Assessment of Biofuels Potential and Limitations

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Biofuels Assessment Report

Preface

Biofuels production, driven by the potential to contribute to energy security, climate change mitigation and rural development, has experienced rapid growth in recent years. Several countries have initiated policies to support biofuel development, production and use in the transportation sector. However, there are growing concerns about the economic, environmental and social sustainability of biofuels, as well as about their ability to actually meet the energy security expectations.

In response to these concerns, as well as the potential impact on oil markets of successes, failures or disappointments likely to be encountered along the biofuel development path, a review and assessment study was commissioned by the International Energy Forum (IEF) Secretariat[1]. The aim of the study was to assess, based on a review of documents provided to the authors by the IEF Secretariat, the extent to which biofuels could contribute seriously and consistently to meeting a substantial portion of future demand in the transportation sector, and to bring some answers to the multitude of questions that have arisen about the viability and sustainability of the various types of biofuels currently in production or under development. Additionally, the study would, where feasible, point out any remaining uncertainties or open questions.

The study assesses the current status of various biofuels and attempts to address some of the concerns, in light of published information, reviews, assessment reports and papers from a number of sources[2]. The findings of this study, contained in this report, will be presented to the 12th Ministerial meeting of the IEF in Cancun, Mexico, March 2010.

Scope of work

Given the experience in 2008 of extreme oil price volatility and the current, relatively low oil price, the IEF Secretariat placed due importance on the provision of a realistic assessment to IEF Ministers of what can be expected from biofuels up to 2030. Many relevant and pressing questions need answers. Examples include these, taken from the Terms of Reference (TOR):

[1] See Annex 1 for the TOR of the study as provided by the IEF Secretariat.

[2] The authors relied on reports and studies provided by the IEF Secretariat but also identified and reviewed additional material from a variety of sources, to the extent feasible. They also sought the views of major international energy organizations and some biofuel R&D centers.

- "Are the existing targets in consuming countries for biofuels achievable?
- "Are the subsidies/tax incentives for biofuels in consuming countries sustainable in economic/budgetary terms given current relatively low oil prices and given increasing budget pressures as a consequence of the economic downturn? If not, what are the consequences?
- "Are consuming countries implicitly counting on producer countries to 'fill the gap' with crude oil supply if they fail to achieve their biofuels supply growth?
- "To what extent will this uncertainty dampen investment in crude oil supply?
- "What are the environmental and food market consequences of the anticipated growth of biofuels in terms of CO2, land-use, water, deforestation?
- "How fast is the technology for second-generation biofuels developing?
- "How realistic is it to expect second-generation biofuels to be of any significant importance in achieving biofuels targets in the next decade? If not, what will be the consequences?"

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List of Abbreviations and Conversion Factors

BTL	biomass-to-liquids
EIA	Energy Information Administration
EU	European Union
FAME	fatty acid methyl ester
FAO	Food and Agriculture Organization
GBC	Global Biofuels Center
GHG	greenhouse gas
ha	hectare
IEA	International Energy Agency
LCA	life cycle assessment
LUC	land-use change
mb/d	million barrels per day
Mtoe	million tonnes of oil equivalent
NRC	National Research Council
OECD	Organisation for Economic Co-operation and Development
OFID	OPEC Fund for International Development
OPEC	Organization of the Petroleum Exporting Countries
Ethanol	20.5 MJ/litre (from HART/GBC) or 0.490 Mtoe/billion litres
Biodiesel	32.8 MJ/litre (FAME type) (from HART/GBC) or 0.783 Mtoe/billion litres
mb/d biofuels	33.617 Mtoe/yr with the present world ethanol/biodiesel basket.

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Executive Summary

1. **All energy production, conversion and use systems have positive aspects as well as drawbacks.** There is no such thing as an ideal energy source and any energy policy decision consists in balancing the pros and cons of different solutions. **This is true in particular for oil, which has tremendous, well-known advantages, but which also faces two challenges:** i) with no serious substitute for transportation, this sector is very vulnerable to severe supply disruptions, and ii), like other fossil fuels, its use creates local pollution and contributes a significant share to increased GHG concentration in the atmosphere, which is the main reason for adverse, anthropogenic climate change.

2. **Biofuels** have been and are being developed in many countries because, together with other policies, they **offer the potential, in part, to address both oil challenges: lack of diversity of sources and resources, and reduction of GHG emissions from the transportation sector.** This immediately raises two questions: i) are they effective – at an acceptable cost – in achieving what they are supposed to do? and ii) are their limitations and disadvantages fully taken into account, when deciding on a biofuel policy?

3. For consuming countries, the objective of improving energy security, through increased diversity of resources, as well as sources of supply, is a sensible and desirable one which indeed may very well be served by certain types of biofuels produced under favorable conditions in certain locations. **The main reason for the dominance of petroleum products is that they are *liquid*, a key feature for energy use in transport, and biofuels currently represent the only other serious, potentially large-scale, commercial, liquid fuel option.** Energy security improvement is a relative issue. Thus while the commercialization of another liquid fuel option will no doubt improve energy security for the transportation sector, unfortunately to quantify the value of an increased diversity of sources (such as biofuels) and to compare it to the additional costs thus incurred is very difficult.

4. On the other hand, consuming countries should recognize that if they want to increase security of supply through a diversification of resources and sources, **oil producing countries can legitimately stake a claim to increased security of demand through a diversification of customers, and more importantly, are justified in being cautious in making new investments in new production capacity,** if there is a risk that energy security and climate change policies in consuming countries could destroy the corresponding demand.

5. **The other main reason often put forward in many countries in favor of biofuels is the assumption that they make a tangible contribution to reducing GHG emissions, particularly in the transportation sector**. Thus, it is important to make sure that this is actually the case at an acceptable cost (other things being equal); that is a cost which is not higher than the cost of reaching the same GHG reduction by other means. Most of the studies reviewed for this report

address this key issue, and most have emphasized that the main difficulty in this task is to make sure that all emissions have been fully taken into account, throughout the entire life cycle, from cradle to grave.

6. **Mounting evidence from research and analysis, however, indicates that, for most first generation biofuels, the net impact on GHG emission reduction is marginal, and in some cases, clearly unfavorable.** It is wrong to generalize such conclusions as applicable to all sources of a particular type of biofuel, as the related net impact differs according to feedstock, location, agricultural practice and conversion technology. The largest impact is determined by land-use change (LUC), for example, through deforestation.

7. Initially, most estimates did not account properly or fully for emissions created by direct and indirect land-use change. **In some cases, these GHG emissions can be very large and, even worse, their impact on global warming is greater as they take place early in the process**, which is linked not only to total emissions but also to the intensity of emission over time (so that an early emission of a ton of CO_2 is more harmful than a late one). On the other hand, some land-use changes created by biofuel crops are beneficial, reducing the land emissions. As each case is specific (e.g., site and crop), each biofuel project should be decided only after a very comprehensive assessment of its GHG total balance, among other key factors, is completed.

8. Growing biofuel crops may result in other detrimental impacts. A number of **recent studies have concluded that prolonged dependence on first generation crops for biofuel production will result in an increased risk of deforestation**, which, when combined with the conversion of grasslands and savannahs to biofuel crops, is known to have a very negative impact on biodiversity. Water consumption is another example, but again this should be checked on a case by case basis (crop, land, region, etc). The use of fertilizers and pesticides has also been blamed, but their use is not generally higher than for food crops, although of course, **production of fertilizers and pesticides should be included in the GHG emission balance.** On the other hand, as an oxygenated, lead-free Octane Index enhancer, ethanol contributes to reducing local car pollution.

9. It is accepted that the overall impact of any biofuel development should be assessed on a life cycle basis (life cycle assessment or LCA), however, according to a recent study, the methodology of present LCAs is still far from being appropriate and standardized. In particular the very important impacts of biofuels on LUC, including emissions of nitrous oxide as a consequence of fertilizer use, is very often miscalculated or done in a way which does not allow comparisons. **There is a strong need for standardizing LCA methodology. In the interim, extreme caution should be exercised when assessing environmental impacts.**

10. Another major concern with present biofuels development is its **competition with food crops and the risk of food price increases due to the conversion of existing food crops into biofuel production and future competition for arable land.** There is converging evidence part of the price increase of certain food crops observed in recent years was due to such factors, but it is difficult to quantify the impact accurately. A recent major study estimated that, if OECD targets for biofuels are implemented by 2020 with first generation technologies, crop prices could increase up to 30%. This supports the conclusion that the risk would certainly be serious if the share of biofuels in transport fuels were to increase dramatically. However, as long as the reasonably attainable shares seem not to exceed 10%, this risk is probably minor. Thus **recent projections, which indicate that the share of biofuels in some major OECD countries may reach or exceed 15% level by 2015, call for careful assessment of the food crop price risk and its impact on poor populations in developing countries.**

11. **The efficacy of biofuel crop production in promoting agricultural diversification and rural development in developing countries,** often cited as a reason for international support, **appears to be of limited value,** at least for first generation biofuels. This is especially so in light of the fact that substantial biofuel subsidies in developed countries have constrained – and will likely continue to constrain – biofuel export opportunities from developing countries.

12. Indeed, there are reasons to believe that in several OECD countries, an important driver for supporting biofuels is actually farm policy, which after all can make sense, provided that costs and benefits are evaluated in a transparent and objective way. Unfortunately, this is not generally the case; in particular the impacts of such farm policies on developing countries' farmers are generally not taken into account. Moreover, **without transparency it is not possible to make sure that the same farm-specific objectives could not be obtained at lower costs with other crops**. Increasing transparency in objectives, costs and benefits should be a commitment for all countries.

13. Within the first generation of biofuels, there is a clear consensus that **only one is acceptable, taking into account the various above-mentioned concerns: this is ethanol produced from sugarcane in Brazil,** provided that the expansion of future sugarcane farming for ethanol production continues to follow current practice and avoids extension to areas that might raise the issue of harmful direct and indirect land use changes. **All the other biofuel crops currently in commercial production offer poor GHG results, (e.g. corn ethanol), at very high prices or with unacceptable environmental impacts (e.g. palm oil diesel).** Even on the grounds of energy security, most do not seem attractive and there is concern that farm policy might be the only serious, but not properly assessed, reason for developing these biofuels.

14. In most countries, policies that encourage the rapid growth of biofuel production have outpaced our understanding of the potential impact of biofuels on the environment, sustainable utilization of natural resources and food security. In particular, **most of the initially established biofuel production targets, which remain generally applicable, are either too ambitious or unsustainable over the long term.** In fact, given the rising concerns about most first generation biofuels, some production targets are being reconsidered, and may be relaxed, delayed or removed. Some have already been revised. Arguably, the expansion of biofuel production was strongly impacted in 2009, due to the financial and economic crisis, but

nonetheless is set to resume its strong growth trend, following economic recovery, even more so now that oil prices have regained some strength.

15. Therefore, **there is an urgent need to review existing biofuel policies in an international context in order to avoid environmental and economic mistakes, to protect the poor and safeguard against food insecurity.** Production of any type of biofuel will involve trade-offs among the multi-dimensional aspects of sustainability. A no-regrets policy should give priority to biofuels which are expected to be cost effective in a not too distant future, while realizing the declared objectives, such as reduced net CO_2 emissions.

16. **Next generation biofuels** currently under development, such as cellulosic ethanol, renewable diesel, biomass-to-liquids (BTL) or Fischer-Tropsch liquids, made from solid bio-waste (agricultural, forest or municipal), grasses, woods, waste paper and/or algae hold better promise. Available data and initial assessments indicate that in general, they **could offer dramatically reduced life-cycle GHG emissions relative to fossil fuels, due to higher yield and the possibility of using by-product plant waste for process energy.** Still, many technical and economic barriers remain; they need to be resolved through further extensive research and development efforts, including, for example, the need to develop more cost effective enzymes, fungi or microbes to break down celluloses into sugars for fermentation and subsequent ethanol production.

17. Despite the large R&D efforts and sizable investments being made by public and private organizations in major OECD countries, progress in the development and commercialization of next generation biofuels has been slow. **Notwithstanding the early targets set by several countries, it is not likely that next generation biofuels will become commercially available on a large scale before another decade or so, at the earliest.** First generation biofuels will continue to constitute the bulk of biofuel supply for another decade and will coexist with next generation biofuels for sometime after. It is important to recall and emphasize that overcoming technical barriers is necessary – but not sufficient – for sustainable commercial penetration of next generation biofuels. **It is essential to insist on the need to conduct, for each new next generation biofuel project, a very detailed and comprehensive assessment of its costs and benefits** (e.g. GHG emission reductions), before policies aiming towards large scale commercialization (e.g. targets, incentives, etc.), are adopted and implemented.

18. Furthermore, it is important to point out that while policies aimed at accelerating the development and commercialization of promising biofuel technologies, with potential for cost competitive advantages, are legitimate in initial stages, these policies should be well reasoned, not disproportionately costly and of limited duration. **For any type of biofuel, commercial sustainability in the long term must be based on the ability of the technology to ultimately survive and compete on its own merits,** i.e. possessing stand-alone overall cost competitiveness without subsidies or incentives favoring it over other similar-use commercially available fuels, taking into account, of course, an appropriate allocation for CO_2 emissions reduction.

19. Nonetheless, given the range and strength of applicable subsidies and incentives, most, if not all, current, first generation biofuel production targets established by OECD countries appear to be achievable, and may be exceeded in the medium term. But **with a few exceptions, such as sugarcane biofuel from Brazil, the ambitious targets are certainly not sustainable over the long term with current generation biofuels.** For next generation biofuels currently being researched and developed, establishing firm targets is premature; they may be considered only after careful evaluation against long-term sustainability.

