert biomass into biofuels is discussed, and conclusions on their future global prospects are drawn[18].

The sugary, starchy or oily biomass used for 1st generation biofuels can be grown on *annual* (e.g. beetroots, cereals, rapeseeds) or *perennial* (e.g. sugarcane, palm tree) crops.

Except for non-edible oils (e.g. Jatropha), those crops are also food crops.

The table below with indicative numbers on biofuels yields illustrates the large range of yields, even within one biofuel option.

Yields depend on agricultural production techniques associated with the natural conditions and the level of inputs.

Table 3 Indicative Bioenergy Yields per Hectare Land Use

gen.	Biofuels	l/ha	GJ/ha
1st	**biodiese**l from		
	sunflower	1,000	35.7
	soybean	500-700	17.8- 25.0
	rapeseed	1,200	42.8
1st	**ethanol** from		
	wheat	2,500	53
	maize	3,100	65.7
	sugarbeet	5,500	116.6
	sugarcane	5,300-6,500	112.4- 137.8
2nd	FT biodiesel eucalyptus plantation	13,500-18,000	463.1- 617.4
	Methanol eucalyptus plantation	49,500-66,000	772.2- 1029.6
	DME eucalyptus plantation	45,000- 60,000	846.0- 1128.0

Source: adapted from Girard/Fallot (2005)

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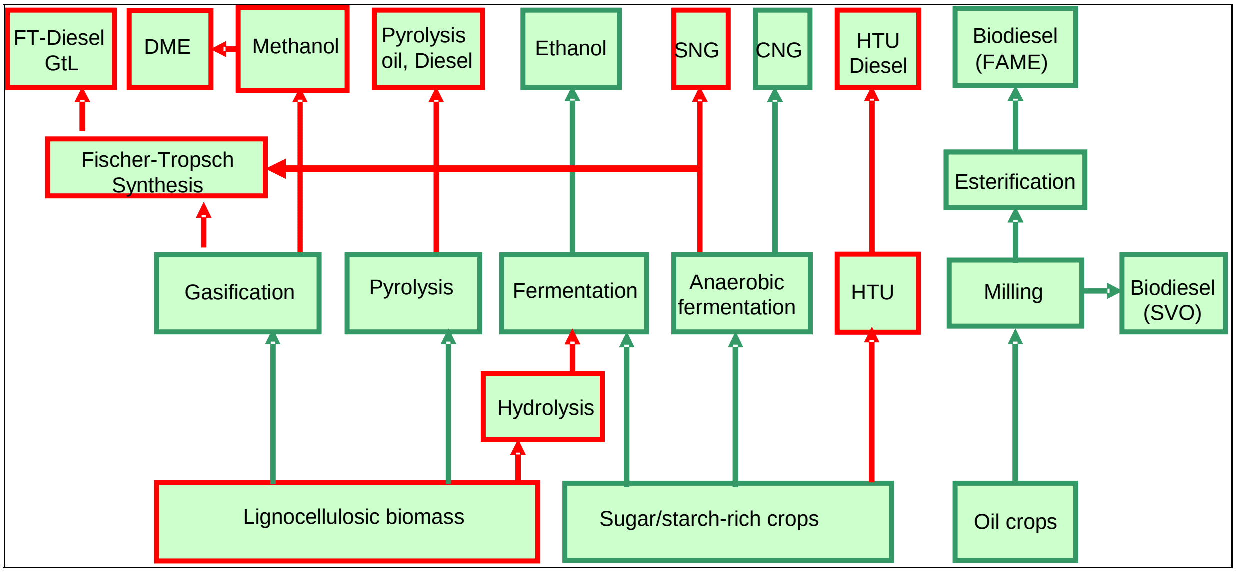
[18] For the technology status of bioenergy in stationary applications (electricity and/or heat), see OEKO (2006c).

Figure 4 Current and Future Biofuels Production Routes



Source: adapted from Girard/Fallot (2006a); **green boxes** and **green arrows** depict 1st generation biofuels, **red boxes** and **red arrows** indicate next generation biofuels

The figure above - read from bottom to top - illustrates the diversity of pathways (conversion routes) for producing transport fuels out of biomass and the differences in maturity of biofuel options.

Technological choices including scaling are not purely technical based on expected performances (yields and learning curve) but are quite specific to the feedstock available, agricultural production techniques, market access, the business model considered and the initial support and incentives envisaged (tax exemptions, collaborative R&D, concessionary finance, employment schemes).

3.1 The 1st Generation of Biofuels

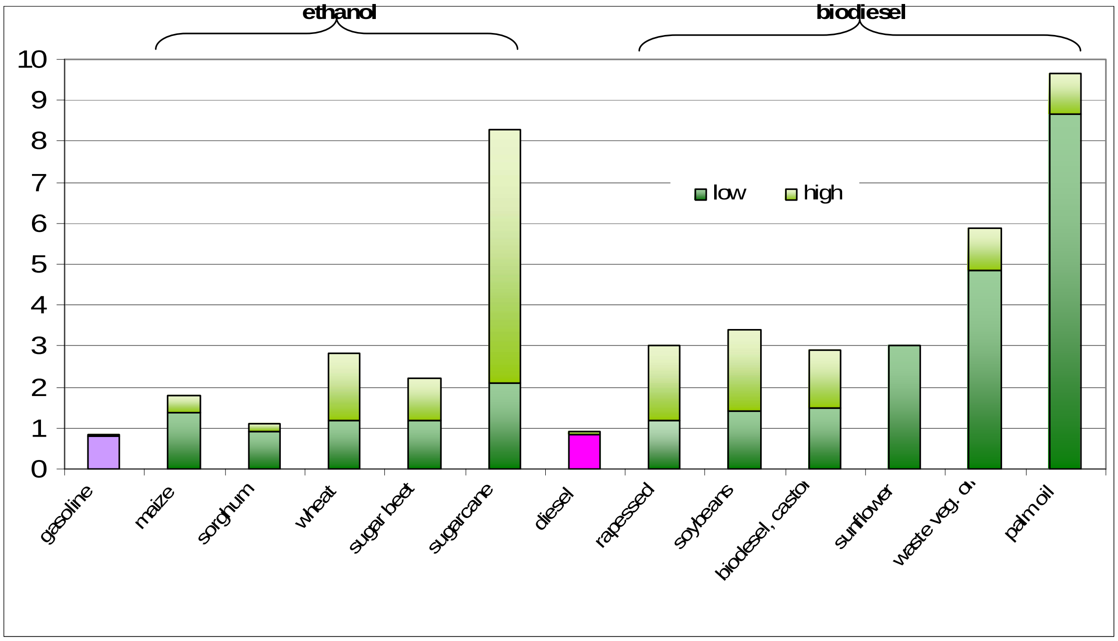
Biofuels such as ethanol from fermenting starch- or sugar-rich plant material, straight vegetable oil (SVO) and biodiesel are called *1st generation* because these technologies already exist, have proven efficiencies, and are used in several countries with at least some understanding of their economics (see Section 6).

Ethanol from biomass as a substitute for or additive to gasoline is currently the dominating biofuel on the global scale. Suitable feedstocks contain high shares of sugar, or starch which is catalyzed into simple sugars, and then fermented into ethanol.

Biodiesel as a substitute for or additive to fossil diesel needs oil-containing plans as feedstock.

The yields of bioenergy crops used for 1st generation biofuels are given in the following figure which includes the (fossil) energy inputs needed to seed, harvest, and process the crops, and also auxiliary inputs like agrochemicals, transport fuels, etc. Note that these “net” outputs depend significantly on regional and technology details (see Section 4).

Figure 5 *Ranges of Net Energy Yield Factors from Bioenergy Crops, and Fossil Fuels*



Source: adapted from WWI/gtz (2006); data give the ratio of energy output per unit of **fossil** energy input

As can be seen from this figure, the term "1st generation" includes biofuels which have very different net energy yields, so that there is a need for differentiation. Sugarcane ethanol and biodiesel from palm oil are attractive biofuel options from a net energy yield perspective[19].

3.1.1 Ethanol from Sugarcane: The Case of Brazil

Sugar cane is the feedstock that already provides a large amount of ethanol in Brazil[20]. The question whether the ethanol program in Brazil can be replicated or not was a central question of the GEF-STAP workshop. The text in the box below is an excerpt from a World Bank draft report (World Bank 2005)[21].

