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AGRICULTURAL MARKET IMPACTS OF FUTURE GROWTH IN THE PRODUCTION OF BIOFUELS

This is the final version of a study which was carried out under the 2005/2006 Programme of Work of the Committee for Agriculture.

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FOREWORD

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EXECUTIVE SUMMARY

The principal objective of the present study is to look at the economics of biofuel production and the likely impacts of an expected growth in biofuel-related demand for agricultural products on commodity markets. It describes the economics and policies in biofuel markets by bringing together available information on production technologies, costs and policy measures in major biofuel producing countries. Additionally based on assumptions where data are missing, production costs are calculated for the year 2004 (the base year for the impact analysis below) and compared across countries and production processes as well as with oil-based fuel prices to show the relative competitiveness of biofuel production. Impacts on agricultural markets are analysed using the OECD partial equilibrium model for temperate zone agricultural commodities, Aglink, in connection with the FAO-counterpart, Cosimo, and the OECD World Sugar Model. A number of modifications are made to the models to allow for this type of analysis, as well as to model the impact of changes in crude oil prices on agricultural production costs. Model results of a set of scenarios are compared in order to identify the specific impacts of expected growth in biofuels production as well as those of changes in world crude oil prices.

Biofuels represent a significant and growing source of demand for agricultural commodities. Ethanol and biodiesel, which have become a ready substitute for oil-based gasoline and diesel, are currently made from starch and sugar crops as well as from vegetable oils, respectively, and hence create an increasing market for these commodities.

Current production costs vary considerably between countries as well as across feedstocks. Available data suggest that only Brazil would be able to produce ethanol in an economically viable manner with world crude oil prices of around USD 39 per barrel, which was the prevailing price in 2004. Oil prices that would allow national biofuel production in the US, Canada and the EU to become profitable without subsidies are generally higher, with estimates ranging from USD 44 to USD 145 per barrel. In particular for the US this implies that with a moderate further increase in crude oil prices as seen in 2005, biofuel production could also become profitable. Important variables determining the production cost differences across countries and feedstocks include in particular the domestic crop prices which are driven by regional supply and demand conditions, as well as by domestic and trade policies. Technical progress also has an important impact on future production costs.

Similar results can be found with respect to the area requirements for a given share of domestic transport fuel consumption. The results of these calculations suggest that the three OECD regions, the US, Canada and EU (15) would require between 30% and 70% of their respective current crop area if they are to replace 10% of their transport fuel consumption by biofuels, assuming unchanged production technologies, feedstock shares and crop yields, and in the absence of international trade in biofuels or use of marginal or fallow land. However, only 3% would be required in Brazil. While technical progress in agriculture and biofuel production as well as land use changes are likely to improve efficiencies of biofuel production processes, both production costs and area requirements suggest a substantial comparative advantage of Brazil relative to OECD countries.

The additional demand for agricultural commodities resulting from increased biofuel production is likely to substantially affect the outlook for their markets. The major producers of biofuels – Brazil, the US, the EU and Canada are covered explicitly in this analysis – are expected to significantly reduce their

exports of the respective feedstock commodities or to increase their imports. Compared to a situation with unchanged biofuel quantities at their 2004 levels, crop prices in 2014 could increase by between 2% in the case of oilseeds and almost 60% in the case of sugar.

The analysis also shows that commodity markets are strongly influenced by crude oil prices. Higher oil prices as currently observed increase production costs in agriculture, but also create higher incentives for biofuel production, thus stimulating demand for feedstock products. The degree to which biofuel quantities would increase strongly depends on parameters that are yet unobserved. Nevertheless, the results of this analysis suggest that the impacts of high oil prices on agricultural markets may well be dominated by their direct effects on agricultural production costs rather than by the increased demand for agricultural commodities.

The impact of biofuel production on agricultural markets is expected to change significantly once "advanced" biofuels become competitive. Technologies to produce ethanol from cellulosic and ligno-cellulosic material are being developed in pilot plants and are expected to allow production costs to fall substantially below those of commodity-based fuels within the next two decades – developments that have not been considered in this analysis. In addition to the cost advantage, area requirements for a given quantity of ethanol would be much lower as the fuels could be produced either from waste materials or from designated fuel crops with a much higher ethanol yield per hectare of land. Due to the possible strong increase in biofuel production as costs fall, however, it is impossible to make an *a priori* assessment on whether the lower land requirements per unit of biofuel energy would be under- or overcompensated by the overall change in biofuel production, and hence whether the eventual market implications would be smaller or larger than those shown in this study.