20. **Establishing strong and ambitious targets before ensuring sustainability (as was the case for most first generation biofuels in OECD countries) appears to have added to uncertainty of supply across the range of liquid hydrocarbon fuels.** This has increased energy security risk in the medium-to-long term, as oil producers become more reluctant to commit to making timely investments on the assumption that biofuel targets are likely to be achieved. No serious studies are available yet to allow quantitative in-depth assessment of such risk. But, given that the ambitious targets established for the share of biofuel appear to be exaggerated and not likely to be unsustainable over the long term, **this risk may actually be less acute than was previously thought. Nevertheless, it is safe to state that this risk is real and would be especially damaging once current world oil production spare capacity is reduced following the economic recovery – apparently underway already - and demand growth resumes**.

Conclusions:

Driven by policies aimed at enhancing energy security through the diversification of energy sources, reducing greenhouse gas emissions and accelerating agricultural development, **the production and use of biofuels have increased rapidly in recent years.** These developments have outpaced our understanding of the potential impact of biofuels on the environment, sustainable utilization of natural resources and food security. **With the exception of sugarcane ethanol in Brazil, all so-called first generation biofuels have experienced some problems and revealed drawbacks which had not been predicted or emphasized in the initial enthusiasm.** Yet, notwithstanding the significant slowdown of growth during 2009, projections indicate that biofuel production growth is set to resume its pre-financial crisis course as of 2010, and is likely to meet, and possibly exceed established targets over the medium term.

Therefore, there is **an urgent need to review existing biofuel policies and their associated targets in an international context** in order to avoid environmental and economic mistakes, to protect the poor and improve food security while ensuring sustainability. **Setting strong and ambitious targets before ensuring sustainability, as has been the case for most first generation biofuels, adds to uncertainty of supply, which would increase market volatility in the medium term.** This in turn would increase energy security risk rather than improve it.

Many countries have commissioned studies to assess the sustainability of current biofuel strategies and policies; some countries have already introduced significant changes to their strategies and policies, including lowering targets and/or slowing down the growth rates to reach targets. These studies and others, from national and international R&D centers and organizations, are addressing the development of criteria for assessing sustainability, such as standardizing comprehensive LCA, establishing limits on land change and/or use for biofuel production, etc.

Next generation biofuels currently under development hold much better promise but require extensive R&D to overcome scientific and technical barriers, and to ensure sustainability. Production of any type of biofuel will involve trade-offs among the multi-dimensional aspects of sustainability. No doubt some biofuels are likely to contribute significantly to the future world mix of liquid transportation fuels, **but establishing firm targets for such promising next generation biofuels is premature** and should be considered only after careful evaluation against long-term sustainability**. In any case, future biofuel production and use should meet several essential criteria:** it should result in significant GHG savings compared to fossil fuels; rely on environmentally sound agricultural and forestry management systems for production of feedstock; preserve biodiversity and cultural heritage; be socially inclusive; and integrate with food, feed and other biomass use sectors. Finally, it should contribute positively to overall land-use. With very few exceptions, this is not the case to-day.

Introduction

High economic growth, underway for several decades in most developing countries across the globe, has resulted in robust demand for various energy sources[3]. A greater need for mobility and peoples' aspirations for improved living conditions have together become the main driver for increasing primary oil demand, which is projected, according to most recent energy "outlooks" by the IEA and OPEC, to rise by about 1.0% per year, reaching approximately 105 million barrels per day (mb/d) level by 2030.

The transport sector, in particular, relies almost entirely on oil supplies for fuel. Several factors, including energy price increases, increased market volatility, in particular during 2008 and 2009; heavy dependence of many countries on imported oil; lingering debate about the ultimate size of remaining, recoverable fossil fuel reserves; and, not least, growing concerns about the environmental impact of fossil fuel usage have provided the impetus for the current strong interest in, and support for, biofuels in many parts of the world. The contribution of biofuels as an alternative energy source is currently very small, but this may change, should the high growth rates of the last few years be sustained in the coming years and decades.

Because biofuels are seen as a clean alternative to fossil fuels, several countries have initiated policies to provide generous government support to biofuel development and production. A number of countries have also established a regulatory framework to promote and facilitate the use of biofuels in the domestic transportation sector. However, there are growing concerns about the overall energy efficiency of different feedstocks, the life cycle environmental benefits of biofuel production and use, the economic rationale of these alternative sources of energy, and the implications for food security and prices. Considering that most of the present generation of biofuels use agricultural commodities such as sugarcane, sugar beet, maize, wheat, barley, rapeseed, soybean, palm oil, and cassava as feedstocks, any developments in the biofuel sector – and formulation of government policies promoting them – are bound to have considerable impact on agricultural production, availability and food prices. This, in turn, raises important questions about food security and poverty across the globe.

This study is a synthesis of recent assessment reports on the status of biofuels and the implications of their development. It provides an overview of the global trends in biofuels supply and demand, as well as a review of the policies that are being implemented or considered in major countries to promote current (first) and next generation biofuel development. The study also discusses the potential of biofuels to address energy security

[3] The slowdown of economic growth in 2008 and 2009, induced by the financial crisis, credit crunch and recession in OECD economies, appears to be transient for most of the rapid-growth developing economies.

concerns and reduce greenhouse gas emissions, as well as the ongoing debate over the implications of biofuel development on food security and rural development, biodiversity, deforestation, water resources and air quality. It also assesses the status of next generation technologies and their potential role in minimizing the sustainability problems associated with first generation biofuels. The analysis points out remaining uncertainties and open questions and outlines policy directions which can best promote the development of biofuels, while addressing, among other concerns, those of oil producing and consuming countries.

This report follows the convention by which a figure is presented in the primary units reported by the source and its Mtoe equivalent is calculated and shown in brackets. In cases where the primary unit was Mtoe, no conversion was made.

1. Global trends in biofuel supply and demand

1.1 Current production and the medium- to long-term outlook

Global production of biofuels has been growing rapidly in recent years, more than tripling from about 18 billion litres (10 million tonnes of oil equivalent {Mtoe}) in 2000 to about 60 billion litres (42 Mtoe) in 2008. Supply is dominated by bioethanol, which accounted for approximately 84% of total biofuel production in 2008. Despite this exponential increase, biofuels still represent a very small share of the global energy picture. Total biomass accounted for 3.5% of total primary energy supply in 2007, according to the OPEC World Oil Outlook (OPEC WOO 2009), with liquid biofuels accounting for about 0.28% of total energy demand and about 1.5% of transport sector fuel use (IEA WEO 2009).

Currently, production is concentrated in a small number of countries (Table 1.1). Together the US and Brazil account for about 81% of total biofuel production and about 91% of global bioethanol production Since 2005, the US has surpassed Brazil as the largest bioethanol producer and consumer, accounting for 50% of global production in 2008 (SCOPE 2009). The EU follows as the third major producer with 4.2%. In contrast, about 67% of biodiesel is produced in the EU, which is also the largest consumer, with Germany and France combined accounting for 75% of total EU production and 45% of global production.

Table 1.1: Biofuel production in 2008, by country

billion litres	Bioethanol		Biodiesel		Total biofuels		Share in total
World	*67.0*	*(32.8)*	*12.0*	*(9.4)*	*79.0*	*(42.2)*	*100.0%*
US	34.0	(16.7)	2.0	(1.6)	36.0	(18.2)	45.6%
Brazil	27.0	(13.2)	1.2	(0.9)	28.2	(14.2)	35.7%
EU	2.8	(1.4)	8.0	(6.3)	10.8	(7.6)	13.7%
China	1.9	(0.9)	0.1	(0.1)	2.0	(1.0)	2.5%
Canada	0.9	(0.4)	0.1	(0.1)	1.0	(0.5)	1.3%
India	0.3	(0.1)	0.02	(0.0)	0.32	(0.2)	0.4%

Source: REN 21 (2009). Note: units are billion litres; Mtoe (in brackets) was calculated. Share in total is in volume.
[Other countries not named in Table 1.1 have a combined 0.8% share of the world total.]

According to a recent study by Hart's Global Biofuels Center (Hart/GBC 2009), global demand for ethanol and biodiesel combined is expected to nearly double between 2009 and 2015 from 95.3 to 183.8 billion litres (50.5 to 100.8 Mtoe) (Tables 1.2a and 1.2b). Ethanol, while accounting for 80% of this latter figure, will only represent 12% to 14% of total global gasoline demand. Although global ethanol supply generally matches demand in 2009 and 2010, it is expected to exceed it in 2015, reaching 168.6 billion litres (82.6 Mtoe) compared to expected demand of 147.3 billion litres (72.2 Mtoe).

Similarly, biodiesel supply is projected to almost double by 2015, reaching 94 billion litres (73.6 Mtoe), and will also exceed the estimated demand of 36 billion litres (28.2 Mtoe) that year.

Hart/GBC estimates supply based on current capacity and projected capacity to be in place by the 2015 time frame. Hart/GBC based their demand figures on the assumption that policy requirements and targets will be implemented and fulfilled and by using gasoline and on-road diesel demand figures estimated in another Hart/GBC study.

The apparent supply/demand imbalance, according to Hart/GBC, will be taken care of by 2015 through some or all of several expected routes; 1) governments increasing blending limits; 2) many proposed projects cancelled; 3) continued low utilization rates; and 4) many existing plants scrapped.

Interestingly, projected supply is well above targeted demand, which increases uncertainty in the motor fuels market, and creates a disincentive to invest in both the upstream and downstream of this domain.

The supply/demand medium-term outlooks (2009, 2010 and 2015) for major ethanol and biodiesel producers and consumers are summarized in Tables 1.2a and 1.2b.

Table 1.2a: Global ethanol medium-term supply/demand outlook

billion liters	2009		2010		2015	
Country	Supply	Demand	Supply	Demand	Supply	Demand
*World **	*83.4 (40.9)*	*82.2 (40.3)*	*101.4 (49.7)*	*99.4 (48.7)*	*168.6 (82.6)*	*147.3 (72.2)*
USA	42.4 (20.8)	42.4 (20.8)	49.2 (24.1)	49.2 (24.1)	61.7 (30.2)	60.5 (29.6)
Brazil	27.5 (13.5)	22.0 (10.8)	29.7 (14.6)	25.9 (12.7)	54.0 (26.5)	47.2 (23.1)
EU	3.4 (1.7)	4.8 (2.4)	4.4 (2.2)	6.0 (2.9)	6.0 (2.9)	9.2 (4.5)
China	3.1 (1.5)	8.5 (4.2)	3.4 (1.7)	8.8 (4.3)	12.8 (6.3)	11.5 (5.6)
India	1.7 (0.8)	0.8 (0.4)	1.8 (0.9)	1.6 (0.8)	9.3 (4.6)	2.1 (1.0)
Indonesia	0.7 (0.3)	0.18 (0.1)	2.2 (1.1)	0.6 (0.3)	6.5 (3.2)	1.1 (0.5)
Malaysia	0	0	0	0	0	0

Table 1.2b: Global biodiesel medium-term supply/demand outlook

billion liters	2009		2010		2015	
Country	Supply	Demand	Supply	Demand	Supply	Demand
*World**	*48.2 (37.7)*	*13.1 (10.3)*	*59.6 (46.7)*	*18.3 (14.3)*	*94.4 (73.9)*	*36.5 (28.6)*
USA	2.8 (2.2)	2.8 (2.2)	3.1 (2.4)	3.1 (2.4)	8.4 (6.6)	8.4 (6.6)
Brazil**	2.9 (2.3)	1.0 (0.8)	4.5 (3.5)	1.8 (1.4)	6.0 (4.7)	2.1 (1.6)
EU	18.6 (14.6)	9.6 (7.5)	21.5 (16.8)	12.8 (10.0)	28.1 (22.0)	16.1 (12.6)
China	5.3 (4.1)	0	6.3 (4.9)	0	11.5 (9.0)	3.5 (2.7)
India	1.8 (1.4)	0	2.0 (1.6)	0	4.2 (3.3)	4.1 (3.2)
Indonesia	2.9 (2.3)	0.08 (0.1)	7.4 (5.8)	0.2 (0.2)	10.4 (8.1)	0.5 (0.4)
Malaysia	4.3 (3.4)	0.25 (0.2)	5.5 (4.3)	0.25 (0.2)	10.5 (8.2)	0.3 (0.2)

Source: Hart/GBC 2009.
Note: Units are billion litres, Mtoe (in brackets) was calculated.
*World was calculated as the sum of regional supply/demand data provided in the above source
**Petrobras has set a target of 0.8 billion litres (0.6 Mtoe) per year by 2011 (Biodiesel magazine, August 2006)

Over the medium term, the US and Brazil are likely to continue to dominate ethanol supply and demand. However, their combined share of production may decrease to 73% of the global total, as the role of countries in the Asia-Pacific region, mainly China, India, Indonesia and Malaysia, rapidly increases. By 2015, the latter region's total production could represent about 22% of global supply.

With respect to biodiesel, the EU is assumed to continue dominating consumption in 2009 and 2010, but its share is also projected to decrease, from 60% to 40%, by 2015 as consumption in Asia-Pacific grows steadily. This region also captures a significant share of biodiesel production, about 50%, by 2015. Table 1.2c provides a comparison between the outlooks for biofuel supply provided by Hart/GBC, EIA, and OPEC.

Table 1.2c: Comparison of medium-term outlooks for biofuel supply [4]

	2007	2008	2009	2010	2015
Hart/GBC, billion liter/yr			131.6 (78.6)	161 (96.4)	263 (156.5)
EIA, mb/d	1.1 (37.0)			1.9 (63.9)	2.8 (94.1)
OPEC, mb/d		1.3 (43.7)	1.5 (50.4)	1.7 (57.1)	2.2 (74.0)

Sources: Hart/GBC 2009, EIA 2009, OPEC WOO 2009.
Note: Units are shown in the left column; Mtoe (in brackets) was calculated.