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[19] Palm oil today comes to more than 80% from Indonesia, and Malaysia where oil palm cultivation covers some 2 percent of total land in Indonesia, and some 12 percent in Malaysia (CSPI 2005).

[20] Brazil exported two billion liters of ethanol in 2005, making it the world's largest exporter (Coelho 2006). To keep pace with the demand, ethanol production would have to increase by some 20% until 2010, putting pressure on land and on transport infrastructures (Neuhaus, 2006). Experience with Brazil's Proalcool program in the 1980ies showed that a rapid expansion of production can lead to severe environmental problems. But since, according to Kaltner et al. (2005), improvement in legislations and environmental enforcement, the problems faced in the early day of Proalcool, has been minimized. Especially the phase-out of pre-harvest burning gives significant environmental benefits, such as elimination of air emissions, and reduced risks of forest fires (Pinto et al. 2001). The expansion of agriculture in the last 40 years has occurred mostly in degraded areas of pasture, not in areas of forest. The expansion of sugarcane plantations into the *Cerrado* was small so far (Kaltner et al. 2005).

[21] Note that this report was reviewed by several experts (e.g., OEKO 2005b), and discussed intensely during the workshop. So far, the report was not released in a final form.

In Brazil, thirty years after the Alcohol Program started, the biofuel experience appears successful and important in many respects, namely volumes reached and costs relative to oil fuels, but also and progressively, environmental performance. The GHG benefits are positive in the case of sugarcane, and production costs were brought down to the point where unsubsidized bioethanol became competitive with gasoline, with a $35-50/bbl world oil price. [22]

The uniqueness of the ethanol program in Brazil must be stressed, however. The price of sugarcane in Brazil is much lower than in other major sugar producing countries, because of exceptionally favorable climate and soil conditions making irrigation hardly necessary. The Center-South region of Brazil is not only endowed with plentiful land, rainfall, and other favorable climatic and soil conditions, but it also has good infrastructure, a functioning capital market, and a sugar industry structure that enables cooperation among various players along the supply chain to achieve high efficiency and low cost. To date, none of the leading sugar-cane producing countries have been able to achieve the same low cost of production as the Center-South region of Brazil. More than one-half of the total world sugar production occurs in areas where the cost of production is close to three times that in Brazil. The sugar industry in Brazil has reached a high level of control of biomass planting, harvesting and logistics, diversifying species for instance and finally ensuring stability in volumes and prices against variability of production conditions.

The World Bank report cited above underlines that replication of the Brazilian ethanol development requires careful consideration of the conditions in other countries. It has been stressed during the workshop that the "uniqueness" of the Brazil case is arguable, as South-South technology transfer could translate the "downstream" conversion technology to other countries, and that the sugarcane production levels in terms of yields and costs might be transferable to other countries as well, as similar climate conditions exist in other parts of the world.

3.1.2 Ethanol from other Crops

Other 1st generation ethanol conversion processes use crops like cassava, maize (corn), sorghum, and wheat[23], as well as potatoes, and sugar beets. So far, their GHG balances (see Section 4) and economics (see Section 6) are not very promising, though, but experiences from countries such as Thailand (JGSEE 2006) indicate opportunities for further improvements.

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[22] $35 a barrel assumes *no* fuel economy penalty although ethanol contains 1/3 less energy. $50 a barrel assumes that a 30% fuel economy penalty is associated with ethanol use, as compared to fossil gasoline. For details, see WB (2005).

[23] There are far more plant species which could be suitable feedstocks for ethanol production, including perennial crops, but their yields, costs, and farming features are not well know (see EEA/JRC 2006).

3.1.3 Biodiesel from Oil Plants

1st generation *biodiesel* uses oilseed-yielding plants like castor, cotton, jatropha, palm, rape, soy, etc. from which straight vegetable oils (SVO) can be derived by physical and chemical treatment (milling/refining)[24]. SVO can then be processed further into fatty acid methyl esters (FAME), also known as biodiesel. Another route for biodiesel is to "hydrotreat" unprocessed bio-oils (from castor, cotton, palm, soy etc.) so that no transesterification is needed[25].

Access to markets is often a problem, namely in marginal areas supplying oilseeds or oil with variable yields and quality. Even with better secured volumes and quality, price volatility remains a characteristic of vegetable oils, making the business risky and inaccessible to small-scale production units with low investment capacity. Some demonstration is still needed on how to support the necessary investments to secure security of supply, including storage facility, training on quality, diversification of feedstocks and of their uses (food, medicine, energy).

With the right business models in place, possibly with government support in capacity-building and environmental issues, market aggregation could be achieved, allowing small-scale to reach larger development impacts.

3.1.4 Biofuels in Developing Countries: Sugarcane, Palm Oil, and More

Technological know-how and experience in biofuels differ widely in developing countries. With the exception of a few countries such as Brazil, countries with large potentials are not those who are developing biofuel technologies and conducting research most actively. Technology transfer and assistance should allow countries with potentials to benefit from know-how and experience gained in other countries. However, biofuel technologies are quite specific to each country, and are determined by its biomass feedstocks available, its infrastructure, its institutions and existing activities involving biomass exploitation. Unless a country with potentials is associated early enough in technology development, its own specifications might not be sufficiently taken into account for the transferred technology to be appropriate.

Sugarcane-based ethanol and biodiesel (SVO or FAME) from palm oil have already very high yields, so that these biofuels offer the best near-term perspectives for developing countries with adequate climate, soils, and infrastructure. For industrialized countries, options to grow these plants are few, so their interest goes clearly into the 2nd generation biofuels.

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[24] SVO is a basic energy carrier that can be used for many purposes including biodiesel production. It has no specific scaling constraints and is thus appropriate for decentralised production, and a good alternative for fossil and wood fuel, with ancillary income-generating benefits at the local level.

[25] Brazil's Petrobras introduced recently such a fuel called "H-Bio".

3.2 “Next Generation” Biofuels

In the last decade, other options for biofuels were researched, and for two “new” conversion routes, there are currently pilot plants in operation – but still far away from being commercially available. All options are at an experimental stage and could enter the market at best within 5 to 15 years if corresponding investments are made (Girard/Fallot 2006 a+b; WWI/gtz 2006).

These “next” or 2nd generation biofuel technologies differ fundamentally in their technology, but are similar in the following respects:

- To extend the biofuel yield, the *whole plant* material is to be used as a feedstock.
- The feedstock is to come from “non-food” perennial crops (in principle, woody biomass and tall grasses) and lignocellulosic residues and wastes (e.g. woodchips from forest thinning and harvest residues, surplus straw from agriculture)[26].

Cellulosic biomass from fast-growing perennial crops such as “short-rotation” wood and tall grass crops can be grown on a wider range of soil types than 1st generation feedstocks (some even on marginal or degraded land), and require less agrochemical inputs. Furthermore, the root systems of perennials remain in place after harvest so that these crops, compared to annual ones, reduce erosion, and could increase carbon storage in soil. However, high biomass yields will only be achieved on good soils with sufficient water supply.

Table 4 Characteristics of Selected Bioenergy Crops for 2nd Generation Biofuels

Energy Crop	**Rotation**	**Annual Yield (dry t/ha)**	**Suitable Climate**
Willow	3–4 years	10 to 15	cold, wet
Poplar	8–10 years	9 to 13	temperate
Miscanthus	annual	10 to 20	temperate and warm
Switchgrass	annual	12 to16	temperate

Source: adapted from WWI/gtz (2006)

Cellulosic biomass as a feedstock for “next” biofuels is promising, but is more difficult to break down and convert to liquid fuels than sugar, starch and oilseed crops (see Section 3.3). The following figure shows routes to convert *whole-plant* material or residues into products.