A number of policy questions have been left aside in this analysis. Without support, biofuel quantities would likely develop less dynamically as in many countries and for most production processes biofuel production is more expensive than the prices net of taxes for gasoline and diesel when taking into account the energy contents of the different fuels – without tax concessions, biofuels would therefore be more expensive than oil-based fuels on an energy basis, although this clearly also depends on the further development of crude oil prices. Public support for biofuel production and consumption undoubtedly results in increased demand for starchy and sugar crops as well as for vegetable oils. Higher prices certainly are in the interest of producers of such commodities, but will be less welcome to their consumers, in particular to livestock producers both in biofuels producing countries and elsewhere. Biofuel policies may therefore be considered an important element in the agricultural policy debate.

Related to domestic biofuel policies, trade in ethanol and biodiesel is facing a number of barriers in several countries that prevent low-cost producers from fully exploiting their export potential. Reducing such barriers (including the set up of international product standards) would not only allow these countries to better sell their product, but would also help to meet the environmental objectives behind many of the national biofuel policies of (potentially) importing countries, provided the fuels are produced in the exporting countries in an environmentally sound manner. The sustainability of biofuel production chains is subject to intensive debate and will need to be taken into account in the evaluation of policies and their market impacts.

A number of caveats on the quantitative analysis in this study need to be mentioned. First, data availability for biofuel production costs and quantities is relatively poor in numerous countries that are or may become important players in this area. Consequently, several simplifying assumptions are made with respect to production technologies across countries, and some potentially important biofuel producers, most notably China and India, as well as a number of feedstock commodities are not taken into account. Second, both the calculation of production costs and area requirements as well as the model-based impact analysis ignore the potential benefits of "advanced" biofuels. Third, the calculation of area requirements remains perfectly static as opposed to projections into the future in that it represents unchanged 2004 conditions in terms of technology, feedstock mix and area use. In addition, neither the potential use of currently unproductive land nor the implications of international trade are taken into account.

AGRICULTURAL MARKET IMPACTS OF FUTURE GROWTH IN THE PRODUCTION OF BIOFUELS

1. Introduction

Biofuels can be defined as “transportation fuels derived from biological (e.g. agricultural) sources”.[1] While only a subgroup among many types of biomass[2], biofuels can come in various forms, either liquid such as fuel ethanol or biodiesel, or gaseous such as biogas or hydrogen.

Biofuels can be produced from a variety of feedstocks. Many of them are agricultural commodities traditionally used in the food chain: ethanol can be made from starchy and sugar crops (such as cereals, sugar cane and others), while the feedstock for biodiesel generally is vegetable oils derived from oilseed crops. Obviously an increased production of these biofuels would draw away agricultural resources from other uses. However, non-food organic materials, such as cellulosic materials from grasses (including straw) and wood, can also be used to produce biofuels, and while the process costs currently exceed those for commodity-based biofuels, an increase in biofuels production from those materials would have less direct links to agricultural markets.[3] Finally, biofuels can even be produced from waste materials, although available quantities of these materials may be relatively small in many areas.

While use of gaseous biofuels in motor vehicles would require engines that differ significantly from the vast majority of those currently in use, liquid biofuels such as ethanol and biodiesel can replace their fossil counterparts, gasoline and diesel, fairly easily as a transport fuel. Low-level blends of biofuels with gasoline or diesel can be used in most cars produced today, and the use of higher-level blends, or even of pure biofuels, often requires only relatively small modifications to motor vehicle engines. In some countries, so-called *flex-fuel* engines are becoming increasingly available in public and private motor vehicles. These cars provide their owners with the flexibility to choose gasoline, ethanol or any blend of the two depending on prices. Finally, ethanol can also be used together with isobutene, a petrol-based co-product of the oil and chemical industry, to produce ethyl tertio butyl ether (ETBE), which can also be used as an additive to gasoline.

The increased interest in biofuels can be explained by a range of factors, including ecological,[4] economic and geo-political reasons. The rapid growth in energy consumption and, more specifically, in fossil fuel use in the transportation sector, has lead to commensurate growth in emissions that are harmful to the environment at local, regional and global levels. High crude oil prices and the finite supply of fossil fuels create additional economic incentives for using alternative fuel sources, and encourage research in this area. Rising oil demand has lead to a growing dependency on a relatively small number of oil supply regions which, in some cases, are considered a geopolitical risk. In addition, farm organisations and other farming groups continue to be on the look out for new markets for agricultural products as a way to generate higher incomes for their producers.