Looking toward the long term, up to 2030, scenarios which assume that declared targets to promote biofuel development in major countries and regions **will be implemented**, show global biofuel supply increasing to 189 Mtoe (a share of 7% of total transport fuel demand) by 2020 and to 295 Mtoe (a share of 10%) by 2030.

The OPEC World Oil Outlook (WOO) 2009 Reference Scenario projects that biofuel supply will total 2.9 mb/d (97.5 Mtoe) in 2020. The outlook assumes that, given the concerns about the sustainability of biofuels, and the impact on food prices, together with the recent financial crisis, global biofuel supply growth will slow in the medium term before picking up in 2015. In the 2009 WOO, policy targets in both the OECD and developing countries are **not expected to be fully met**. Biofuel consumption in the EU is unlikely to exceed 66% of the stated target of 0.9 mb/d (30.3 Mtoe) by 2020, while total biofuel supply in the US is projected to reach only 1.2 mb/d (40.3 Mtoe), compared to a target of 2.3 mb/d (77.3 Mtoe) by 2022. The 2009 WOO assumes second generation biofuels will contribute modestly to biofuel supply after 2015. Beyond 2020, global biofuel supply is projected to increase by about 2 mb/d (67.2 Mtoe) during the period from 2020 to 2030, reaching 4.7 mb/d (158.0 Mtoe) in 2030.

In the IEA World Energy Outlook (WEO) 2009 450 Scenario[5], global biofuels consumption in the transport sector is projected to reach 123 Mtoe in 2020 and 278 Mtoe in 2030. This scenario assumes that second generation biofuels (cellulosic ethanol and Fischer-Tropsch diesel sourced from sustainably grown biomass) will account for the bulk of the increase in both the road and aviation sectors, becoming cheaper in the medium to long term. Biofuels would represent 7% and 11% of road transport in 2020 and 2030 respectively and 15% of aviation fuel in 2030 in this scenario.

The 2009 EIA outlook projects that total production of biofuels will increase from 0.8 mb/d (27 Mtoe) in 2006 to 3.9 mb/d (131.1 Mtoe) in 2020 and to 5.9 mb/d (198.3 Mtoe) in 2030 in the reference case, an average annual growth rate of 8.6% between 2006 and 2030. Two scenario

[4] Conversion factor from mb/d to Mtoe/yr is 33.617.
[5] The 450 scenario assumes governments adopt commitments after 2012 to limit the long term concentration of greenhouse gases in the atmosphere to 450 parts per million of carbon dioxide equivalent (ppm CO2-eq).

variants were also examined: a high and a low oil price case. In the low price case, only the least expensive and most cost-effective feedstocks and production technologies would be competitive. However, in the high price case, advanced production technologies become more widely used, raising biofuels production in 2030 to 7.2 mb/d (242 Mtoe), compared to 4.8 mb/d (161.4 Mtoe) in the low price case. In both cases, advanced generation technologies are assumed to become commercially available after 2012.

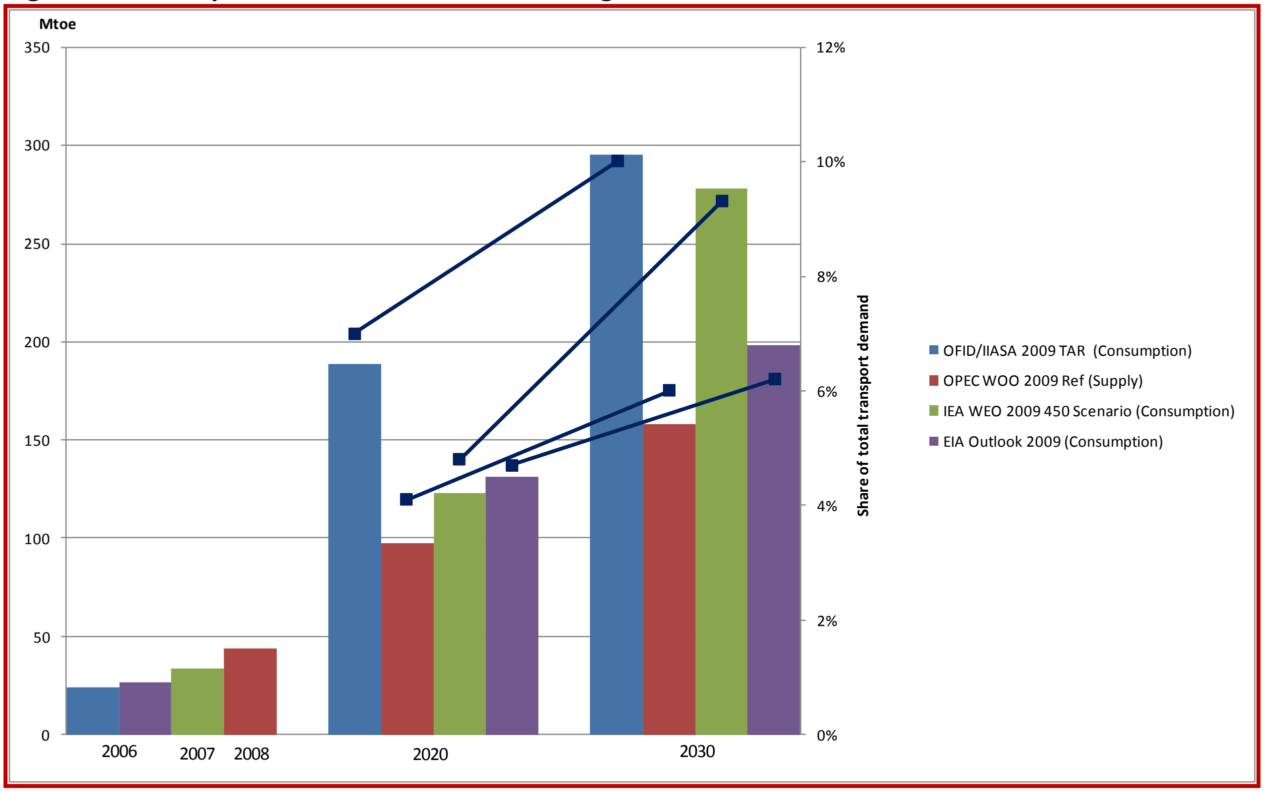
Table 1.3 provides a summary of four scenarios and is presented in Figure 1.1. The differences observable in the projected share of total transport demand may be explained by different modelling approaches and assumptions about the extent of implementation of stated biofuel targets, development and the speed of market penetration of second/next generation technologies. For example, the OFID/IIASA TAR scenario and IEA WEO 450 scenarios both suppose a very strong political will worldwide to combat climate change, whereas the OPEC and EIA scenarios are more “business as usual".

Table 1.3: Comparison of various biofuel long-term outlooks

Scenario		Base year		2020 Demand	2020 Share of total transport demand	2030 Demand	2030 Share of total transport demand
OFID/IIASA 2009 TAR (Consumption)	Mtoe	24.4	*2006*	189	7%	295	10%
OPEC WOO 2009 Ref (Supply)	mb/d (Mtoe)	1.3 (43.7)	*2008*	2.9 (97.5)	4.1%	4.7 (158)	6%
IEA WEO 2009 450 Scenario (Consumption)	Mtoe	34	*2007*	123	4.8%	278	9.3%
EIA Outlook 2009 (Consumption)	mb/d (Mtoe)	0.8 (27.0)	*2006*	3.9 (131.1)	5.0%	5.9 (198.3)	6.5%

Source: OFID/IIASA 2009, OPEC WOO 2009, IEA 2009, EIA 2009. Notes: units are shown in the first column. Mtoe (in brackets) was calculated.

Figure 1.1: Comparison of various biofuel long-term outlooks



Source: Table 1.3 above.

1.2 Land requirements

Demand for land that can be cultivated for food or animal feed production is rising, a trend which has increased pressure on land and other related resources, such as water. An expansion of biofuels production would add substantially to this pressure, as shown by a major study commissioned by OFID and conducted by the Vienna-based International Institute for Applied Systems Analysis (OFID/IIASA 2009).

According to the FAO definition (FAO 2008), total agricultural land area consists of arable land, permanent crops and permanent pasture. Globally, arable land accounts for 28% of this area, while permanent pasture accounts for most of the rest of the area, about 68%.

Currently, around 1.6 billion hectares (ha) of land are estimated to be in use for crop production, with nearly 1.0 billion ha under cultivation in developing countries. The area of land used for biofuels production is estimated to be about 1.6% of total cultivated land (OFID/IIASA 2009), mostly in Brazil and the USA. The potential for arable land expansion is mainly in South America and Africa, with relatively limited scope for expansion in Asia, where most of the increase in demand for food is expected.

Biofuel expansion would require both an increase in agricultural productivity and an expansion of land area, in addition to that which will be required to meet increased demand for food and animal feed production. This would increase pressure to convert permanent pastures and forests, particularly in developing countries. This conversion of land for biofuel production will result in extra GHG emissions, due to carbon losses from vegetation and soil, and pose a potential risk to biodiversity.

The OFID/IIASA scenario estimated global growth in cultivated land used for food and feed production of 98 million hectares (Mha) by 2020 and 147 Mha by 2030, compared to 2000. Biofuel production expansion will result in additional cultivated land use ranging from 18 Mha to 36 Mha in 2020 and 19 Mha to 44 Mha in 2030 in different biofuel development scenarios, with about two thirds of this expansion occurring in developing countries. These increases represent 20 - 40% of the net total cultivated land expansion during the period 2000 – 2020 and 15 – 30% during the period 2000 - 2030.

The impacts of this extra land requirement will be discussed in Chapter 4.

1.3 Biofuel Types

Different biofuels types can be produced from biomass in a number of ways. Generally, biofuel conversion technologies are categorized as first and second (next/advanced) generation biofuels. First generation biofuels, ethanol from sugar and starchy crops and biodiesel from oilseed crops and animal fat, use well-established and simple conversion technologies. Second (next) generation biofuels, from cellulosic biomass and algae, use less proven technologies. The most common types of biofuels are ethanol and biodiesel. Key aspects and requirements of the main production technologies, as well as uses of each, are briefly described below.

Ethanol

Ethanol is currently produced from sugar crops (sugarcane, sugar beet, sweet sorghum) or starchy crops (corn, wheat, cassava) through a process of fermentation and then distillation, employing first generation technology. The basic production process of ethanol from both types of crop is similar. However, the energy requirement for starch-based ethanol is significantly more than that of sugar-based ethanol due to the additional process involved in converting starches into sugar. Energy and GHG balances are, therefore, more favourable for ethanol production from sugar crops than from starch crops.

Production of ethanol from sugar cane results in a variety of by-products (co-products) including bagasse, a residual fibre which is used as a primary fuel source for sugar mills. According to the OFID/IIASA study (OFID/IIASA 2009), this makes a sugar mill more than self-sufficient in energy, allowing sugarcane-based ethanol to achieve energy balances ranging from two to eight times more energy output, when compared to fossil use input. Often co-generation of heat and electricity is possible and surplus electricity can be sold on to the consumer electricity grid, thus offering an additional source of income. Surplus bagasse has industrial applications and can also be used as livestock feed. Ethanol production from starchy crops produces high-value livestock feed and distillers' grain.

Ethanol can be used in blends of up to 10% in conventional spark ignition engines or in blends of up to 100% in modified engines (this is the practice only in Brazil; other countries using high blends go up to 85%). Though ethanol energy content is 66% of that of gasoline, it has a higher octane rating and, when mixed with gasoline, ethanol improves vehicle performance and reduces CO_2 emissions. Ethanol also has very low sulphur content, thus its use reduces SO_2 emissions, a component of acid rain. On the other hand, ethanol use could increase nitrogen oxide (NO_x) emissions, which play an important role in the formation of ground ozone and acid rain.

Next generation bioethanol is produced from cellulosic biomass. Cellulosic feedstock can be comprised of woody or herbaceous wastes from forestry and agriculture, municipal solid wastes and dedicated crops, which include short term species (willow, poplar, eucalypt) and perennial grasses (miscanthus, switch grass). The production process for cellulosic ethanol is very difficult and currently there is no commercial output from this source, though research is ongoing. An overview of the main features of these technologies is provided in Chapter 5.

Biodiesel

Conventional biodiesel is produced from vegetable oil and animal fat through a process known as esterification. Major feedstocks are rapeseed, soybean, palm and jatropha. The production process provides additional co-products, typically bean cake, an animal feed, and glycerine, which can be used in several industries.

Biodiesel can be blended with diesel or used in pure form in compression ignition engines without engine or infrastructure modification. Its energy content is only about 88 – 95% that of diesel, but the fuel economy of both are generally comparable as biodiesel raises the cetane[6] level and improves lubricity (FAO 2008). At the same time, biodiesel use reduces emissions of particulate matter and CO emissions.

An advanced option in the production of synthetic biodiesel is the Fischer-Tropsch biodiesel also known as FT diesel or biomass-to liquid (BTL) biodiesel, a second generation technology which is still under development.

A detailed review of ethanol and biodiesel production technologies is available in NRC 2009 and IEA Bioenergy 2008.

1.4 Policy measures affecting biofuel development

Several countries have adopted policies to promote liquid biofuel development led by the US, the EU, Brazil, Canada, Australia and Japan. A growing number of developing countries such as China, India, the Philippines and Thailand, have also started to introduce similar policies.

Government support measures for biofuels include mandates and targets, import tariffs, tax incentives, direct production subsidies and R&D support.

Mandates and targets

Blending mandates and targets for the use of biofuels are increasingly being imposed in many countries (Table 1.4) and are key drivers in the growth of the biofuel industry.