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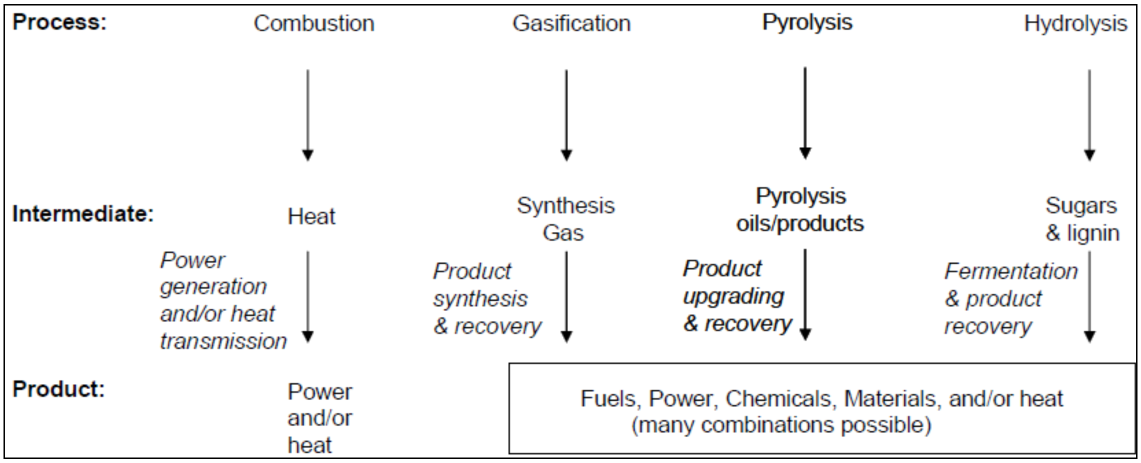
[26] Residues are either primary, secondary or tertiary, depending on their release (after biomass harvest, during processing, or after end-use respectively). Given soil fertility requirements, primary residues should considered available only if their use can be fully compensated by fertilizer inputs.

Figure 6 Traditional and New Lignocellulosic Conversion Routes



Source: WWI/gtz (2006)

3.2.1 The Biochemical Route: Lignocellulosic Ethanol

One of the two “next” generation biofuel technologies options is to upgrade existing processes of fermenting sugars. The key is to use enzymatic-enhanced pre-treatment of (hemi)cellulose. This requires GMOs to provide for the needed enzymes, and sophisticated process controls.

3.2.2 The Thermochemical Route: BtL

The other “next” generation option is to completely break down biomass by means of thermal gasification, and then to synthesize biofuels using the Fischer-Tropsch process. This route is called “biomass-to-liquid” (BtL), and discussed further in Section 3.3.

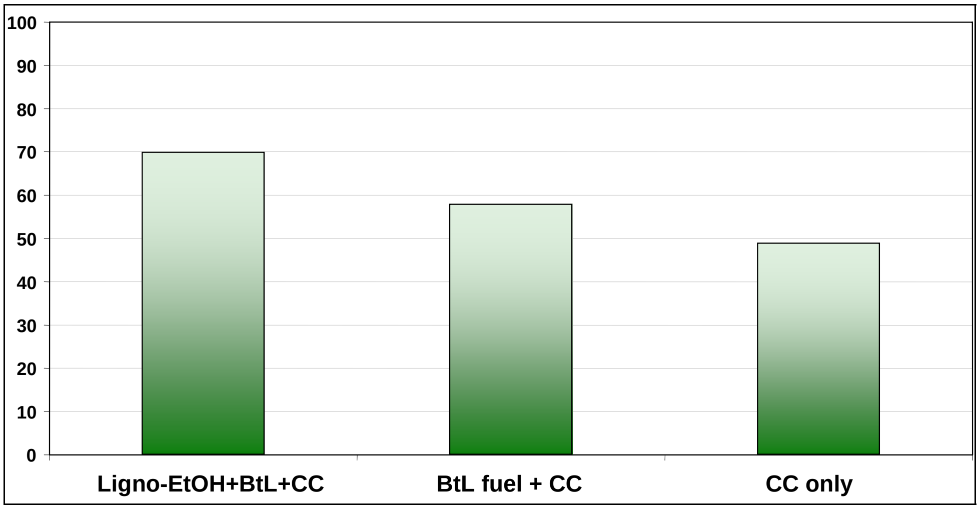
3.2.3 Competitors: Pyrolysis, HTU, and More

Other RTD efforts for “new” biofuels focus on pyrolysis, including “flash” or “fast“ processes for wet biomass without pre-drying. Similar efforts concentrate on hydrothermal upgrading (HTU). Other research aims to convert solid biomass into a natural-gas equivalent called substitute natural gas (SNG), while some even target hydrogen (H_2) as the key output product.

3.3 Hybrid Concepts and Biorefineries

Biomass from residues and crops can be converted not only into biofuels for electricity, heat and transport, but also to *biochemicals and biomaterials* which are nearly equivalent to those derived from fossil hydrocarbons. As the distinction between biofuels for electricity and heat on the one side, and biofuels for transportation on the other becomes obsolete with the evolution of technologies for feedstock conversion, *combinations* of 1st and 2nd generation conversion routes, and technological coupling of biofuel and electricity conversion ("hybrids") are potential options in the near future: Instead of optimizing for one output, the relative strength of each route can be brought together into new configurations with higher overall efficiency. Electricity generation with combined-cycles (CC) can be combined with BtL plants, and integration with lignocellulosic EtOH could yield even higher efficiency (following figure).

Figure 7 Processing Efficiency (in Percent) for Three "Hybrid" Scenarios



Source: adapted from WWI/gtz (2006)

The use of biomaterials has a far longer tradition than the conversion of biomass to bioenergy, and biofuels[27]. Two examples are the use of wood in the pulp and paper industry for cellulose fibers and polymers, and the use of plant oils for lubricants and surfactants. In going beyond hybrid schemes, full *biorefineries* have been conceptualized which would integrate also biomaterials in the product portfolio of biomass conversion (see following figure).

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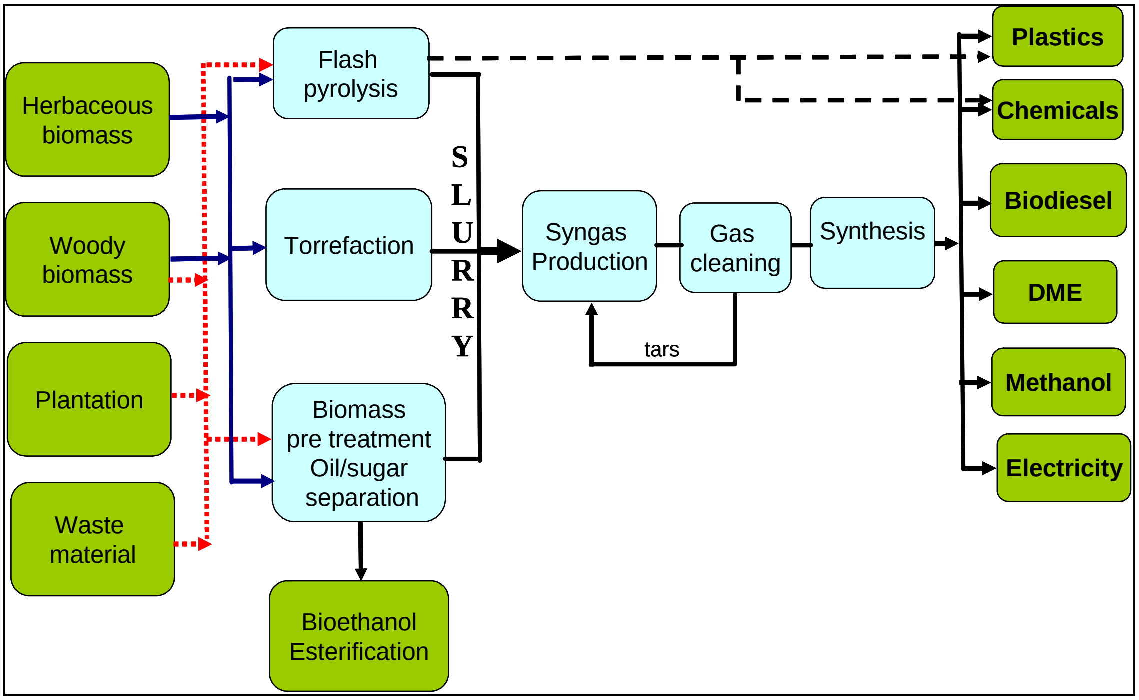
[27] Before 1900, a large share of the chemical "industry" was based on biomass; it served as a feedstock for chemicals from wood, sugars, starches, and fats. The convert these feedstocks into useful chemicals, mainly fermentation, and thermochemical processing was applied. For a discussion of the current status of biorefineries, see EC/DOE 2005.

Figure 8 Biorefinery Integrated Approach



Source: Girard/Fallot (2006)

The bio-plastics and products from biochemicals could, after their end-of-life, be further re-used to “feed” biorefineries as biogenic wastes, which would nearly close the material cycle. Still, one has to consider that “full-scale” biorefineries are still just a concept needing further development, and that implications for developing countries are rather unclear (OEKO 2006c).