Because renewable fuels are generally still more expensive to produce than fossil-based fuels, their commercial viability often depends on policy interventions by governments, although in the future this will depend on the further development of crude oil prices. In many instances, biofuel production has been promoted by government programmes, either through the provision of market incentives or by market regulations. In terms of market incentives, tax concessions are typically given through lower or zero excise taxes relative to those applying to traditional fuels, but can be provided through direct tax subsidies, too. Vehicle taxes and subsidies can promote sales of cars running on biofuels, while public investment subsidies, such as for research and development etc. can increase biofuel supplies. Regulatory measures include fuel blending standards and bans on certain chemical ingredients in fuels which can alter the transport fuel mix.

This study does not try to address all of the different driving forces listed above. Its main objective is to determine what impact future biofuel developments can have on agricultural commodity markets through a quantitative assessment of several scenarios based on the use of an agricultural trade model. Through comparing the model results of different scenarios with one another, the specific impacts of changes in biofuel developments can be identified. This extends and deepens an earlier analysis of biofuel developments published in OECD (2002).

The report is organised as follows. Sections 2 and 3 will briefly summarise the various processes used in biofuel production and provide estimates of production costs for each of these processes. Section 4 focuses on current and planned national programmes and policies to promote biofuel production and use. Section 5 then summarises the baseline projections used for the quantitative analysis of the impacts of biofuel developments on agricultural commodity markets and shows to what degree biofuel developments are explicitly or implicitly taken into account in the projections. It also briefly discusses the model used for the analysis and how it was adapted for the purpose of the current exercise. Section 6 outlines the different scenarios analysed and discusses their results. After a brief and qualitative assessment of longer-term developments in "modern" biofuels, i.e. of biofuels that are made from feedstocks other than food and feed commodities in section 6 a final section 7 summarises the main findings of the study and provides a set of conclusions. The methods of modelling biofuel developments and crude oil prices are laid out in more detail in Annex 3, which also provides the different technical and other parameters employed in the model.

Much of the information and particularly of the data used in this study is drawn from a consultancy report prepared by experts of the Copernicus Institute of the University of Utrecht in the Netherlands[5]. This report brings together recent information about national biofuel policies and production targets – summarised in section 4 of this report – as well as technical and economic data on the various biofuel production systems that are used in the quantitative analysis. Annex 4 outlines the conclusions offered in the full report.

While this study has a global focus that goes beyond the OECD countries, it remains selective in that not all countries with actual or potential biofuel markets are explicitly covered. Instead, it is focused on those countries where biofuel markets have achieved a significant size already, or where they are expected to reach significant volumes in the medium term.

2. Basic information on biofuels

Currently, two different types of biofuels represent the bulk of renewable transport fuels around the world: ethanol and biodiesel. Other fuels, such as biogas and hydrogen (which itself can be produced from various organic sources) or synthetic gasoline and diesel (such as biomass-to-liquid, BTL), currently play only a minor role. This study therefore concentrates on ethanol and biodiesel.

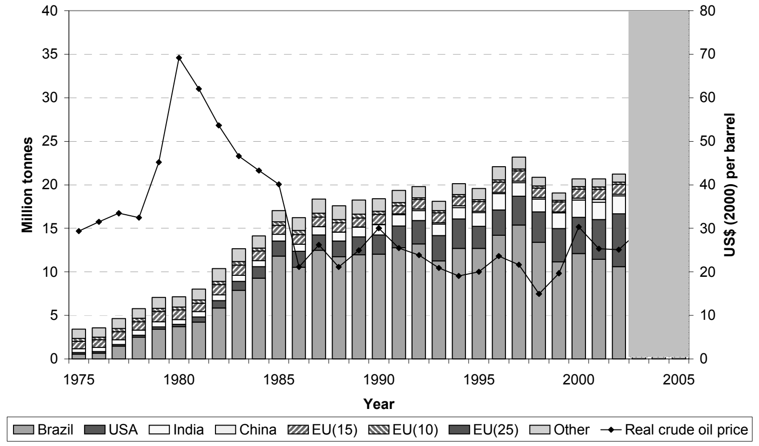
Both ethanol and biodiesel can be produced from a wide range of feedstocks. Ethanol plants currently in production mostly use sugar or starchy crops. Sugar cane in Brazil and cereals in the US and in Europe are the most important feedstocks, but sugar beet, cassava and others can be used as well. In general, ethanol is produced by fermenting sugar to alcohol which then is distilled to remove water. Starchy feedstocks first have to undergo an enzymatic process where the starch is broken down to sugars. In all cases, the feedstock value represents an important share in total production costs for ethanol, and currently the ethanol produced in Brazil from low-cost sugar cane represents a fuel that could compete on a production cost basis with oil-based gasoline without any subsidies[6, 7]. Substantial research is underway to produce alcohol from cellulose, where the cellulose and hemi-cellulose[8] is broken down to sugars. As most of the plant material is cellulose, hemi-cellulose and lignin (the latter of which can be used to produce energy used in the conversion process), and indeed a much larger variety of feedstocks could be used in this process (including waste cellulose, dedicated cellulosic crops and wood residuals), this alternative could offer significant cost reduction potentials in the longer run, and would substantially reduce the land requirement for the production of any given ethanol quantity[9].