[6] Cetane is a measure of fuel's ignition delay. High cetane numbers imply shorter ignition delay periods. Usually associated with diesel engines

Table 1.4: Voluntary and mandatory targets for transport fuels in major countries

	Blending mandates		Biofuel targets	Volumes required per year	
	Bioethanol	Biodiesel	Biofuels total	Bioethanol	Biodiesel
Canada	E5 by 2010	E2 by 2012			
USA			20% by 2022	130 billion liters by 2022	
EU Total			10% by 2020		
Australia	regional only				
Japan			5% by 2030	6 billion liters by 2030	
South Africa	E8-E10 proposed	B2-B5 proposed	4.5% biofuels		
Brazil	E22 to E25 exist.	B5 by 2013			
Columbia	E10 existing	B5 by 2008			2.5 billion liters by 2013
Peru	E7.8 by 2010	B5 by 2010			
China	E10 in 9 provinces			13 billion liters by 2020	
India	E10 in 13 regions				2.3 billion liters by 2020
Indonesia					
Malaysia		B5 by 2008			
Philippines	E10 by 2011	B2 by 2011			
Thailand	E10 by 2007	3% share by 2011			

Source: UNEP 2009.

Note: The numbers after E and B refer to the % blend by volume of the respective fuel. For example, E10 indicates a blend of 10% ethanol and 90% gasoline; and B5 means a blend of 5% biodiesel and 95% diesel.

Tariffs

Many countries apply tariffs to protect domestic agriculture and biofuel industries. With the exception of Brazil, major ethanol producing countries apply significant tariffs (Table 1.5)

Table 1.5: Applied import tariffs on ethanol in selected countries

Country	Applied tariffs
Australia	5 % + A$ 0.38143/liter
Brazil	0
Canada	Can$ 0.0492/liter
Switzerland	SwF 35/100 kg
US	2.5% + US$0.51/gallon
European Union	Euro 0.192/liter

Source: Steenblick 2007

Tax incentives

Tax exemptions are the most widely used instruments to stimulate biofuel demand. The US was one of the first countries in the OECD to implement ethanol fuel tax exemptions with the 1978 Energy Tax Act. Several other countries have since followed with different forms of tax exemptions.

Subsidies and support

Several countries provide investment incentives (grants, loans) and subsidies to promote biofuel distribution, storage and use infrastructure. Flexible Fuel Vehicles (FFVs) are also being promoted through various measures, such as reduced registration fees and road taxes in Sweden, tax incentives for vehicles capable of using higher blends of ethanol in Brazil (OFID/IIASA 2009) and incentives for FFVs production in the US.

Research and development

Many biofuel producing countries fund R&D for biofuel technology. Current funding is particularly directed towards second generation biofuels, mainly cellulosic ethanol and biomass to liquid biodiesel. Comprehensive and accurate data on the level of expenditure on biofuel R&D are not available, but what is available from the EU Commission does indicate accelerated expenditure, especially by industry. A recent EU report (Wiesenthal, T. et. al. 2009), estimates the total expenditure by EU countries, both public and private, in 2007 to be around 347 million Euros, with industry contributing the lion share at 269 million Euros. When the latter figure is compared with the estimate for 2005 of 50 million Euros, it is clear that, irrespective of the inaccuracy and incompleteness of data, the field is witnessing phenomenal growth rate. R&D intensity, measured as the proportion of R&D expenditure to total investment by the industry in the sector, is reported to be around 4-5%, on the high side when compared with other sectors. The picture is similar in the US where both public and industry expenditure on biofuel R&D and investment has exploded in the last few years.

One proxy measure which demonstrates the increased level of R&D funding in the US, and globally, is offered by the noticeable increase in the number of biofuel technology patents. In 2007, biofuel patents dominated renewable energy, at least in terms of sheer numbers. Over the last six years, a total of 2,796 biofuel related patents were published, with the number rising steeply by over 150% in each of the past two years as shown in Table 1.6 (Kamis and Joshi 2008).

Table 1.6: Biofuel patents from 2002 – 2007

Year	Number of Patents
2002	147
2003	271
2004	302
2005	391
2006	640
2007	1045

Source: Kamis and Joshi 2008.

1.5 Costs, economic viability of biofuels

Liquid biofuels compete directly with gasoline and diesel. Given the relative size of energy markets in comparison with agricultural markets, energy prices tend to drive the prices of biofuels and biofuel feedstocks. Since feedstocks account for the largest share of total biofuel production costs, the relative prices of agricultural feedstocks and fossil fuels will determine the competitiveness of biofuels. The relationship differs according to crops, locations, and technologies used in biofuel production.

According to an OECD-FAO study (2008), estimated average production costs of biofuels in major producing countries, using different feedstocks, are lowest for Brazilian sugarcane ethanol. For this feedstock, energy costs are negligible because Brazil uses the sugarcane co-product, bagasse, as a process fuel. In Europe and the US, this is not the case but revenues from selling other co-products offset some of the costs. The net production costs, however, after subtracting co-product values, still remain lowest for Brazilian ethanol. The OECD-FAO study also found that Brazilian ethanol is the only biofuel which is consistently priced below its fossil fuel equivalent. For all other biofuels, net production costs exceed the price of fossil fuels.

An earlier study by the FAO found that Brazilian sugarcane was competitive at much lower crude prices than other feedstocks and locations (**FAO 2008)**. Another analysis by Tyner and Taheripour (2007) (referenced in FAO 2008) highlighted the importance of relative feedstocks and crude oil prices for the economic viability of the biofuel production system. This relationship could shift over time in response to changes in energy and feedstock prices and technological development. Economic viability could also be influenced by policy interventions. With the exception of Brazilian sugarcane ethanol, first generation biofuels are not generally competitive with fossil fuels without government support (OECD 2008).

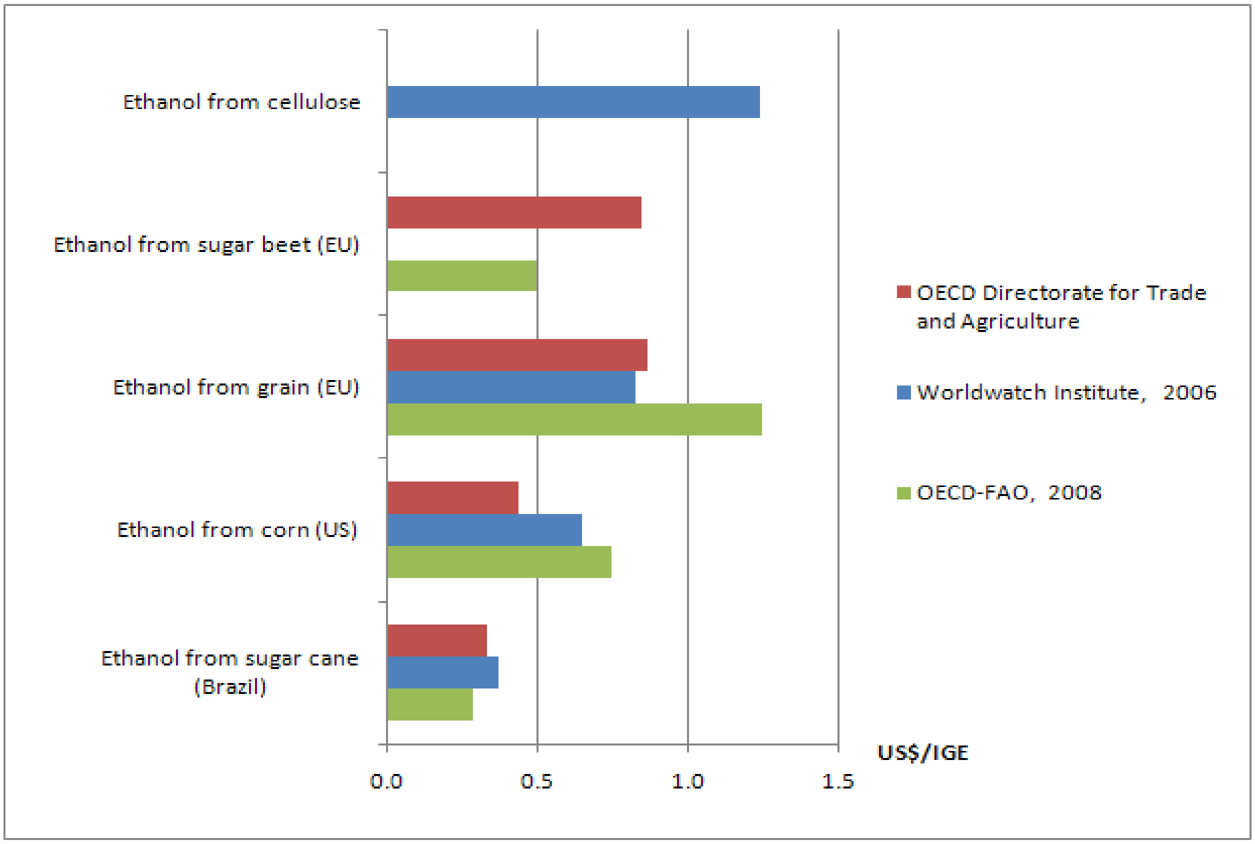
Tables 1.7a and 1.7b provide recent compilations of production costs for ethanol and biodiesel from different sources. These compilations are plotted in Figure 1.2a and Figure 1.2b.

Table 1.7a: Production costs for ethanol, in main producing countries

	Worldwatch Institute, 2006 (euro/l Gasoline Eq.)	OECD Directorate for Trade and Agriculture ($ /l Gasoline Eq.)	OECD-FAO, 2008 (US$/IGE)
Ethanol from sugar cane (Brazil)	0.21 - 0.3 0.263 - 0.375 (US$/IGE)	0.331	0.29
Ethanol from corn (US)	0.33 - 0.52 0.413 - 0.65 (US$/IGE)	0.437	0.75
Ethanol from grain (EU)	0.41 - 0.66 0.513 - 0.825 (US$/IGE)	0.869	1.25
Ethanol from sugar beet (EU)		0.848	0.5
Ethanol from cellulose	0.66 - 0.99 0.825 - 1.24 (US$/IGE)		

Source: Worldwatch Institute 2006 (data extracted from graph), OECD 2008 (data extracted from graph). For comparability, production costs are converted to gasoline/diesel equivalent by dividing production costs per litre of fuel by the energy content relative to gasoline and diesel (O.66 for ethanol, 0.89 for diesel).
Exchange rate Euro/$ = 1.25 in 2005-2006

Figure 1.2a: Maximum production costs for ethanol, in main producing countries



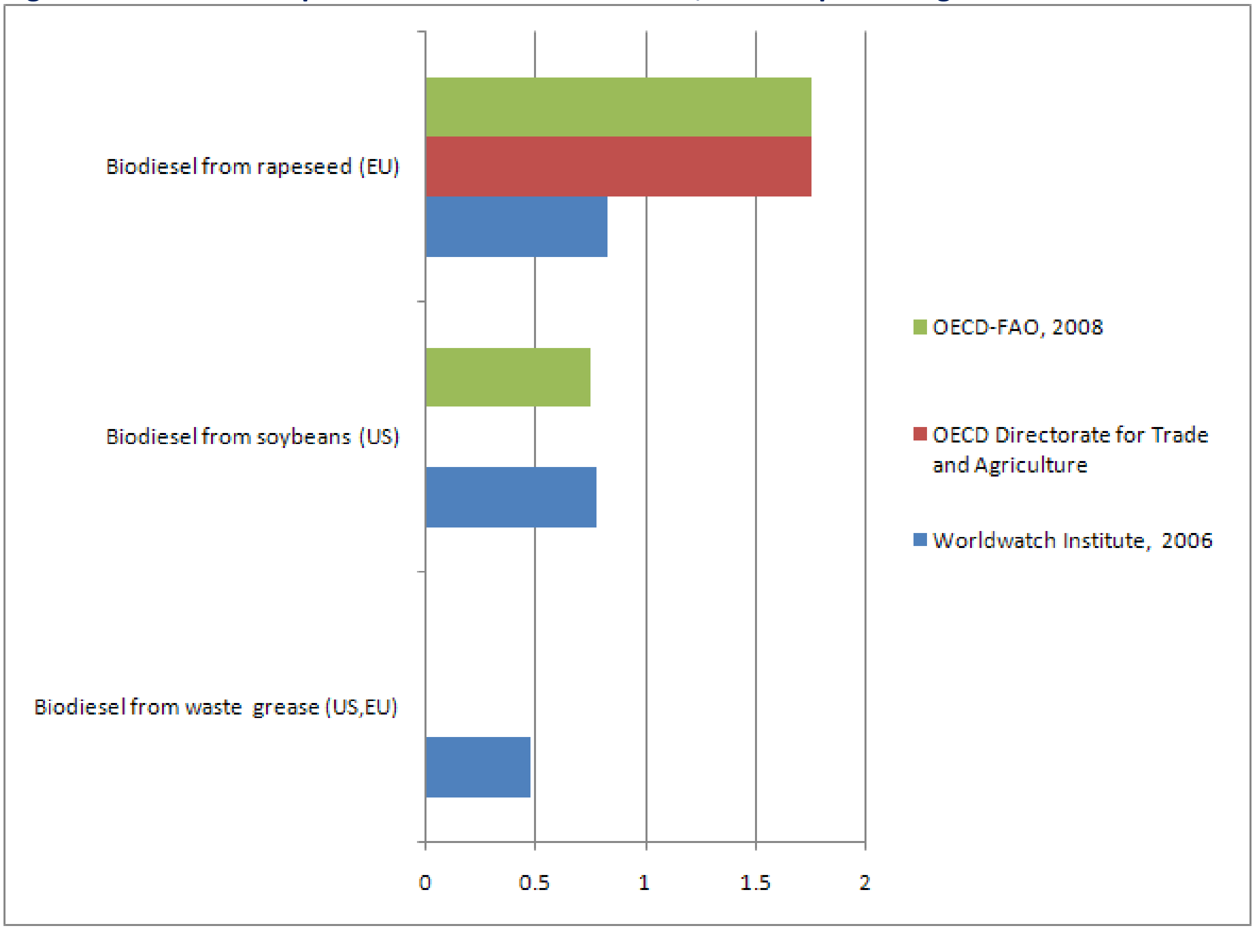
Source: Table 1.7a above.