3.4 Biogas: an “in-between” Biofuel?

In addition to the liquid biofuels discussed before, another biofuel option needs attention: Biogas can also be upgraded to SNG, and compressed so that it gives a “green” compressed natural gas (CNG) which can be used in gas-engine vehicles (buses, cars, trains, trucks etc.)[28]. Biogas-derived SNG can be “blended” with natural gas in any mixture.

Traditionally, biogas is derived from the anaerobic fermentation of biomass residues like dung, liquid manure, or organic household wastes. Nowadays, biogas digesters can make use also of bioenergy crops such as maize (corn), wheat, and *double cropping* systems which can integrate various plant varieties into their rotation, and give net energy yields comparable to the best palm oil, or sugarcane plantations.

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[28] Biogas could be further processed into a *green GtL* (gas-to-liquid), thus becoming directly available as a clean-burning liquid fuel. The costs of doing so, however, seem extremely high with current technology.

In Europe, interest in “modern” biogas as a transport fuel is growing, and its technology might be suitable for developing countries as well. Nevertheless, current markets for CNG vehicles are, with the noteworthy exception of countries such as Argentina, rather small, and gas transmission and distribution infrastructures are often missing in developing countries.

4 Life-Cycle Analysis of Biofuels

The environmental attractiveness of biofuels lies in their ability to substitute fossil fuels and the associated prospect of avoiding the release of fossil carbon in the atmosphere. However, this potential benefit needs to be confirmed and quantitatively specified along the whole supply-chain, including biomass production and conversion, and biofuel use.

This is the purpose of life-cycle analyses (LCA), providing assessments for:

- Energy: biofuel energy output with regards to energy input;
- Net GHG emissions: CO_2, CH_4 and N_2O emissions, and potential C sequestration.

LCA studies, most of which have been carried out for industrialized countries, allow to conclude that 1st generation biofuels can provide only modest GHG mitigation benefits with high variability within any given biofuel option[29]. Best results in terms of GHG emission reduction for today’s biofuels give ethanol from sugarcane in Brazil.

Two striking features of existing LCA studies are important for the GEF: the wide range of results in terms of net energy balances and net GHG emissions, and their apparent lack of focus on evaluating GHG impacts on a per-hectare basis, which is surprising since land is the primary resource for biofuel production.

Relatively few studies focus on the question of relative land-use efficiency for different biofuel pathways. Also, little analysis has been reported of the impact on LCA results of different yield levels for a given biofuels pathway, e.g. ethanol from switchgrass assuming different switchgrass yields. The impacts may be substantial. But measurements of how yields change at any single geographical site (as characterized by its soil type, climate, topography etc.) with different inputs require considerable time and effort.

The wide variation in results from LCA studies is due in part to the wide range of plausible values for key input parameters, with values often dependent on local conditions.

While many numbers go into a biofuels LCA analysis, there appear to be three key input parameters that introduce the greatest variations and uncertainties into the results[30]:

(i) allocation method for co-products,

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[29] The technical background paper on LCA studies of biofuels provides a systematic overview and analysis of available studies (see Larson 2005).

[30] The uncertainty stems most prominently from the lack of empirical data on N_2O releases from fields, and on the soil carbon balance. The variation is a result of the different efficiencies of plant varieties, agrochemical use, and climate/soil-related differences in yields, as well as differences in co-product ratios of downstream conversion of the biomass.

(ii) (ii) N_2O emissions (which evolve from nitrogen fertilizer application and leaf litter decomposition), and

(iii) (iii) soil carbon dynamics.

The impacts of N_2O emissions are especially significant for grain and seed based biofuels since average annual fertilizer rates are higher for these.

A variable that many biofuel LCA studies choose to leave entirely out of the analysis is the extent of soil carbon build-up (or degradation) associated with growing biomass.

The potential to sequester carbon in a soil is very site-specific and highly dependent on former and current agronomic practices, climate, and soil characteristics. Thus, converting previously heavily–tilled land to production of a perennial crop like switchgrass could result in substantial build-up of carbon in the soil.

On the other hand, if woodlands or grass lands are converted to bioenergy crop production, there could be a *decrease* in soil organic carbon. The issue of carbon storage in soils is complicated by the fact that the process is relatively slow, so that measuring changes is difficult.

Despite the large variation in LCA results for GHG savings with alternative biofuels systems in the literature, it is possible to draw a few robust conclusions:

- Obviously, maximizing GHG savings with biofuels benefits from high (and ecologically sustainable) biomass yields, efficient conversion of biomass to fuel, and efficient use of the produced fuel.
- Conventional grain- and seed-based biofuels can provide only modest GHG mitigation benefits by any measure, and will be able to provide only modest level of fuel displacement in the long term in any case due to high land requirements. Very broadly, grain or seed-based biofuels might give 20-30% GHG reductions relative to petroleum fuels; with sugar beets in the same range. If favorable production systems and full by-product use is assumed, net GHG reductions could be in the 50-65% range.
- More efficient land use can be expected with dedicated high-yielding lignocellulosic energy crops in the longer term. Future advanced cellulosic conversion of perennial energy crops to ethanol, FT-Diesel etc. might give 80-90+% reductions.
- Ethanol from sugarcane in Brazil gives 90% reduction, though.

While GHG mitigation per vehicle-km is an important measure, land-use efficiency in achieving GHG reductions may be the most important consideration.

The current knowledge of GHG balances of biofuels indicates a broad range (Larson 2005+2006), but for specified regions like the EU, quantification is already possible with regard to the different bioenergy crops, conversion routes, and by-product utilization rates (OEKO 2006a).

For other regions like the USA, and a few developing countries (Brazil, China, India), some data on the life-cycle GHG balances exists as well, and countries like Thailand have ongoing research in that area[31].

Data to establish life-cycle GHG balances exist for most countries, but resources to collect, compile and review such data as well as capacities to carry out such analysis is often missing.

Therefore, one can expect to establish credible ranges of GHG balances for bioenergy in the near future, if funding is available and data from real-world projects is used[32].

5 Biofuels: Environmental and Social Concerns

Besides the GHG impacts discussed before, other potential problems and conflict areas might arise from increased bioenergy use. The following section summarizes the most prominent issues in that respect.

5.1 Land Use Competition

One of the central conflict areas in cultivating bioenergy crops is its land use which varies depending on crops species, cultivation methods, and soil and climatic conditions (Elbersen et al. 2005; EEA 2006; Fritsche et al. 2004). Depending on its spatial distribution and cultivation practices, increased bioenergy cropping *could* result in loss of habitats, endangering or extinction of rare species, obstruction of migration patterns and corridors, and degradation of soils, and water bodies. Similarly, land-use for biofuels could compete directly with food and feed production (see figure below), as well as indirectly through economic (price) feedbacks.

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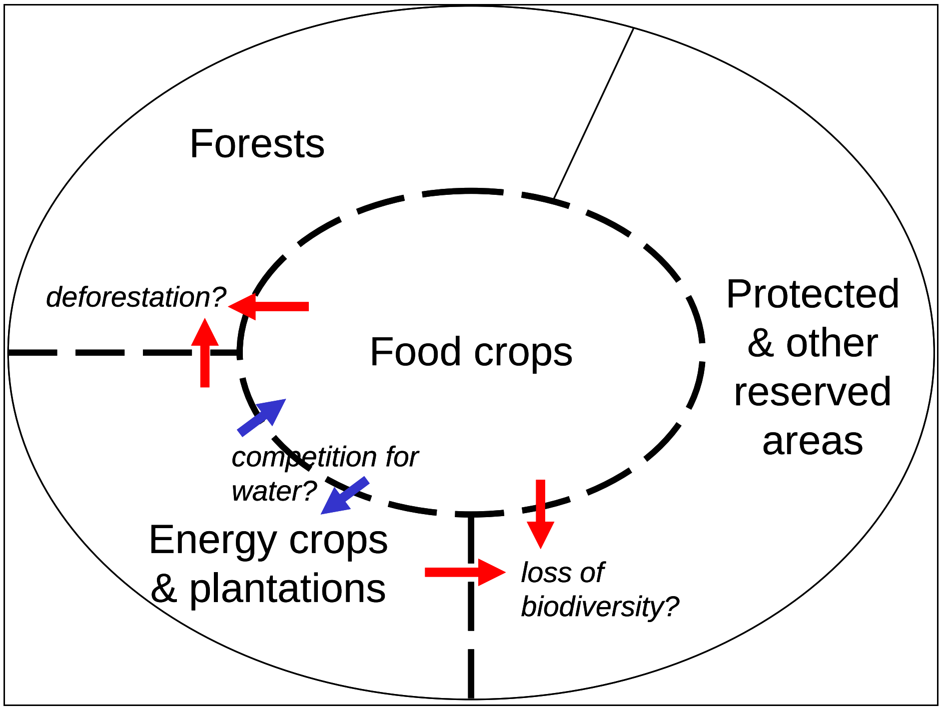
[31] see Bauen et al. (2006) for a general methodology, and WWI/gtz (2006) and Hill (2006) for a review of LCA data for the USA, and the GTZ country studies for Brazil (Kaltner et al. 2005), China (Gehua et al. 2006), India (TERI 2005), and Tanzania (Janssen et al. 2005).