Biodiesel is generally produced by transesterification of vegetable oils (so-called “fatty acid methyl esters”, FAME). Currently, the predominant oils used in biodiesel production are rape and sunflower oil in Europe, and soya oil in North America. Again, the cost of the feedstock represents the major component of total production costs of biodiesel, such that cheaper oils such as palm oil or even used frying oil could have a significant cost advantage.

Both ethanol and biodiesel can be used either as pure fuels, or blended with gasoline and diesel.[10] Low-rate biofuel blends (such as up to 5% of ethanol in gasoline, or of FAME in conventional diesel) generally do not require any modifications to existing vehicle engines. Higher shares of ethanol or biodiesel require some modest modifications in tanks, fuel pipes, valves and/or engine components. A flex-fuel engine for motor vehicles which is compatible with any ethanol blend share between 0% and 100% is available on some national markets, most notably in Brazil. It is also possible to blend ethanol with diesel, though blending shares are generally much lower than in gasoline as the low cetan-number of ethanol makes it difficult to burn by compression ignition, and an emulsifier is needed to prevent the ethanol from separating from the diesel.

Global production of ethanol and biodiesel has been increasing in recent years at an impressive rate. Ethanol, having been produced for decades (beverage alcohol is not considered here) for many uses including industrial and pharmaceutical applications, has seen a steep rise following increased crude oil prices in the mid-1970s before slowing down in the mid-1980s when crude oil prices plummeted again. Ethanol production, which used to be clearly dominated by Brazil, started to rise again with the beginning of this decade particularly in the US, but in other regions as well (Figure 1). More recently, new ethanol production plants are being developed in a number of countries, including several developing ones.[11]

Figure 1: Global production of non-food alcohol, 1975-2005



Source: Production data for 1975 to 2002 are from FAOSTAT 2005; production data from 2003 to 2005 are from F.O. Licht (2005). Crude oil prices are from the Aglink data base.

Note that the two sources for ethanol production are not directly comparable. For 2001 and 2002, F.O. Licht reported global ethanol production 19% and 27% higher than FAO data, respectively.

Biodiesel, which is solely used for fuel mostly in the transport sector, started to be produced in the early 1990s. While production quantities are well below those of ethanol (by about factor 20), biodiesel supplies have rapidly grown, with the vast majority of global production being in the EU. Germany, France and Italy accounted for more than 80% of global biodiesel production capacity in 2002.[12] In the analysis for this study, the EU-15 is treated as an aggregate block. Differences between Member States in terms of productivity in both agriculture and biofuel industries are therefore not taken into account, which might bias results in terms of biofuel competitiveness.

3. Economics of current biofuel production processes

Production costs of biofuels vary widely across processes and regions. While the technology to produce ethanol from grains and sugar crops, or biodiesel from vegetable oils, is fairly well established, the main sources of differences in biofuel production costs are due to costs of the feedstock, energy used (both heat and electricity) and the prices received for by-products from the production process. Given the importance of feedstock and by-product prices, agricultural policies can have a major impact on overall production costs for biofuels. Table 1 provides a synopsis of biofuel production costs and allows for a comparison with oil-based fuel prices for the year 2004.[13]

Table 1: Production costs of ethanol and biodiesel and petrol-based fuel prices in major biofuel-producing countries, 2004, USD per litre of fuel