Table 1.7b: Production costs for biodiesel, in main producing countries

	Worldwatch Institute, 2006 (euro/l Diesel Eq.)	OECD Directorate for Trade and Agriculture ($ /l Diesel Eq.)	OECD-FAO, 2008 (US$/lDE)
Biodiesel from waste grease (US,EU)	0.21 - 0.38 0.263 - 0.475 (US$/lDE)		
Biodiesel from soybeans (US)	0.33 - 0.62 0.413 - 0.775 (US$/lDE)		0.75
Biodiesel from rapeseed (EU)	0.33 - 0.66 0.413 - 0.825 (US$/lDE)	1.75	1.75

Source: Worldwatch Institute (2006), OECD 2008. For comparability, production costs are converted to gasoline/diesel equivalent by dividing production costs per litre of fuel by the energy content relative to gasoline and diesel (O.66 for ethanol, 0.89 for diesel).
Exchange rate Euro/$ = 1.25 in 2005-2006

Figure 1.2b Maximum production costs for biodiesel, in main producing countries



Source: Table 1.7b above.

2. Energy Security

While energy security is a major driver for developing biofuels in consuming countries, the documents under review do not generally address the issue in detail, probably because, since security itself is an externality, it is very difficult to put a value on a level of energy security so as to internalize the costs. Any such analysis should make a distinction between the short term (risks of supply disruption) and the longer term (energy balances).

2.1 Energy security in the short term: the challenge here is to overcome, without delay, the impacts of a supply disruption, whatever the cause (hurricane, accident in a strait, pipeline rupture, etc). In this case, the key feature of an emergency response is its immediate availability, and it is obvious that biofuels are of little help, as the time lag between any decision and the availability of products is measured in months or even years. In the short term, security tools (on the supply side) are spare capacity and stocks, because they can provide immediate deliveries.

2.2 Energy security in the long term: the key words are capacity, diversity and predictability.

- There is little doubt that biofuels contribute to increasing fuel production **capacity**, at least at first sight: the volumes which are produced add to those derived from fossil fuels when the energy balance is positive, which is generally the case (see Table 3.1)

- Similarly, biofuels clearly contribute to **diversity** of sources and of resources: the raw materials, the geographical areas, the processes, and the actors are all different. It can be argued that, as long as the order of magnitude of the targets is around 10%, it does not make a big difference; on the other hand it should be recognized that this order of magnitude is equivalent to the output of the largest single oil producers, Russia or Saudi Arabia.

- Today, **predictability** is a major drawback for biofuels, because most targets are very ambitious and seem neither realistic nor sustainable. This results in an additional uncertainty on the call on fossil fuels, in this case oil for the transportation sector, already adversely affected by many other factors such as economic growth and geopolitical issues. There is a risk in sending a negative signal to investment. As long as biofuels policies continue to be viewed as neither realistic nor sustainable in the long term, this risk of under-investment is large (i.e. underinvestment by major producers is very likely in response to large demand uncertainty). This damages long-term energy security, one of the main reasons for government policies to incentivize development and deployment of biofuels.

When conditions are right for biofuels to contribute significantly and sustainably (i.e., well above say a 10% share) in the long term, as in the case of sugarcane ethanol in Brazil, then energy security is truly improved. This is currently not the case for most first generation biofuels in most countries. In the short to medium term, again, biofuels can only marginally enhance energy security in individual countries as domestic harvests of feedstock crops for first generation biofuels can meet only a small share of the demand for transport fuels. There may be a few exceptions, in addition to Brazil. According to the World Bank Development Report (2008), recent projections indicate that "30 percent of the U.S. maize harvest could be used for ethanol by 2010, but it would still account for less than 8 percent of U.S. gasoline consumption" (World Bank 2008). Next generation biofuels hold better promise of wider improvement in energy security, if developed and deployed after a careful assessment of their sustainability (economic, environmental, etc.).

3. Implications for greenhouse gas (GHG) emissions

Fossil energy balance–the ratio of energy contained in biofuels to the fossil energy used in their production–is usually taken as a measure for evaluating the energy performance of different biofuel production pathways. The balance is also a useful measure of a particular biofuel's relative effectiveness in contributing to energy supply and can be indicative of its GHG emission impact.

Studies of the fossil energy balance for different biofuels (summarized in Table 3.1 and plotted in Figure 3.1) indicate that their net contribution to energy supply can vary widely. The variations in estimated fossil energy balances—across feedstocks, fuels and for some feedstock/fuel combinations—depend on feedstock productivity, agricultural production processes and conversion technologies. The high fossil energy balance, sugarcane biofuel, reflects the use of a co-product, bagasse (the biomass residue from sugarcane) as an energy input for its processing, as well as the feedstock's own productivity. The range for lignocellulosic[7] feedstocks is even wider, reflecting the current uncertainties regarding this technology and the diversity of potential feedstocks and production.

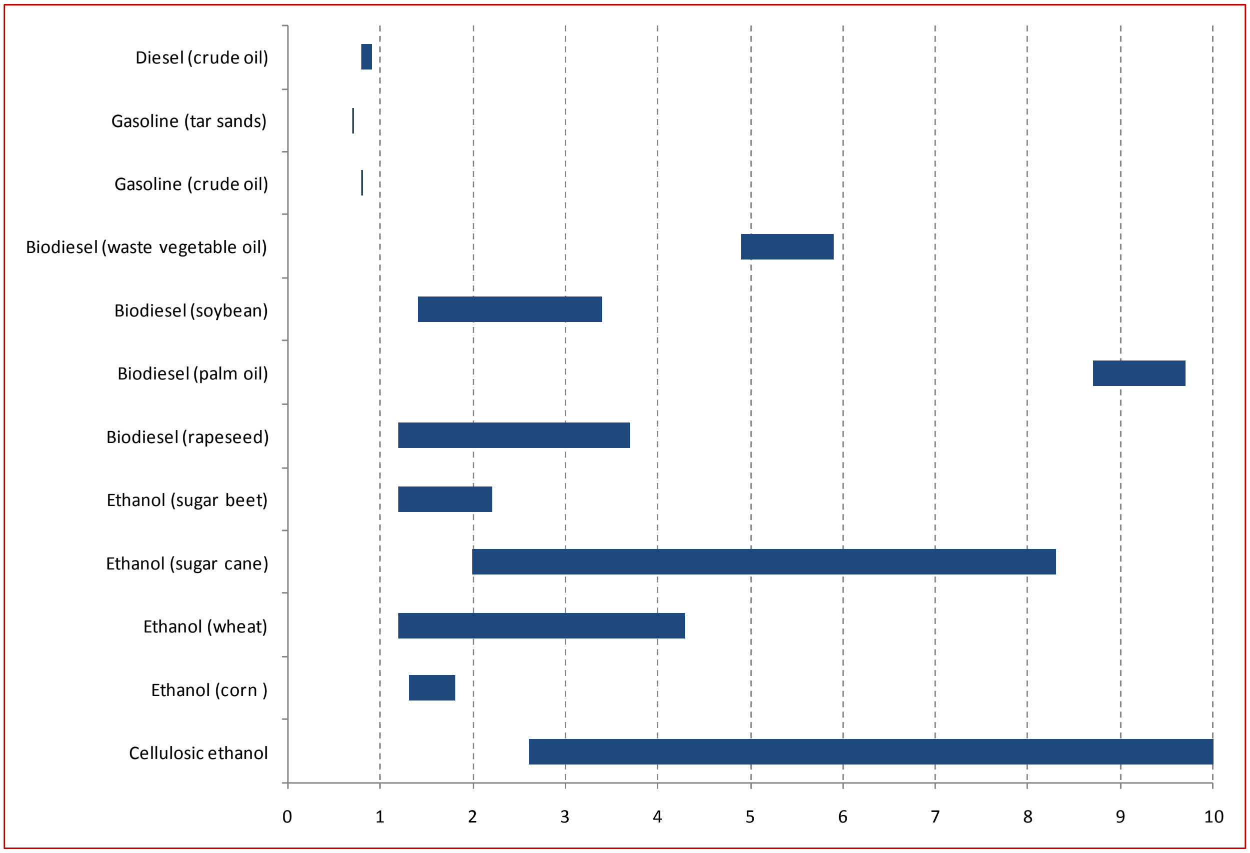
Table 3.1: Fossil energy balances of different fuel types

Fuel (feedstock)	Fossil Energy Balance (approx.)
Ethanol (corn)	1.3 - 1.8
Ethanol (wheat)	1.2 - 4.3
Ethanol (sugar cane)	2 - 8.3
Ethanol (sugar beet)	1.2 - 2.2
Biodiesel (rapeseed)	1.2 - 3.7
Biodiesel (palm oil)	8.7 - 9.7
Biodiesel (soybean)	1.4 - 3.4
Biodiesel (waste vegetable oil)	4.9 - 5.9
Cellulosic ethanol	2.6 - 35.7
Gasoline (crude oil)	0.8
Gasoline (tar sands)	0.7
Diesel (crude oil)	0.8 - 0.9

Source: Worldwatch Institute 2006, Balances for cellulosic biofuels are theoretical

[7] Lignocelluloses (cellulose, hemicellulose, and lignin) includes agricultural and forestry residues, 'herbaceous wastes' (straw, stalks, leaves, wood) and dedicated energy crops (perennial: miscanthus, switchgrass; short term species: willow, poplar).

Figure 3.1: Fossil energy balances of different fuel types



Source: Table 3.1 above

Biofuels are, in theory, carbon neutral as their combustion releases the carbon dioxide that was sequestered by the plant through photosynthesis back into the atmosphere. In addition, growing biomass can increase soil carbon stock. Therefore, biofuels' potential for reducing GHG emissions is significant. However, emissions occur throughout the biofuel life cycle system: during the harvesting, storage and transportation of raw material production, as well as during biofuel processing, and finished product storage, transportation, distribution, and use. In addition, the possibility of generating co-products[8] could have implications for net GHG emissions as these are considered "avoided emissions". Thus, fossil energy balance is only one determinant of the emissions impacts of biofuels; fertilizers and pesticides, soil treatment, irrigation technology and land use change can also have major impacts.

Most Life Cycle Assessment (LCA) studies for first generation technologies show net GHG savings. The findings summarized in Table 3.2, and presented in Figure 3.2, indicate variations ranging from negative to significant improvements, depending on several factors. These factors

[8] Co-products include livestock feed (rapeseed cake, soybean meal), biomass (straws, bagasse) and industrial use material (glycerin). Effective use of co-products significantly improves the energy and environmental performance of the biofuels production system.

include the type of technology used in production, the process fuel used (natural gas, coal, oil, renewable) in production, the presence or absence of co-generation, the impact allocation and fate of co-products, and the agricultural technology (yield, use or absence of irrigation, etc.).

Some of the negative results for corn ethanol can be explained by the inconsistent exclusion of co-products from some of the studies and the use of old data. When consistent assumptions are used, comparable results can be extrapolated. The energy mix is also important in explaining some of the negative results. For example, the use of coal as a process fuel has clearly been shown to lead to worsened GHG emission performance (Menichetti et. al, SCOPE 2009). This is the case for the negative impacts reported for sugarcane ethanol in the Gallagher review. A combination of the above mentioned factors also enter into play in the case of soybean biodiesel.

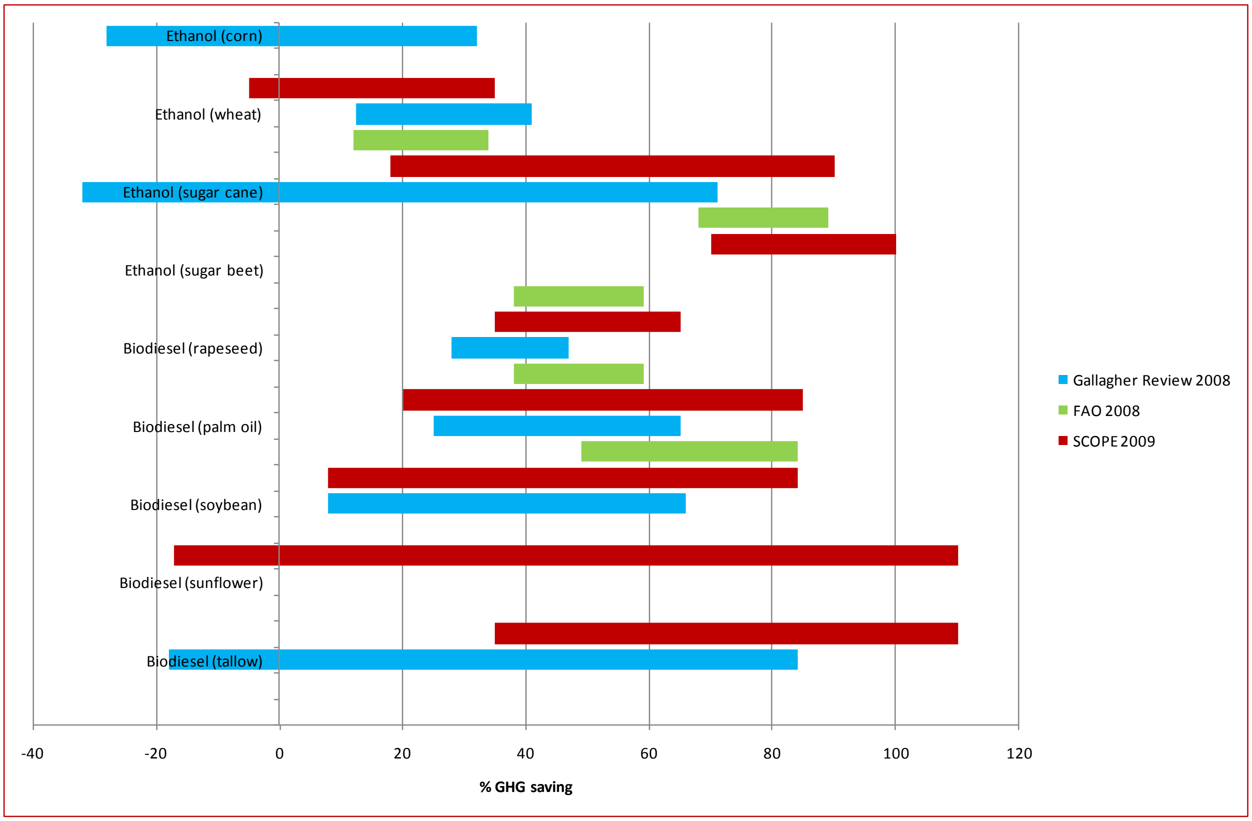
Table 3.2: Estimated GHG savings of first generation biofuels

Fuel (feedstock)	SCOPE 2009	FAO 2008	Gallagher Review 2008
Ethanol (corn)	-5 - 35%		-28 - 32%
Ethanol (wheat)	18 - 90%	12 - 34%	12.5 - 41%
Ethanol (sugar cane)	70 -100%	68 - 89%	-32 - 71%
Ethanol (sugar beet)	35 - 65%	38 - 59%	
Biodiesel (rapeseed)	20 - 85%	38 - 59%	28 - 47%
Biodiesel (palm oil)	8 - 84%;	49 - 84%	25 - 65%
	-868% w/rainforest conversion;		
	-2070% w/ peat forest conversion		
Biodiesel (soybean)	-17% - 110%		8 - 66%
Biodiesel (sunflower)	35% - 110%		
Biodiesel (tallow)			-18% - 84%

Source: SCOPE 2009, FAO 2008, RFA 2008

.