[32] In that context it should be noted that UNFCCC's CDM Methodology Panel has approved only few CDM methodologies for biofuels due to open issues of GHG "leakage" from activities outside of the project boundaries.

Figure 9 Drivers of the Food-versus-Fuels Competition



Source: Girard (2005); presentation at the GEF-STAP Workshop

5.1.1 Drivers of Land Use Competition

In the next decades, however, land use will – in all probability – be more influenced in terms of quantity by *non-energy* purposes:[33]

An *increase* in agricultural land use is to be expected in the developing world, due to population growth, changes in diet, increasing export options for food and feed, as well as degradation and salinization of currently cultivated land, limits of irrigation, and ongoing desertification (FAO 2003, WBGU 2004). Modern farming practices, intensification, improved breeding, and pest management could well *counterbalance* these trends, though. At the same time, demand for wood products (timber, paper etc.) will increase (FAO 2000), in parallel to economic development with additional pressure on land from settlements, and transport infrastructure.

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[33] For example, soybean production in Brazil has expanded rapidly in recent decades; sometimes the land is used for only a short period of time, after which new areas are exploited (FBOMS 2004). The loss of habitat is the most serious threat to the biodiversity in the Cerrado area. Although the Cerrado is very rich in biodiversity, only 1.5% of this land is protected today (Kaltner et al. 2005).

Increases in bioenergy cropping must be seen in that context – it would be *one* of several drivers of increased land use. Furthermore, bioenergy cropping competes with other land uses only with respect to *arable* and *grass*land. In principle, *marginal or degraded* land could be used for bioenergy cropping systems as well. Even assuming low yields, this could represent a potential of 25% of global primary energy use[34].

To minimize land use competition, it has been suggested to *prioritize* bioenergy production on marginal and degraded lands,[35] and to restrict bioenergy developments on arable and grasslands to those conditions where strict land use policies can avoid "leakage" (OEKO 2006b).

5.1.2 Food versus Biofuels

Besides land use per se, competition between land use for food production, and land use for bioenergy production might arise. This has a special quality insofar as *food security* is concerned, and the MDGs clearly require policies to reduce hunger, and increase food security.

Available analysis of the food-vs.-fuel issue clearly indicates that in *general*, biofuels are *not* a primary cause of hunger, nor a direct driver of food insecurity. Quite contrariwise, bioenergy crops could well be a means to *alleviate* poverty, and to *increase* food security through income generation (FAO 2006a). The food production world-wide is balanced, i.e., enough food of sufficient quality is available, but there is an unequal access to food within developing countries (WBGU 2004). Food security is not just a problem of production but of *access* (FAO 2005a+b).

Yet, large-scale bioenergy developments have indirect influences on land-use activities before and outside the projects; for example, impacts on land prices and rents. Mechanisms need to be considered to avoid the negative impacts of such shifts.[36]

In that respect, a switch to large-scale bioenergy production might have adverse indirect impacts on food security which need further attention. As long as liquid biofuels mainly come from plants which can be also used for food/feed production, the economic effects of coupling the energy (i.e., biofuel) market with food/feed markets could increase food/feed prices, and – hence – worsen the access to affordable food/feed for many. The *indirect* effect of increased prices for traditional agro-products, however, could increase farmer (and country) income, and thus help increasing food security, depending on the distribution of the increased income.

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[34] Estimates of the global potential for biomass plantations on degraded land are in the order of *1 billion hectares*, i.e., 1,000 million hectares (Lal 2006), representing a minimum bioenergy potential of approx. 100 EJ/year.

[35] Encouraging evidence that such a strategy *is* possible comes from India where rural projects are concerned with the production of biofuels from Jatropha, a perennial, nitrogen-fixing plant which grows on poor soils, and requires only little irrigation to establish the plant (TERI 2005). The Brazilian "Social Biodiesel" program aims at similar goals, but uses castor, and oil palm (Kaltner et al. 2005).

[36] *Positive* impacts also need to be taken into account in this context, for example the restoration of degraded land by bioenergy activities, e.g. planting perennial plants.

It must be noted also that increased use of biogenic *residues and wastes* as a biofuel feedstock is in *indirect* competition to food supplies, mainly in poor areas of developing countries where these materials are used as inexpensive fertilizers, soil conditioners or animal feed.

As the overall outcome of such developments is still unclear, the FAO announced recently to research the food-versus-fuel issue in more detail, both conceptually and through in-depth country studies, aiming to derive knowledge on how to avoid or at least minimize potential negative food security impacts, and to determine to which extent and under which circumstances biofuels could contribute positively to food security (FAO 2006b). The outcome of this research should be considered key in safeguarding future biofuels development against food/feed competition.

5.2 Loss of Biodiversity

Land-use-based conflicts could arise also between bioenergy crop cultivation and biodiversity due to the loss of habitats, migration corridors and buffer zones (areas adjacent to protected areas). Furthermore, biodiversity impacts could arise from bioenergy production itself, depending upon cultivation form and harvest procedure.

As different bioenergy sources have quite different effects on biodiversity, varying from extremely damaging to benign, the biodiversity impacts could be minimized by preferring crop varieties and farming schemes which cause low (or positive) biodiversity impacts.

Furthermore, ecological stepping-stones (small-scale, distributed biotopes, landscape mosaics) within cropping areas could alleviate negative impacts.

Of special concern are the conversion of extensive, high-nature value farming to more intensive mono-cropping, and the conversion of primary forests[37] - both would clearly lead to a severe loss of biodiversity.

It has been suggested to use the “human appropriation of net primary production (HANPP) as an aggregated indicator for the loss of biodiversity (Haberl et al. 2005). In that respect, perennial bioenergy crops (see Section 3.2) might be less damaging to biodiversity than intensely managed annual cropping system (Haberl/Erb 2006).

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[37] A primary forest is a forest that has never been logged and has developed following natural disturbances and under natural processes, regardless of its age (definition from the Convention on Biological Diversity).

5.3 Other Environmental Impacts

5.3.1 Soil Erosion and Other Soil Degradation

The increase of *annual* bioenergy crops could further lead to soil erosion, and overuse of irrigation, agrochemicals, and heavy harvesting equipment might degrade fertile soils[38]. Soil erosion is especially a problem in regions with long dry periods with limited soil cover followed by heavy bursts of rainfall falling on steep slopes with instable soils.

In contrast, *perennial* bioenergy crops could improve soils, and help reduce erosion on currently used arable land by creating year-round soil coverage (EEA 2006, Elbersen et al. 2005) This is the case not only for woody biomass and perennial grasses, but also for sugarcane (and oil palm) which maintains soils better than annual cereal crops, and can increase soil carbon (if fertilized). Furthermore, there is an opportunity to incorporate legume crops which could improve the nitrogen balance further (Fujisaka 2005).

As regards agricultural and forestry *residues* (e.g., straw, wood thinnings), their use as feedstock for biofuel conversion could *reduce* humus creation and soil carbon, and increase plant nutrient exports which would then have to be compensated.

5.3.2 Water Use and Water Contamination

Agricultural water use is a serious concern especially in arid and semi-arid regions, where water is scarce and highly variable throughout the year. An increase in irrigated land could lead to water scarcity, to the lowering of water tables as well as reduced water levels in rivers and lakes.

Potential effects of increased water abstraction are salinization, loss of wetlands, and disappearance of habitats through inundation caused by dams and reservoirs.

In general, there has been an important increase in competition for water between agriculture, urban land uses and nature in more arid parts in the world in the past (JRC/EEA 2006).

Besides potential conflicts on the availability of water for irrigation, other impacts on ground and surface water supplies could arise from agrochemicals (fertilizers, pesticides) applied during cultivation. Current conversion technologies for biofuels offer effective options to control water pollution, but still facilities to process e.g. palm oil could cause discharges of organically contaminated waste water (Kittikun et al. 2000).