Biofuel production costs		Ethanol from				Biodiesel from
		Wheat	Maize	S/cane	S/beet	Veg. oil
US$ / l of fuel	USA	0.545	**0.289**			0.549
	CAN	0.563	0.335			0.455
	EU-15	**0.573**	0.448		**0.560**	**0.607**
	POL	0.530	0.337		0.546	0.725
	BRA			**0.219**		0.568

Petrol-based fuel prices		Gasoline (IFP) 1)			Diesel (IFP) 1)		
		W/ tax	W/o tax	RSC	W/ tax	W/o tax	RSC
US$ / l of fuel	USA	0.540	0.384	0.311	0.570	0.373	0.301
	CAN	0.680	0.401	0.311	0.680	0.391	0.301
	EU-15	1.316	0.406	0.311	1.286	0.396	0.301
	POL	1.200	0.392	0.311	1.090	0.382	0.301
	BRA	0.840	0.394	0.311	0.490	0.384	0.301

Notes: Ethanol and biodiesel production costs are based on data available in the literature (see Smeets *et al.,* 2005) referring to particular countries or regions - production costs for those countries or regions are shown in **bold** figures. Detailed cost data for them are provided in Annex 1. Calculations for other countries or regions take into account differences in feedstock and by-product prices, as well as differences in exchange rates and shares of oil and gas in domestic electricity production, but assume the same technology as used in the country or region the literature data refer to. By-product values are taken into account in the cost estimates where relevant.

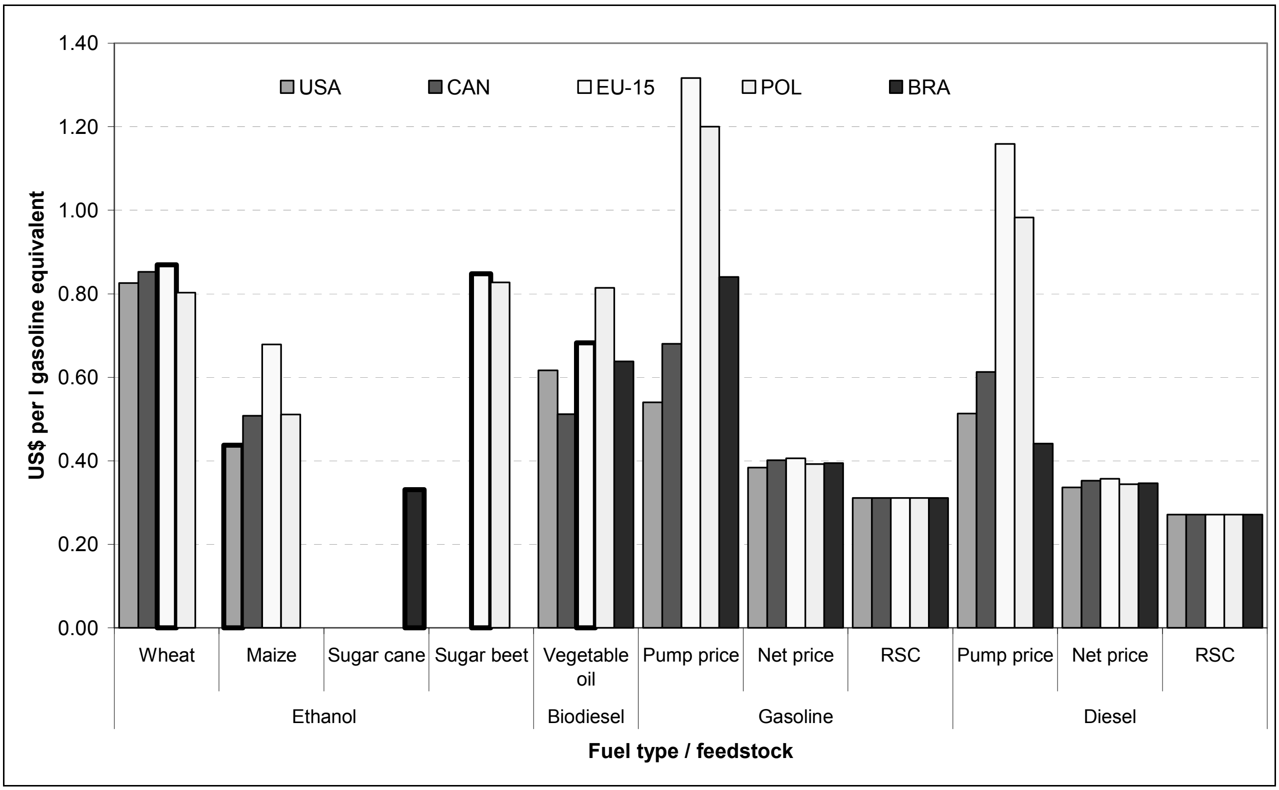
1) Regional Supply Costs (RSC) of gasoline and diesel are calculated as the sum of the crude oil price per litre plus approximated costs of refining and regional distribution, as reported by Metschies, G.P.: "International Fuel Prices" (IFP). Net fuel prices without tax additionally take into account approximated local industry margins and distribution costs as reported by IFP. Gross fuel prices are observed prices at the pump, reported by IFP. Gasoline prices for the EU-15 are weighted averages of prices in Spain, France and Sweden, with 2004 ethanol production quantities as weights. Diesel prices for the EU-15 are weighted averages of prices in Germany, France and Italy, with 2004 biodiesel production quantities as weights.