Figure 3.2: Estimated GHG savings of first generation biofuels



Source: Table 3.2 above.
Notes: When biodiesel (palm oil) production is the result of rain- or peat-forest conversion, the GHG savings (very negative) are outside the range of this chart (as can be seen in Table 3.2)

Of all the feedstocks, results for sugarcane are the most convergent. Most of the studies agree that ethanol from sugarcane can provide significant GHG reductions, when compared to conventional gasoline. Emissions reduction can be higher than 100% due to credits for co-products in the sugarcane industry. The Brazilian industry's move towards integrated processing, combining production of ethanol with other non-energy products and selling surplus electricity to the national grid, demonstrates this counter-intuitive dynamic.

Though the results for sunflower biodiesel indicate the highest improvements in GHG emissions savings, the wide range of reported values introduces large uncertainties.

The main results for second generation biofuels, (Table 3.3) show considerable improvement in GHG emissions.

Table 3.3: Estimated GHG savings of second generation biofuels

Fuel & Feedstock	SCOPE 2009	Gallagher Review 2008
Cellulosic ethanol (switchgrass)	88% - 98%	
Cellulosic ethanol (poplar, switchgrass, forest residue)	10% - 102%	
Cellulosic ethanol (wheat straw)	84% - 98%	
Cellulosic ethanol (poplar)	70%	
Cellulosic ethanol (grass and wood)	65%	79 - 90%
Ethanol (various lignocellulose)	15% - 115%	
FT Diesel (various lignocellulose)	28 - 200%	
FT Diesel (residual wood)	80% - 96%	92 - 96%
Biomethane (manure)		34% - 174%

Source: SCOPE 2009, RFA 2008.

Most of the analyses have focused on CO_2. While it is the major driver of global warming, other gases such as methane (CH_4) and nitrous oxide (N_2O) contribute significantly. N_2O is a more potent GHG; it is almost 300-times greater in its global warming potential than CO_2 (for an equivalent mass). Those studies which have included N_2O were based on the IPCC approach (*low emission factor for N_2O)* and may, therefore, have underestimated the importance of N_2O, considering the high N_2O fluxes associated with some biofuel systems such as corn and rapeseed. One study (Crutzen et al 2007, referenced in RFA 2008) concluded that the IPCC emissions factor for N_2O underestimates emissions by a factor of 3 and 5. Other studies, though not in agreement with those findings, acknowledged that the IPCC Tier 1 factor can, sometimes, underestimate emissions from some feedstocks by 14 – 50% (Gallagher review, RFA 2008).

The recent biofuels study by UNEP (UNEP 2009), points out that if those observations, accounting for the underestimation of N_2O emissions, were corroborated, the results of many LCAs would have to be reconsidered.

LCAs often do not include emissions from direct or indirect land use change (LUC) which is associated with the scaling-up of production required to meet the existing mandates for production of liquid biofuels. **Those emissions can be very large and, more importantly, even worse as they take place early in the process, thus increasing their impact on global warming** (an early emission of a ton of CO_2 is more harmful than a late one)**.**

Direct LUC occurs through conversion of native ecosystems, such as grassland, forests and peatland, to energy crop lands, or through returning abandoned croplands to production. Indirect LUC can occur when existing food/feed cropland is diverted to energy crops, thus inducing conversion of native ecosystems in another location to food/feed production to meet total demand. These land conversions can have substantial impact on the GHG balances of biofuels. Conversion of grassland to cultivated land can release 300 tons of carbon per hectare.

When forestland is converted, 600 – 1000 tons of carbon per ha are emitted (OFID/IIASA 2009). If grown on abandoned, degraded or marginal land, biofuel crops would have positive net GHG balances through the increase in soil carbon stocks. However, if that land has the potential to revert to forestland, conversion to biofuels represents a lost opportunity for carbon storage.

Complete assessment of emissions associated with LUC is a very complex and sometimes difficult issue, due to many uncertainties and a lack of data or knowledge. Such an assessment would require an accounting of all emissions associated with the biofuel system including those from: fertilizers; technologies under development; the land categories that would be affected (peat, pastures, forest, crop land, marginal land, etc.); the carbon stocks in those land categories along with the rates of release of carbon associated with land conversion; potential carbon uptake rates in those land categories; the type of feedstocks; their yields and the likely rates of change in future yields; quantities of by-products (co-products) and their potential uses (livestock feed, energy from sugarcane bagasse, etc.).

Recent studies have shown that the conversion of land from forest, grassland and abandoned cropland to land for biofuel crops not only leads to significant CO_2 emissions but can create ‘carbon debts’ of up to several hundred years (Fargione et al. 2008, Searchinger et al. 2008). Carbon debt is the time required to compensate for the CO_2 emissions resulting from the conversion of a native ecosystem through savings in fuel production and use (SCOPE 2009, OFID/IIASA 2009, Gallagher review (RFA 2008)). When this issue is taken into account in evaluating the GHG emissions reductions associated with biofuel feedstocks, such as palm oil, the net result can be dramatically negative (SCOPE 2009: reference to Beer et al 2007).

The OFID/IIASA study, using a general equilibrium model, showed that the estimated GHG savings resulting from the expansion of biofuels can only be expected after 30 to 50 years. For the period from 2020 to 2030, net GHG balances are dominated by carbon debts due to direct and indirect LUC.

The above discussion, supported by mounting evidence, indicates that for most first generation biofuels, the net impact on GHG emissions reduction is small or marginal, and in some cases, clearly unfavourable. However, it would be inappropriate to generalize and apply such conclusions to all sources of a particular type of biofuel, as the related net impact differs according to feedstock, location, agricultural practice and conversion technology.

It is therefore, important that each biofuel project’s development plan be decided upon only after a comprehensive assessment of its total GHG balance, among other key factors, is considered, with a need to improve and standardize the methodology of Life cycle assessments (LCA).

Next generation biofuels should offer dramatically reduced life-cycle GHG emissions relative to fossil fuels, due to the higher energy yield per ha and the possibility of using by-product plant waste for process energy (OFID/IIASA 2009).

4. Other Impacts and Issues

The expansion of biofuels production may result in several other significant detrimental impacts: the risk of food price increases and future competition for arable land which threatens food security, especially for the very poor; an increased risk of deforestation resulting in biodiversity loss; pressure on water resources (especially in water-scarce regions); the degradation of water quality; and air pollution.

4.1 Food security and rural development

Food prices have risen sharply in recent years, mainly as a result of increased demand for cereal and oil seeds for biofuels, low global food stocks, high oil and fertilizer prices and market speculation. After four decades of mainly declining or flat trends, real food prices increased 64% by early 2008 from their 2002 levels (FAO 2008).

Though high prices are not unusual in individual agricultural markets, the recent, sharp increase was distinguished by the fact that it affected all major food and feed commodities and because those prices may remain high for a sustained period (OECD – FAO Agricultural Outlook 2008).

The implications of expanded biofuel production on long-term food crop prices have been analyzed in the recent OFID/IIASA study. The results indicated that if the announced biofuels targets in OECD countries, and some developing countries, were realized by 2020 with first generation biofuels, crop prices would increase by around 30%, when compared with a reference scenario without biofuels. **This reinforces the conclusion that the risk would be serious if the share of biofuels in transport fuels increased dramatically, especially using first generation biofuels.** Employing a scenario of accelerated introduction of second generation biofuels (cellulosic ethanol), the study indicated that the price impacts on cereal crops in 2020 would be only half that, or around 15%. The pattern of price impacts in 2030 was found to be similar. Summarizing the various analyzed scenarios, the study found that agricultural commodity price changes depend, to a large extent, on the share of first generation biofuels in the mandated biofuel technology mix.

In developing countries, the impact on non-cereal crops is found to be stronger than on cereal crops, due to high biofuels targets, the higher share of biodiesel, and slower access to second generation biofuels. The largest price increase of about 50% occurs among coarse grains (which generally refers to cereal grains other than wheat and rice). Given the importance of corn as a staple food crop in many developing countries, particularly in Africa, this has serious implications for food security. The price of protein feeds and livestock, however, would decline by 30 to 40% in the case of protein feed, if compared to the reference scenario. This is caused by co-products entering the market in large volumes.

Overall, the trend is for upward pressure on agricultural commodity prices, which will have implications for food security and poverty levels. In the short term, it will negatively impact food security at the national and household levels (FAO 2008). The study by FAO examined the impacts of higher food prices on availability of, and access to, food at both these levels. It indicates that higher prices will have negative impacts for net food-importing developing countries, especially for low-income, food-deficit countries. On a *household* level, there will be widespread negative impacts on food security. Particularly at risk are poor urban households and poor net food buyers in rural areas who, according to empirical evidence, tend to be the majority of rural poor.

In the long run, the study concludes that growing biofuel demand and the rise in commodity prices could provide opportunities for enhancing agricultural growth and rural development. Like other commercial crops, biofuel crop cultivation does have the potential to stimulate economic growth in poor, developing countries. Studies on sub-Saharan African countries have concluded that commercial crops can help farmers get access to credits and stimulate private investment in distribution, retail and market infrastructure, as well as in human capital (FAO 2008). These developments can provide the conditions for farmers to boost their income and increase food production on their land. The study, however, notes the necessity of active government support policies that promote smallholder participation, while also addressing equity and gender issues. Another study (Cotula et al. 2008) pointed to security of land tenure as an important ingredient. Where land tenure policies are not effectively applied, the spread of commercial biofuel crop cultivation may result in a loss of access to land for poorer households which could subsequently have a negative impact on local food security and economic growth.

Other studies, however, have challenged the efficacy of first generation biofuel crop production in promoting agricultural diversification and fostering rural development in developing countries. The OFID/IIASA study indicated that only modest benefits in rural development would be achieved in developing countries. In fact, the agricultural sectors in *developed* countries benefit relatively more than those in developing countries, in terms of percentage gain in value added, 6 - 8% in the former and only 3% in the latter, by 2030.

Large-scale, commercial production of second generation biofuel feedstocks in tropical grasslands and woodlands offers better opportunities (OFID/IIASA 2009). However, to achieve this potential, there would need to be effective mechanisms for new technology transfers to and among developing countries, as well as the **removal of subsidies and trade barriers (e.g.,**

tariffs) that constrain biofuel export opportunities in developing countries, both of which are very unlikely.

4.2 Deforestation

The expansion of crop cultivation is a major contributor to deforestation. Forests, which play an important role in both the conservation of biodiversity and in mitigating global climate change, account for 30% of the world's land area. During the past decade, more forests were cleared than replanted (OFID/IIASA 2009). The FAO estimates the rate of global deforestation, in the 1990s and beginning of this century, at 8 – 9 Mha hectares per year (OFID/IIASA 2009) and the risk of this process accelerating increases with increased demand for food and energy crops.

One study (Ravindrath et al. in SCOPE 2009) showed that for a scenario of significantly increased first generation biofuel production using jatropha and sugarcane, the total land requirement in 2030 would account for 17% of current arable land, about 7% of permanent pasture and about 24% of forest area. This scenario represents a land demand equivalent to 85% of ongoing deforestation. Oil palm is even more likely to replace forests since much of the area suitable for its cultivation is covered with tropical forest (See Table 3.2). The IIASA analysis indicates that during 2000 – 2020 and 2000 – 2030, biofuels feedstock use may be responsible for up to 20 and 24 Mha, respectively, of additional deforestation. **The analysis suggests that prolonged dependence on first generation crops for biofuels will increase the risk of deforestation.**

The recent UNEP (UNEP 2009) report underscores this risk and points out that two-thirds of the current expansion of palm oil cultivation in Indonesia is based on the conversion of rainforests. If that trend continued, it says, the total rainforest area of Indonesia would be reduced by 29%, when compared to 2005 levels.

4.3 Biodiversity

Biodiversity provides and maintains essential ecosystem services to agriculture, including nutrient cycling, regulation of pests and diseases, maintenance of soil fertility and water retention.