5.4 Other Social Impacts and Human Health

The cultivation of bioenergy crops could cause further social impacts such as restrictions on access to land for small-scale farming, labor conditions, and distributive impacts from infrastructure needed for bioenergy development.

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[38] On the other hand, adequate bioenergy cropping systems could be operated on degraded land (see Footnote 34).

In addition, direct impacts on human health, depending on the type of crop being cultivated, farming systems and practices, and harvesting procedures. Especially with the cultivation of sugarcane and oil palm, air pollutants caused by field burning could cause adverse health effects[39]. Pesticides are the primary cause of health risks for agricultural workers. Workers often are not educated about the health risk of using pesticides. Application of pesticides by airplane leads to driftings of pesticides into the dales and damages the crops and the animals of peasants (Bickel/Dros 2003). Medical care is often not available on the plantations (Zamora et al. 2004).

5.5 Summary of Environmental and Social Concerns of Biofuel Developments

With respect to developing countries, the specific challenges from future biofuel developments regarding environmental and social impacts have been summarized recently as follows (UNCTAD 2006):

- avoiding diverting too much land from food production to energy crops;
- avoiding sharp rises in the prices of food, especially for net-food importing developing countries;
- finding ways to ensure that small farmers do not face undue barriers to participation in the sector;
- and gaining access to relevant energy technology.

With the addition of potential health and labor impacts, this list seems to capture the challenges adequately.

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[39] It should be noted here that for sugarcane, non-burning harvest systems are becoming mainstream in Brazil.

6 The Economics of Biofuels

It was mentioned several times during STAP workshop that a sustainability framework can be misleading if it does not include economic sustainability, all the more as problems of pollution or such as child labor are linked to lack of local incomes.

Costs of biofuels need to be compared with those of their fossil fuel equivalents as to identify whether cost competitiveness is given at which level of production and within which time horizon. Here, expected yields, feedstock costs, interest rates, and cost of workforce are important factors, and dynamic effects such as scale and learning effects, but also economic feedbacks from agricultural markets, land use policies, and oil prices need to be taken into account.

All forms of biomass have alternative uses (see Section 2.6.1) and may be highly valued as animal feed or fuel, especially in marginal areas. Infrastructure requirements might also add to the cost of biofuels. These factors limit the commercial viability of potentially cheap feedstocks.

6.1 Costs of 1st Generation Ethanol

For starch-based 1st generation ethanol, costs depend on feedstock costs, investments in and operation of conversion processes, but also on the revenue from byproducts[40]. Other than residue utilization and economic of scale, few options for further improvement exist.

In comparison, the Brazil case illustrates that a improved feedstock and technology learning fostered by sustained commitment from government can bring production costs of bioethanol down to the point where (unsubsidized) ethanol became competitive with a 35-50$/bbl oil price (World Bank 2005).

With oil in the 50$/bbl price range, even starch-based ethanol in larger plants, and sugarcane ethanol can be economically competitive (see following figure).

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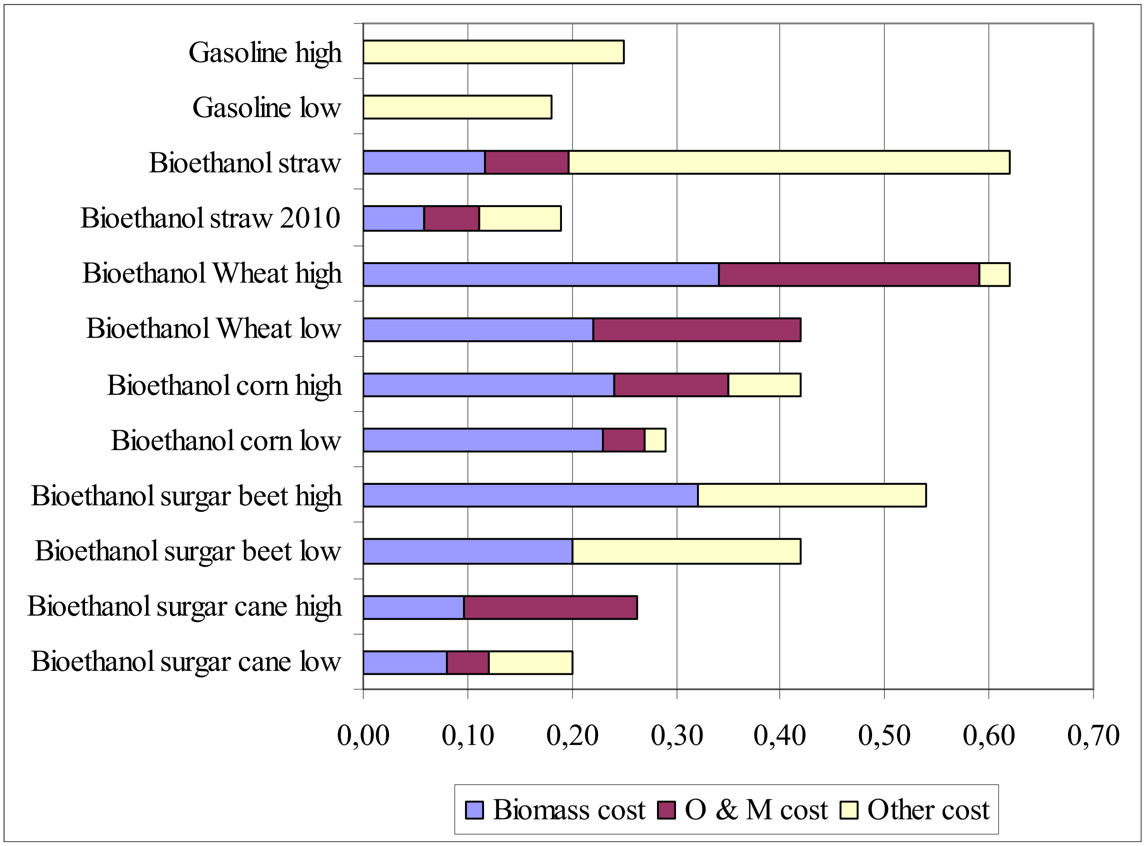
[40] The two common methods for refining starches into sugars differ primarily in the feedstock pre-treatment, and by-products: *wet* mills co-produces a variety of products, while *dry* mills grind heterogeneous seed into granules, requiring less investment, producing fewer co-products. Wet mills co-produce corn oil, gluten, germ meal, starches, dextrin, and sweeteners such as high fructose corn syrup. Sold mostly as processed foods and feeds, these products together comprise more than one-quarter of a wet mill's economic output. The primary co-product of dry mills is DDGS which provides some 20 percent of the dry mill revenue.

Figure 10 Bioethanol in Europe, USA and Brazil for low and high Production Costs Breakdown in Comparison to Gasoline



Source: Girard/Fallot (2005); data are given in US$/l of fuel. In the case of gasoline, full cost is given for comparison. Low and high prices correspond to different world market prices. These figures are only indicatives as great variation occurs and the detail of the cost breakdown is not always provided. The largest part of other cost is capital cost.