Sources: Cost data: OECD Secretariat based on data provided in Smeets *et al.* (2005)
Fuel price data: IEA (2005); Metschies, G.P.: "International Fuel Prices 2005" and earlier issues.
Exchange rates are from the Aglink Database.

In 2004, production costs for ethanol from wheat are estimated to exceed net gasoline prices (*i.e* net of tax) by between 35% and 42% in the countries analysed. The same holds for ethanol based on sugar beet in the EU.[14] In contrast, ethanol from maize can be produced at significantly lower costs in most of these countries.[15,16] With the exception of maize in the US, however, all these costs are higher than the regional supply costs of gasoline. Among the countries analyzed, Brazil is the only one where ethanol production costs – based on sugar cane – are not only below tax-free prices for gasoline, but are only about 70% of the regional supply costs of gasoline. Production costs for biodiesel are found to be within or close to the range of production costs for ethanol from different feedstocks on a per litre basis in most countries, and higher than tax-free prices for petrol-based diesel. In the EU, for which technological and cost data are available in the literature, biodiesel production costs were about four Euro-cents higher than those for ethanol on a per litre basis. Data for the EU may hide, however, differences in the production costs of biofuels across Member States. It is important to note that differences of production costs across countries in this calculation are mainly caused by different feedstock prices rather than through alternative technologies as the latter by assumption in the calculations are the same.

Higher excise tax rates for gasoline and diesel compared to ethanol and bio-diesel, respectively, ensure that at the pump biofuels are generally sold at prices lower than petrol-based fuels even where production costs are higher. However, ethanol and bio-diesel have lower energy contents than gasoline and diesel, so these values are not strictly comparable.

Figure 2: Production costs of ethanol and biodiesel and petrol-based fuel prices in major biofuel-producing countries, 2004, USD per litre of gasoline equivalent



Notes: Notes for Table 1 apply. Bars with **bold lines** indicate the country for which cost data originally is found in the literature. Cost estimates for other countries are based on their respective crop prices and regional information about their energy mix in the electricity generation, but on the same technology assumptions. By-product values are taken into account in the cost estimates where relevant.
For comparability, all production costs are converted to gasoline equivalent by dividing production costs per litre of fuel by the energy content relative to gasoline, *i.e.* 0.66 for ethanol, 0.89 for biodiesel and 1.11 for petrol-based diesel. See also note 17 on this issue.