Increased biofuel production could have negative impacts on biodiversity through habitat loss following land conversions, agrochemical pollution and the dispersion of invasive species. The degree of impact depends on the extent of associated land use changes and conversion, as well as the type of biofuel stocks (SCOPE 2009, FAO 2008).

Deforestation and conversion of grasslands and savannahs to biofuel crops, in combination with large-scale monocropping, has the highest negative effect on biodiversity. Conversion of abandoned land and extensively used grasslands has lower biodiversity losses. The impact can be positive—through the restoration of degraded land when converted to biofuel production.

Pollution from fertilizers, pesticides used to control diseases, and herbicides used to suppress weeds, can also have a significant negative impact on biodiversity. This pollution can decrease species richness of the soil and aquatic systems and change species composition. Moreover, eutrophication caused by nutrient pollution leads to changes in biogenic habitat (e.g. coral reefs) and the functioning of aquatic ecosystems. **Though the impact is generally no different from that associated with food crop production** it could be very high with large-scale production of certain biofuel crops, which are fertilizer and pesticide intensive, such as corn.

Second generation biofuels feedstocks, under minimum tillage systems and reduced fertilizer input through recycling of by-products, are, in general, resistant to pests and diseases and would thus maintain biodiversity. However, some of the species under consideration as feedstocks are known to be invasive, facilitating native species extinction, altering the composition of biogenic habitat and changing ecosystem processes such as water filtration and nutrient cycling. This raises concerns as to how to manage them and avoid unintended consequences.

4.4 Water Resources

The cultivation of crops and biomass for food and energy requires large amounts of water. Irrigation water withdrawals account for 70% of the total use of renewable water resources. By 2030, agricultural water withdrawals are projected to grow by 11% compared to 2000 (OFID/IIASA 2009).

At present, the water requirement for biofuels from food crops is modest compared to that of food production. It is estimated that biofuel crops account for 1 – 1.4% (FAO – SCOPE) of total crop evapotranspiration[9] and about 1.7 – 2% (SCOPE - FAO) of total irrigation water in 2005. Rapid expansion of biofuel production, however, would place an additional strain on water supply. In some important agricultural areas, water is already a constraining factor in food production. With increasing food demand, those areas have little excess water and capacity for large-scale biofuel production.

The water requirements of biofuel-derived energy are about 400 – 700 times larger than other energy sources such as fossil fuels, wind and solar. More than 90% of the water needed is used in the production of feedstocks. A relatively small amount is used in processing. The impact of

[9] The sum of evaporation and plant transpiration from Earth's surface to atmosphere

processing on water resources is, therefore, less than that incurred in the agricultural phase; processing has other negative impacts due to potential chemical and thermal discharge into aquatic systems from refineries and some waste co-products.

Narrowing down future water demand for biofuels is difficult as several uncertain parameters come into play. These include the percentage of energy demand met by biofuels, which in turn is driven by oil prices and the costs of other transportation alternatives, as well as policies and economics; the choice of feedstock, depending on technology development and political direction; the location of the cultivation of biofuel feedstocks; and the projected scope of increases in water productivity of the primary feedstock crops. Therefore, the water demand implications of large scale biofuel production remain uncertain. **Impacts need to be evaluated on a case by case basis (crop, land, region etc.).**

Expansion of first generation biofuel production will have implications for water quality as well as quantity. Severe water pollution can occur due to runoff from agricultural fields and from waste produced during the production of biofuels. Nitrogen contamination from fertilizers or eutrophication of surface water and ground water is a major problem, particularly with corn cultivation.

A recent study by UNEP (UNEP 2009) suggests that water quality issues, from eutrophication and acidification, have already lead to a significant environmental degradation in certain regions. For example, in the Mississippi drainage basin, greater application of fertilizers and subsequent run-off from the Mid-West corn acreage (increasingly grown for ethanol), has affected not just the local environment (streams, rivers, lakes) but also the regional environment (northern Gulf of Mexico). The UNEP study also points out that although many biofuels cause higher environmental pressures than fossil fuels, less than one-third of a representative sample of LCAs on biofuels contained results that covered these issues. **The study concludes that water, in addition to land use change, is one of the most important limiting factors to expansion of biofuel supply in the future.**

Organic waste from the sugarcane ethanol production ("vinasse") is another problem, when it is used as a fertilizer. The high organic content of the vinasse rapidly consumes oxygen, severely degrading water quality. The conversion of pastures and forests for feedstock production can exacerbate the runoff of excess nutrient into surface water.

4.5 Air quality

The production and use of biofuels produce a range of emissions that have impacts, not only on climate, but also on air quality, with implications for human health and the environment. In contrast to GHG emissions, air pollution impacts are regional and seasonal in nature, thus their lifecycle assessments are markedly different.

The air pollutants most commonly investigated, where air quality specifically is concerned, are Particulate Matter (PM), Nitrogen Oxides (NO_x), Carbon Monoxide (CO), Ozone (O_3), Sulphur oxides (SO_x) and Volatile Organic Compounds (VOCs).

PMs are mainly associated with the combustion of fuels and have respiratory health effects. Nitrogen oxides play an important role as a precursor in the atmospheric formation of ground level ozone, PM and acid rain. Ground ozone, which is chemically formed in the atmosphere through chemical reactions involving NO_x, CO and VOCs in the presence of light, causes and exacerbates respiratory problems and is associated with forest and agricultural degradation, with important implications for food supply (Chameides 1994 referenced in SCOPE 2009 Ch 10). SO_x, which contribute to PM and acid rain, are emitted from coal and crude oil combustion and refinement, but are generally present in low quantities in biofuels.

VOCs are emitted from both anthropogenic and natural sources and contribute to ozone formation and PMs. Anthropogenic sources include combustion of fuels and gasoline evaporation. In particular, ethanol vehicle emissions are high in certain VOCs that have adverse health impacts.

Natural VOCs are emitted from all trees and plants, including agricultural crops. These biogenic VOC emissions are often very large when compared to those from anthropogenic sources, especially in rural areas. Emissions differ according to plant type, temperature and light. Thus changes in agriculture or vegetation cover will have implications for the level of VOC emissions. In general, emissions from grass are less than those from woody plants, thus the conversion of forest land to crop production tends to decrease VOC emissions. Tree plantations of a number of species considered for cellulosic ethanol or biodiesel (poplar, willow, oil palm) are significant VOC emitters. In one study, VOC emissions were found to be four times higher over palm plantations in South East Asia than over the natural forest (Nemitz et al. referenced in SCOPE 2009 Ch. 10).

Few studies have examined the air quality implications of biofuel use from a life cycle perspective. One such analysis (Hess et al. SCOPE 2009) indicated that corn ethanol and cellulosic ethanol increase life cycle emissions relative to gasoline fuel. Given that energy requirements for corn and cellulosic ethanol production and transport are higher than that of petroleum, these results are expected. However, CO and sulphur emissions from low fraction ethanol blends are shown to decrease. **Thus, as an oxygenated, lead free octane index enhancer, ethanol contributes to reducing local car pollution.** In another study (Hill, 2009), cellulosic ethanol was found to decrease PM emissions. The net impacts are therefore highly uncertain for cellulosic ethanol.

One of the largest sources of PM and NO_x from biofuel production comes from burning sugarcane before harvest (to get rid of dead leaves and other biomass 'trash'). The Hess study indicated that net air quality is severely impacted by sugarcane ethanol production, even if only a small fraction of the harvested area is burned. This is of major concern given the role of NO_x in ground ozone formation.

The biodiesel LCA, with allowance for co-products, suggests there is an improvement in air quality in comparison to petro-diesel. However, given that the net impact of emissions is dependent on base feedstock and the allocation of co-products, the results are highly uncertain. Other studies show inconsistent results for biodiesel.

5. Next Generation Biofuels

Next (second and third) generation biofuel technologies are considered to offer the solution for the sustainability problems associated with first generation biofuels. Second generation biofuels use cellulosic biomass which include, herbaceous lignocellulosic species such as miscanthus, switchgrass and reed canary grass (perennial crops) and trees such as poplar, willow and eucalypt (short rotation crops), as well as forestry and agricultural residue. Algae are also being evaluated as a more promising advanced feedstock option in the distant future (often referred to as third generation).

Feedstocks for second generation biofuels generally produce higher biomass yields per hectare than most first generation crop feedstocks (the exception being sugar cane crop feedstocks). In addition to their fast growth and short-rotation characteristics, essentially the entire crop is available as feedstock. Given their relatively high projected energy conversion efficiency (IEA 2008), second generations feedstocks are projected to have higher overall energy yields (Table 5.1a and Table 5.1b). They require less tillage and chemical inputs. They also allow a wide range of land to be used for cultivation including degraded and marginal land, therefore reducing or avoiding the potential for land use competition with food and animal feed production. However, some feedstocks are considered invasive[10] (or potentially so) and thus could have negative impacts on water resources and biodiversity. Cellulosic biomass has lower handling costs than first generation biofuel crops and is easier to store, given its resistance to deterioration. On the other hand, it can often be bulky and thus require well developed and costly transportation infrastructure (FAO 2008).

[10] Species that are introduced outside their native habitat could spread and have negative impacts on native biodiversity.

Table 5.1a: Biofuel yields for different first generation feedstocks and countries

Crop	Global/national estimates	Biofuel	Crop yield (tonnes/ha)	Conversion efficiency (liters/tonne)	Biofuel yield (liters/ha)
Sugar beet	Global	Ethanol	46.0	110	5060
Sugar cane	Global	Ethanol	65.0	70	4550
Cassava	Global	Ethanol	12.0	180	2070
Maize	Global	Ethanol	4.9	400	1960
Rice	Global	Ethanol	4.2	430	1806
Wheat	Global	Ethanol	2.8	340	952
Sorghum	Global	Ethanol	1.3	380	494
Sugar cane	Brazil	Ethanol	73.5	74.5	5476
Sugar cane	India	Ethanol	60.7	74.5	4522
Oil palm	Malaysia	Biodiesel	20.6	230	4736
Oil palm	Indonesia	Biodiesel	17.8	230	4092
Maize	USA	Ethanol	9.4	399	3751
Maize	China	Ethanol	5.0	399	1995
Cassava	Brazil	Ethanol	13.6	137	1863
Cassava	Nigeria	Ethanol	10.8	137	1480
Soybean	USA	Biodiesel	2.7	205	552
Soybean	Brazil	Biodiesel	2.4	205	491

Source: FAO 2008

Table 5.1b: Typical yields of second generation feedstocks
(using IEA Bioenergy typical biofuel yields for forest residue)

Dry tons/ha	Current yield, Dry t/ha	GJ/ha	Litres/ha	Expected yield	GJ/ha	Litres/ha
Miscanthus	10	200	1250- 3000	20	400	2500-6000
Switchgrass	12	240	1500- 3600	16	320	2000-4800
Willow	10	200	1250- 3000	15	300	1875-4500
Poplar	9	180	1125- 2700	13	260	1625-3900

Source: Worldwatch Institute 2007: Biofuels for Transport: Global Potential and Implications for Sustainable Energy & Agriculture; IEA Bioenergy

Second generation biofuels can also reduce life-cycle GHG emissions because of the higher energy yields per hectare and the potential of leftover plants (mostly lignin) to be used as process energy. The technology, however, is at an early stage of development. Substantial technological and economic barriers impede its commercial deployment, including high production costs, logistics and supply challenges. Another important barrier is the set of agricultural/forestry sector changes needed to regularly supply the lignocellulosic feedstock depend on changes in agricultural management, as well as policy changes, both of which will take time to implement.

5.1 Conversion technologies

The main technological conversion pathways for cellulosic biofuel production are bio-chemical and thermo-chemical. The bio-chemical process involves breaking down the cellulosic biomass via acid or enzymatic hydrolysis into sugars, which are then fermented and distilled to obtain ethanol. Enzymatic hydrolysis is the preferred choice as it has higher yields, requires less chemical input and is more environmentally sustainable. The hydrolysis step is technically challenging and research is continuing to develop more efficient ways of conversion.

The thermo-chemical pathway involves pyrolysis or gasification of biomass to produce synthetic gas (syngas) which can then be used in a chemical process (Fischer-Tropsch) to produce a range of liquid biofuels including FT diesel, methanol, methane and hydrogen fuel. The FT process is a well-established technology used in the production of liquid fuels from coal and natural gas. Production from biomass, however, is still under development. A key challenge is the production of clean syngas required for the FT process. Research is being conducted on several gasification options and on the production of catalysts that are resistant to contaminants (IEA Bioenergy 2008). The diesel produced from the FT process is a high quality product with energy intensity similar to that of conventional diesel, a high cetane number and low sulfur content.

Both conversion processes according a recent report by the IEA (2008) have an overall biomass to biofuel conversion efficiency of about 35%. Ranges of indicative biofuel yields per dry ton of biomass are shown in Table 5.2

Table 5.2: Indicative yields of second generation conversion technologies

Process	Biofuel yield (liters/dry t)		Heating Value (GJ/litre)	Energy yields (Gj/dry t)		Process Efficiency %
	Low	High		Low	high	
Biochemical Enzymatic hydrolysis ethanol	110	300	0.0211	2.3	5.7	12-29
Forest Residues	125	300		2.6	6.3	13-32
Thermo-chemical F-T Diesel	75	200	0.344	2.6	6.9	13-35

Source: IEA Bioenergy 2008

5.2 Cost estimates

Future projected costs of lignocellulosic biofuels range from \$0.60 - \$1.30/l gasoline equivalent (lge), depending on assumptions for feedstock costs, the timing of commercial availability of conversion technologies and the feedstock supply chain. Potential cost reductions could lower total costs to \$ 0.25 and \$0.35/lge, according to some estimates (IEA Bioenergy 2008).

The IEA has developed cost projections based on the potential market penetration of second generation biofuels to 2050, as summarized in Table 5.3.