6.2 Costs of 1st Generation Biodiesel

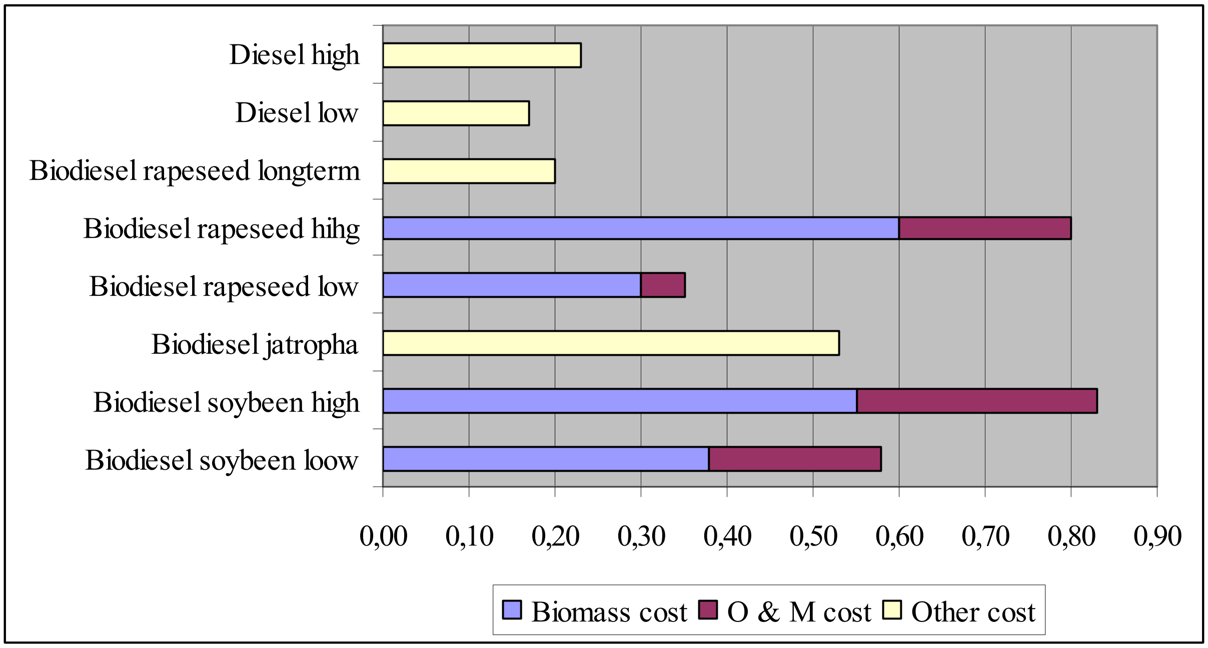
Similar to ethanol, SVO and biodiesel from oil plants are established and proven technologies, their costs depend heavily on two factors:

- costs of the feedstock (> 90 percent for SVO, some 85 percent for FAME), and;
- revenues from by-product utilization (cake, glycerol).

With such a high dependency on feedstock costs and price volatility in competing uses, 1st generation biodiesel seems a less attractive option unless palm oil is considered, or new conversion processes like hydrotreating become less costly.

On the other hand, cost for small-scale biodiesel from low-input systems like jatropha grown on low-cost marginal or degraded land with low-cost labor could be competitive with fossil diesel if overall efficiency and by-product use is assured.

Figure 11 Biodiesel Production Costs Breakdown in Europe, USA and India in Comparison to Diesel



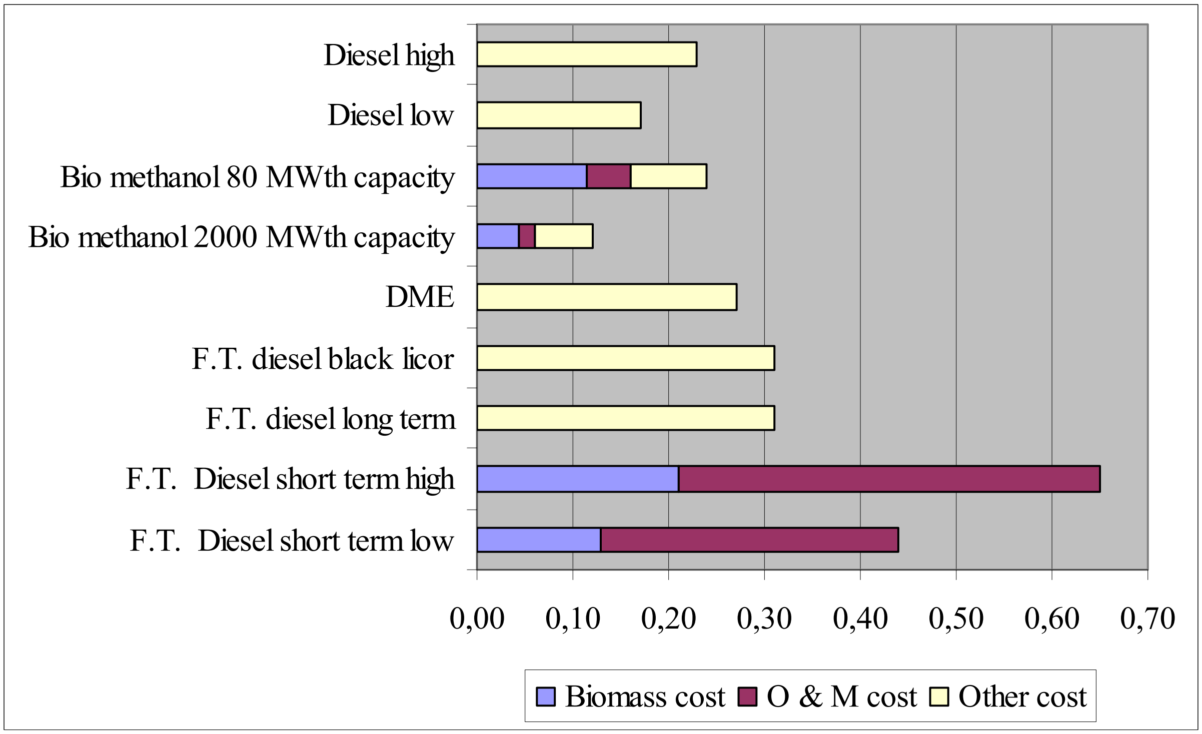
Source: Girard/Fallot (2005); data are given in US$/l of fuel. Diesel oil costs are full cost, fluctuation depending on the oil price. Long-term cost of biodiesel is an estimate on the basis of better use of co-products

6.3 Costs for 2nd Generation Biofuels

The costs of 2nd generation liquid biofuels can be assessed currently only from small-scale pilot plants using assumptions on technology learning, and depend heavily on scaling issues. Furthermore, the options of hybridization (see Section 3.3) must be considered which could result in lowering their overall cost.

An overview of the expected costs of some of the 2nd generation biofuel routes is given in the next figure, concentrating on diesel substitutes.

Figure 12 2nd Generation Biodiesel Production Costs Breakdown in Comparison to Diesel



Source: Girard/Fallot (2005); data are given in US$/l of fuel. Diesel oil costs are full cost, fluctuation depending on the oil price. Where no detail is provided, all production cost are summarized as “other cost”.

6.3.1 Cost for FT-Diesel (BtL)

The *thermochemical* route is well known, as the basic technology has been developed for coal and lignite and brought on-stream in Germany during World-War II. Afterwards, East Germany and South Africa (Sasol) developed this technology further. Today, Fischer-Tropsch (FT) synthesis has been elaborated by Shell, and plants in Indonesia and in Dubai are on-stream with natural gas as feedstock. Still, biomass-to-liquid (BtL) has only one small pilot plant in operation, with an “alpha” plant being built.

A drawback of the thermochemical route for biofuels is the strong dependence on the scale-up. To be competitive, the capacity has to be in the order of a small oil refinery (approx. 1 million tonnes per year). In addition, the economics rely on low feedstock costs, and successes in cost reduction for the gas cleaning, and catalytic conversion. FT systems based on biomass will prefer require sites near refineries, and need sophisticated logistic to handle the massive annual feedstock inflow. Cost projections indicate that in the longer-term (i.e. 2020 time horizon), BtL from lignocellulosic residues could become cost effective with a $50/bbl oil price, while BtL from dedicated energy crops might need a $60-70 range.

6.4 Costs for 2nd Generation Biofuels: Ligno-Ethanol

The technology of converting hemicellulose to ethanol has been used with wood chips in Switzerland, and residues of the Kraft pulp process ("black liquor") are used as a feedstock for ethanol production in Sweden since 1908. The major drawback is the energy and capital intensive milling, the large amount of sulfuric acid, and high steam requirements. Furthermore, sulfuric acid at elevated temperature is quite corrosive. Currently, this technology is not competitive with fossil-fuel-based products. But with the development of *enzyme* production using GMOs the cost could be reduced drastically. Nevertheless, even with lower-cost enzymes, the biochemical route depends on milling, heat and acid, but at less and at reduced conditions.

On the other hand, the enzymatic biochemical route needs more sophisticated process control which in turn leads to larger plant sizes to meet economies of scale. NREL (2002) calculates the necessary capacity of this technology for corn stover as feed to be in the 1 million tonnes per year range, or an equivalent output of some 200,000 tonnes ethanol/year. It is obvious that this capacity can only be used at sites with a high supply of biomass residues and an elaborated logistical infrastructure.

As the process development of GMO enzyme production today is well away from the costs needed to make the enzymatic biochemical route competitive at oil prices in the 50 $/bbl range, it must be considered *uncertain* when market introduction can be expected[41].

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[41] The concept of "biorefineries" is gaining interest globally (Schaverien 2005). As with the 2nd generation biofuel technologies to which biorefineries are closely related, it is currently not possible to know with any certainty how future biorefinery concepts will perform, what they will cost, and which products they are going to deliver to the market. The concept is promising insofar as oxygenated chemicals become more relevant in the market, and biochemical conversion knowledge is benefiting from developments of "white" biotech, i.e. GMO-related processing.

7 Open Questions and Controversial Issues

A number of issues remained unresolved at the workshop, revealing diverging views and the need for further information and research.

7.1 Sustainable Bioenergy Potentials

Estimates for bioenergy – and, hence, biofuels - potentials vary widely (see Section 2.3) and depend strongly on how the two crucial issues of competition with food and the use of marginal land are tackled:

(i) Can food supply sufficiently benefit from sustainably increased yields (through more intensive agricultural and post-harvest practices) so as to leave land available for growing energy crops?
This is currently a key issue in Europe (EEA 2006; IE/BFH/UH/OEKO 2006). It must be noted, though, that agricultural land use in industrialized countries is influenced also by the share of organic farming, as this will reduce yields for food crops[42].

(ii) Will marginal land be restored for growing bioenergy crops, or even restored through bioenergy farming? This is a key issue for developing countries, as a large portion of degraded and marginal land is found there (Lal 2006).
Biofuel plantations established on degraded soils can be productive and profitable only – in the classical sense of cost-effectiveness - if soil-related constraints to biomass production are alleviated through adoption of appropriate soil restorative measures.
Biofuel plantations established on unrestored marginal soils cultivated with marginal inputs will produce marginal yields – but as they need only small inputs, and could benefit from low land rents, and labor costs, they might have an economic potential (Painuly/Kumar 2005; Patwardhan 2005).

During the GEF-STAP Liquid Biofuels Workshop, discussions focused on the second issue, as the first issue is more relevant for industrialized countries[43].

Furthermore, the replicability of the “Brazilian model” for ethanol was debated (see Section 3.1.1), as this might be another – additional - option for developing countries (Coelho 2005; Coelho et al. 2006).

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[42] This is not the case in developing countries, though: the productivity (in terms of yields per hectare) of organic farming there is similar to “conventional” agriculture, as the latter has rather low intensities. In some cases, organic farming even gives higher yields.

[43] From a global point of view, one has to consider the total land use impacts, though: If industrialized countries “switch“ from traditional agricultural products to bioenergy and biofuels, they will have to import more food/feed commodities (assuming population and diets to remain unchanged), so that land use for agriculture in developing countries will increase accordingly. This could be offset through increases in yields, though.

7.2 Cost-Effectiveness of Biofuels

Cost competitiveness has been a major problem for biofuels until recently – with oil prices low, and benefits not internalized, the 1980ies and 1990ies did not see any major deployment. The only case of a biofuel use reaching competitiveness to fossil petroleum is found in Brazil, and this did not come overnight. Several decades of experience and learning eventually led to the large-scale production of a competitive biofuel (see Section 3.1.1).

Biofuels nowadays used in industrialized countries (i.e. 1st generation biodiesel from rapeseed and sunflower, and ethanol from starches) have the distinctive feature of their costs being mainly composed of biomass feedstock costs, which cannot be much reduced and may even increase if revenue from competing uses (animal or chemical feedstocks) rise, or in the event of adverse weather conditions[44].

Feedstocks for current biofuels in developing countries (1st generation biodiesel from palm oil, castor, soy, and ethanol from cassava, sorghum etc.) are in competition with food/feed production, so that their economy is also affected by the development of agricultural commodities on the world market[45].

The questions are then whether the only prospects for biofuels lie in the rise of fossil oil price, and to what extend "next" generation biofuel technologies can deliver on the prospective cost reductions.

Levels of oil price are commonly associated with competitiveness thresholds for biofuels. However, those thresholds are quite uncertain since oil price rise may cause the biofuel price to increase too, given the fossil fuel used along the biofuel supply-chain (machinery, transport, agricultural inputs).

Furthermore, the "lesson" from the oil price crises of the 1970s and 1980s must be kept in mind when interest in biofuels was paramount, but quickly dissolved once the oil price dropped again in the 1990s. With the perspective of "peak oil" a few decades away, it seems unrealistic that oil prices could drop much below a 50$/bbl level, though.

Other prospects for biofuel competitiveness require further investigation to reveal true costs. Indeed, some costs components are not included in prices and might well otherwise change the terms of competition. Examples are environmental costs but also fossil fuel subsidies that exist in many countries.

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[44] With unabated global climate change impacts, weather conditions might worsen significantly in many parts of the world in the next decades.

[45] The exception is the "rural biodiesel" strategy which focused on plants like jatropha, castor, etc. grown on marginal lands with low-input farming practices, and low labor costs. Here, the cost-effectiveness is different, as the marginal cost for fossil diesel supply are also higher.

7.3 Biofuels Trade

During the Workshop, global biofuel trade was controversial: the discussion brought up positions in favor of biofuels trade (for example, scaling effects to reduce costs, overcoming limited market sizes) as well as opposing issues such as questionable share of proceeds for the rural poor, and overall benefits, as well as controllability of social (distributive) impacts of larger-scale projects.

7.4 Government Support for Biofuel Programs

Biofuels need initial support to develop as a complete supply-chain and to bring together relevant stakeholders. Initial support comprises commercially viable models, monitoring, information dissemination, R&D, and training.

Relevant questions from the workshop are:

(i) What is the optimal timing to support a technology?

(ii) At what stage should the market be left free of intervention?

Answers depend not only on the identification of possible inflection points in market developments but also on views on the respective roles of market and state, the strength of institutions enforcing regulations and the availability of public funds versus private finance.

Clearly, bioenergy and biofuels are not the only energy options which need governmental support – renewables in general are subject to such interventions, but also cleaner fossil fuel technologies[46] and nuclear energy receive substantial subsidies (EEA 2004; UNEP/UNF 2004).

As biofuel technologies – especially the “next generation” – are still in the pre-commercial stage, governmental support is crucial to bring such options closer to the market, as successful technology learning depends on gaining market shares, not on time.

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[46] As regards cleaner fossil fuel technologies, carbon capture and storage (CCS) is currently the key focus of governmental support schemes in IEA countries.

8 Workshop Findings

It is widely accepted that much more energy services could be obtained from sustainable biomass than is presently the case, and that biomass has a considerable *potential* in contributing to increased energy security, economic development, and climate change and air pollutant mitigation.

As regards liquid biofuels for transport, which is the specialist issue the GEF asked STAP for advice on, the best known example in developing countries is ethanol from sugarcane in Brazil, and many developing countries are looking to replicate this approach.

A key question for GEF is the GHG mitigation potential of liquid biofuels for transport. A secondary but equally important question is whether biofuels can be produced without negative effects on soil, water and biodiversity as well as the satisfaction of primary human needs such as food. These questions and others related to sustainable development, such as cost aspects and local benefits of biofuels, were all covered in the workshop with the participation of a group of experts from developing and developed countries.

The workshop findings, summarized in this report, provided the basis for STAP's conclusions adopted by the STAP, together with STAP's recommendations to the GEF, which are published in a separate document on the STAP and the GEF websites.

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List of Acronyms

ADB	Asian Development Bank
CBD	Convention on Biological Diversity
CDM	Clean Development Mechanism
CIS	Commonwealth of Independent States
EBRD	European Bank for Reconstruction and Development
EC	European Council
EEA	European Environment Agency
EEB	European Environmental Bureau
EIB	European Investment Bank
EJ	ExaJoules
EU	European Union
EUGENE	European Green Electricity Network
FAO	Food and Agriculture Organization of the United Nations
FSC	Forest Stewardship Council
GEF	Global Environment Facility
GHG	greenhouse gases
GTZ	Deutschen Gesellschaft für technische Zusammenarbeit GmbH
HANPP	human appropriation of net primary production
IDB	Inter-American Development Bank
ILO	International Labor Union
ISO	International Organization for Standardization
IUCN	International Union for the Conservation of Nature and Natural Resources
KfW	Kreditanstalt für Wiederaufbau
NGO	Non-governmental Organization
OECD	Organization for Economic Cooperation and Development
OEKO	Öko-Institut (Institute for applied Ecology)
RSPO	Round Table on Sustainable Palm Oil

SRC	short rotation coppice
UNFCCC	United Nations Framework Convention on Climate Change
WBGU	Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (German Government’s Advisory Council Global Change)
WWF	World Wide Fund for Nature
WWI	WorldWatch Institute

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