Table 5.3: Second generation biofuel cost assumptions

Conversion technology	Assumptions	Production costs (\$/lge)		
		2010	2020	2030
Bio-chemical ethanol	Optimistic	0.8	0.55	0.55
	Pessimistic	0.9	0.65	0.6
FT diesel	Optimistic	1	0.6	0.55
	Pessimistic	1.2	0.7	0.65

Source: IEA 2008, Energy Technology Perspectives to 2050 (referenced in IEA Bioenergy 2008)

The projections assume a dramatic acceleration of second generation biofuels production after 2030 to meet 26% of transport fuel demand by 2050. Thus, slower deployment would imply higher costs.

Another projection for biofuel costs (IEA Bioenergy 2008), based on an earlier IEA analysis in the WEO 2006, indicated that, excluding any subsidies, biofuel production costs would have to be about \$0.80/lge to be competitive with gasoline and diesel prices at \$100/bbl.

Madhu Khanna, from EBI and the University of Illinois, recently provided another set of cost estimates for the US case, as summarized in Table 5.4, which also shows the corresponding reduction potential of life cycle GHG emissions.

Table 5.4: Projected cost of first and second generation biofuels for the US market

	Feedstock cost	Refinery cost	\$/gallon ethanol (net of co-product value)	Greenhouse gas emissions relative to gasoline
Corn ethanol	1.66	0.78	2.00	75%
Corn stover	0.86	1.46	2.20	18%
Miscanthus	1.41	1.46	2.75	11%
Switchgrass	2.90	1.46	4.24	43%

Source: Khanna, M.

The EU RENEW project (renewable fuels for advanced power trains) estimated a cost of Euro 0.85/lge for biodiesel from forest residue, decreasing to Euro 0.77/lge by 2020, due to more intensive production of short rotation crops.

5.3 Prospects and implications

Research programs on improving overall process efficiency and integration of various process steps are underway in many countries, often with government support. Process operating units are in place at the University of British Columbia in Canada, at Lund University in Sweden and at the US National Renewable Energy Laboratory. Several companies have announced plans, or have already begun to develop second generation biofuels demonstration facilities. In the US, the DOE has put forward a program of support for demonstration plants and research with a goal of producing 147 billion litres of ethanol by 2017. The report by the IEA, Bioenergy 2008, provides a comprehensive summary of activities by companies and government institutions.

It is expected that, given the complexity of the technical and economical challenges involved, wide deployment of commercial plants will not take place before 2015 or 2020 (IEA 2009, OFID/IIASA 2009). Therefore, uncertainties exist as to the extent of the contribution of second generation biofuel technologies to the global transport fuel demand by 2030.

Addressing these uncertainties, the OFID/IIASA analysis examined a range of assumptions on the expected share of second generation biofuels in total transport biofuels in three scenario variants (Table 5.5). Scenario V1 assumes gradual deployment after 2015, while scenario V2 assumes delayed arrival of second generation biofuels with first generation biofuels capturing the market until 2030. In scenario V3 rapid deployment of second generation biofuels in developed countries is assumed due to accelerated development, driven particularly by the US' ambitious targets.

Table 5.5: Share of second generation biofuels in total transport biofuels by scenario, summary

Scenario	Share of second generation biofuels	
	2020	2030
Global average		
TAR V1	2	12
TAR V2	0	0
TAR V3	22	38
Developed Countries		
TAR V1	4	18
TAR V2	0	0
TAR V3	33	51

Source: OFID/IIASA 2009

The analysis indicates that rapid deployment of second generation technologies after 2015, if done to meet the biofuel production target scenario, would imply about 315 million dry tons of biomass requirement by 2020, increasing to 725 million dry tons in 2030. Developed countries would account for 95% and 83% of the demand, respectively.

The biomass requirement in 2020 implies that 32 Mha of land will be needed (assuming an average typical yield of about 10 dry tons/ha), if all the biomass comes from plantations of dedicated crops (perennial grass and short rotation forest crops). However, due to the availability of large amounts of forest and agricultural residues, the land requirements would actually be lower. By 2030, with the average yield assumed to increase to about 15 dry tons/ha, land requirements would not exceed 50 Mha in the scenario with rapid deployment and would be less than 20 Mha in the other scenarios.

The IEA analysis in the WEO 2006 indicates similar findings. With the assumption that second generation biofuels become widely commercialized before 2030, increasing biofuels' share to 10% of global transport demand, land requirements would go up only slightly to 4.2 % of arable land, due to higher energy yields per hectare and the use of waste biomass.

With respect to GHG savings, the analysis shows that rapid deployment of second generation biofuels can increase GHG savings compared to that for first generation biofuels (Table 5.6).

Table 5.6: Net cumulated GHG savings of biofuels scenarios

Scenario	Net GHG savings first - second generation biofuels (Gt CO2 Eq.)	
	2000-2020	2000-2030
WEO -V1	-2.4 to -1.6	-0.7 to 1.1
WEO-V2	-2.6 to -1.8	-1.3 to 0.3
TAR-V1	-5.3 to -4.0	-3.2 to 0.2
TAR-V3	-3.8 to -1.8	0.7 to 5.0

Source: OFID/IIASA 2009 *(Ranges reflect high and low estimates of GHG savings for different feedstocks).*
Note: WEO is the OFID/IIASA reference scenario based on the IEA WEO 2008. The units represent the reduction in GHG resulting from more rapid introduction of second generation technologies replacing first generation technologies to meet same targets.

There is, however, a need to ensure that only marginal land or waste and residues are in fact the supply sources for biofuel feedstocks, otherwise the negative impact could be higher. Given that second generation technologies, unlike first generation technologies, do not produce co-products that can be used for animal feed, they do not offer the possibility of offsetting any land use change in the same way (Gallagher 2008 (RFA 2008)).

5.4 Algae-derived biofuels

Algae are microscopic, aquatic plants that convert water and CO_2 in the presence of sunlight into biomass, oils, and oxygen. The oil produced can be converted into very high quality diesel and the carbohydrate content of the biomass can be converted into ethanol.

Algae require no fresh water or arable land. At the same time, because they feed on CO_2, algae production could also be used for CO_2 capture from large sources. Another benefit is the high oil yield per hectare, when compared to first and second generation biofuels (Table 5.7, Hart/GBC 2008)

Table 5.7: Oil yields for algae and other biodiesel feedstocks

Feedstocks	Oil yield (barrels/ha/yr)
Soybean	2.5
Sunflower	5
Jatropha	12
Palm oil	36
Algae	360

Source: Global Biofuels Center 2008

The conversion process for algae oil into biodiesel is similar to that of the process for vegetable oil. However, the cost is very high at present. The need for large facilities, low costs and the prevention of contamination are some of the key challenges. Research is currently being conducted on the optimum strains of algae and on the reduction of cultivation, oil extraction and processing costs by governments and private institutions.

The US Defense Advanced Research Projects Agency is funding research into jet fuel production from algae. Royal Dutch/Shell is collaborating with a company in Hawaii to build a demonstration plant to commercially harvest algae and demonstrate the technical viability of converting algae into diesel (IEA Bioenergy 2008). BP signed a contract with the University of California, Lawrence Berkeley National Laboratory and the University of Illinois at Urbana Champaign establishing a $500 million joint Energy Biosciences Institute that will conduct biotechnology-based alternative energy research. Most recently, ExxonMobil announced last July an investment of $600 million to produce liquid transportation fuels from algae. The effort involves a partnership with the Synthetic Genomics Company. A summary of activities by some companies and institutions is provided in the reports by Hart/GBC and IEA Bioenergy 2008. Another experiment has been launched in France by the French Petroleum Institute (IFP) and the National Institute for Agronomic Research (INRA).

In conclusion, next generation biofuels offer significantly better promise than first generation biofuels, in terms of their expanded contribution to liquid fuels with fewer impacts or limitations. However, there are many technical and economic barriers and further extensive R&D efforts are required. Despite large efforts made by public and private organizations in major OECD countries, progress in the development and commercialization of next generation biofuels has been slow. It is unlikely that they will become commercially available on a large scale before another decade, at the earliest. First generation biofuels will continue to constitute the bulk of the biofuels for another decade and will coexist with next generation biofuels for sometime thereafter.

6. Conclusions

Driven by policies aimed at enhancing energy security through a diversification of energy sources, reducing greenhouse gas emissions and accelerating agricultural development, production and use of biofuels has increased rapidly in recent years. These developments have outpaced our understanding of the potential impact of biofuels on the environment, sustainable utilization of natural resources and food security. **With the exception of sugarcane ethanol in Brazil, all so called first generation biofuels have experienced some problems and revealed drawbacks** which had not been predicted or emphasized in the initial enthusiasm. Yet, notwithstanding the significant slowdown of growth during 2009, projections indicate that biofuel growth is set to resume its pre-financial crisis course as of 2010, and is projected to meet, and possibly exceed, government established targets over the medium term.

Therefore, to avoid potentially costly environmental and economic mistakes, there is an urgent need to review existing biofuel policies and targets in an international context, both to protect the poor and to improve food security while ensuring sustainability. **Setting strong and ambitious targets before ensuring sustainability, as has been the case for most first generation biofuels, adds to uncertainty of supply**, which could increase market volatility in the medium term. This in turn would increase energy security risk rather than improve it.

Many countries have commissioned studies to assess the sustainability of current biofuel strategies and policies; some countries have already introduced significant changes to their strategies and policies, including lowering targets and/or slowing down the growth rates to reach targets, developing criteria for assessing sustainability, such as standardizing comprehensive LCAs, establishing limits on land change and/or use for biofuel production, etc.

Next generation biofuels currently under development hold much better promise, but require extensive R&D to overcome scientific, technical, and sustainability barriers. Production of any type of biofuel will involve trade-offs among the multi-dimensional aspects of sustainability. **No doubt some biofuels are likely to contribute significantly to the future world mix of liquid transportation fuels, but establishing firm targets for such promising next generation biofuels is premature and should be considered only after careful evaluation against long-term sustainability.** Future biofuel production and use should meet several essential criteria: biofuels should result in significant greenhouse gas savings compared to fossil fuels; rely on environmentally sound agricultural and forestry management systems for production of feedstock; preserve biodiversity and cultural heritage; be socially inclusive; integrate with food and other biomass use sectors and contribute positively to overall land-use. With very few exceptions, this is not the case today.

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Annex

Terms of Reference

for

Biofuels Assessment Report

Introduction

The Closing Statement by Host Italy and Co-hosting Countries India and Mexico of the 11th **International Energy Forum** (IEF) in Rome, 20-22 April 2008 contains the following paragraph on biofuels: "While welcoming the development of alternative sources of energy, Ministers highlighted some drawbacks and limits of biofuels. A realistic and comprehensive assessment of their future and potential environmental and economic implications is an important factor for investment decisions in the coming years. The IEF Secretariat was asked to work together with IEA, OPEC, and other relevant organizations to ensure this assessment will become available".

The Summary Report by CEOs of the 3rd **International Energy Business Forum** (IEBF), Rome, 21 April 2008, also contains a paragraph on biofuels: "Biofuels can contribute to satisfy the energy demand growth. The ethanol boom creates rural jobs and develops agribusiness, yet raising several concerns. CEOs noted that the problem with biofuels is twofold: increased land use leads to the destruction of forests and wetlands in tropical countries, while support for corn-and-grain-based biofuels production in wealthy countries contributes to food price escalation. The shift of cultivation toward biofuels, a radical transformation of human habits, is something that needs to be thoroughly and comprehensively evaluated".

The Background paper to the **Jeddah Energy Meeting** (22 June 2008), jointly prepared by the Kingdom of Saudi Arabia and the Secretariats of IEA, IEF and OPEC has a brief reference to the impact of biofuels on the refining industry: "In addition, while contributing to energy supply growth, biofuels are having a compounding effect on the refining industry in some regions".

Elsewhere in this background paper, uncertainties about energy and environmental policies in consuming countries are quoted as an important factor behind the oil price development, which can to a significant extent be interpreted as uncertainties regarding the achievement of ambitious biofuels targets. Also noted in the Jeddah background paper is the relationship between oil prices and biofuels: "Higher oil prices will enhance the flow of investment into alternative fuels, which will put a floor to oil prices".

In the **London Energy Meeting**, 19 December 2008, the UK government presented a paper on a comparison between IEA and OPEC oil demand and supply projections in the medium and long term. Not surprisingly, different future projections on biofuels were among the key factors that were identified as causing diverging projections between IEA and OPEC.

Scope of work

The points above try to set the context of the assessment report. Given the 2008 experience of extreme oil price volatility and the current relatively low prices, it is more than ever important for IEF Ministers to get a realistic assessment of what can be expected from biofuels up to 2030. Many relevant questions urgently need to be answered. Here are a few that we see:

- Are the existing targets in consuming countries for biofuels achievable?
- Are the subsidies/tax incentives for biofuels in consuming countries sustainable in economic/budgetary terms given current relatively low oil prices and given increasing budget pressures as a consequence of the economic downturn? If not, what are the consequences?
- Are consuming countries implicitly counting on producer countries to 'fill the gap' with crude oil supply if they fail to achieve their biofuels supply growth?
- To what extent will this uncertainty dampen investment in crude oil supply?
- What are the environmental and food market consequences of the anticipated growth of biofuels in terms of CO_2, land-use, water, deforestation?
- How fast is the technology for second-generation biofuels developing?
- How realistic is it to expect second-generation biofuels to be of any significant importance in achieving biofuels targets in the next decade? If not, what will be the consequences?

Some of these questions have been addressed in studies, reports and documents which have been published by various organizations recently. These documents [have been] provided to the authors… in order to assess to what extent they can contribute seriously and consistently to bringing some answers, pointing out where feasible, any remaining sizable uncertainties or open questions.