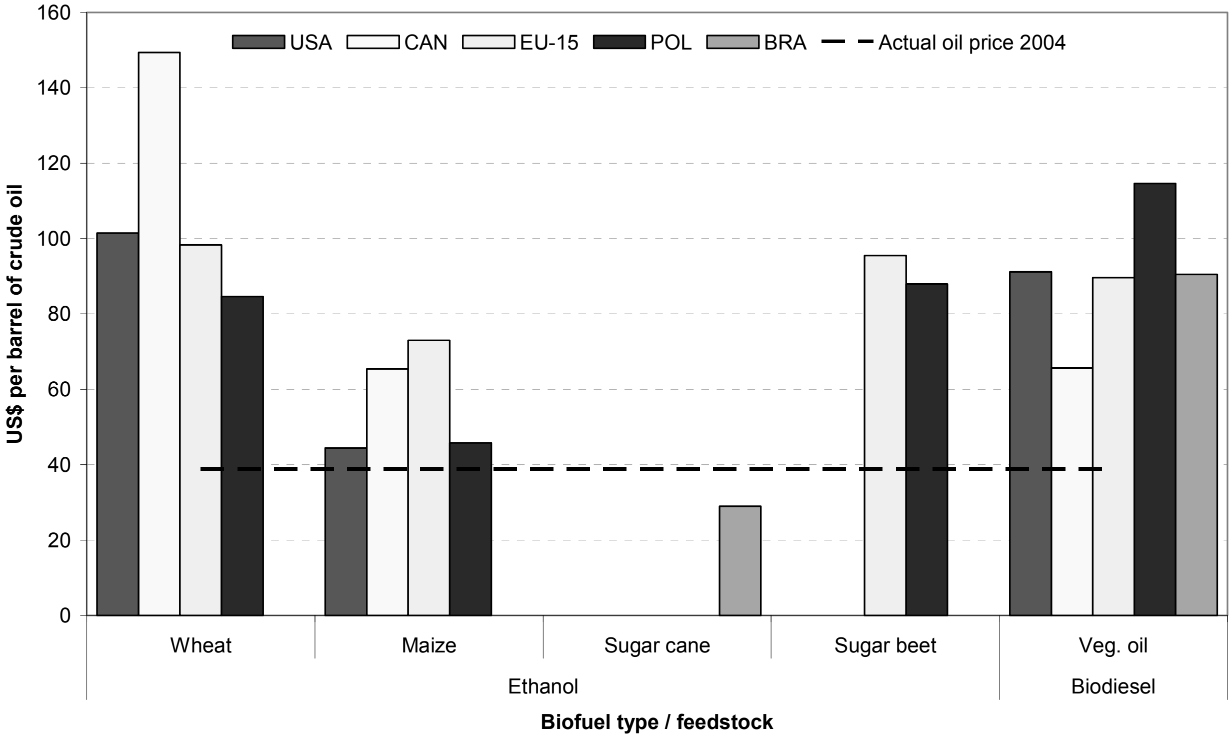
Source: See Table 1.

Figure 2 compares costs and prices across fuel types, feedstocks and regions for the year 2004. Costs and prices for all fuels (including biodiesel and diesel) are expressed in USD per litre of gasoline equivalent to take into account the differences in the energy content of various fuel types.[17] The data supports the hypothesis that Brazil is by far the most cost-effective producer of fuel ethanol – with production costs of about USD 0.22/litre of ethanol or USD 0.33/litre of gasoline equivalent, ethanol is produced at a cost lower than the price of gasoline net of tax, and at comparable costs to the regional supply costs of gasoline (see note 1) of Table 1). No other major ethanol producer was able to produce ethanol at a cost competitive with domestic gasoline prices without some form of subvention, mostly in the form of tax rebates (see section 4), even though production costs for ethanol made from maize in the US were only about five cents higher than net gasoline prices on an energy basis and should fall below net gasoline prices at moderately higher crude oil prices.[18]

On an energy basis, however, biodiesel can be produced in the EU at a substantially lower cost than ethanol, given the higher energy content of biodiesel compared to ethanol. Biodiesel production costs were, however, still almost 1.5 to 2 times the oil-based diesel price net of tax, and biodiesel production therefore heavily depended on government support to overcome the cost disadvantage (see Figure 2).

The year 2004 was characterised by world crude oil prices substantially above those reported for earlier years, averaging about USD 39 per barrel. Oil prices have increased further since then and have been above USD 60 per barrel since spring 2005,[19] further improving the viability of ethanol and biodiesel production. With current technology and domestic crop prices, higher crude oil prices and hence gasoline and diesel costs could quickly make biofuel production viable without tax concessions at least in the US ethanol case. Using 2004 data, threshold prices for crude oil can be calculated that would make tax-free gasoline and diesel as expensive on an energy basis as ethanol and biodiesel production.[20] For US ethanol from maize, this threshold oil price is calculated to be around USD 44 per barrel. While Brazil ethanol is calculated to be competitive already at USD 29 per barrel of crude oil, other countries' ethanol production would become viable without support only at higher oil prices. This is particularly true for the EU, where domestic prices for coarse grains and sugar beets that are higher than those at world markets, makes ethanol production less cost effective.[21,22] Threshold prices for biodiesel are substantially higher than those observed in 2004 as well, ranging from USD 66 per barrel in Canada to USD 115 per barrel in Poland. In all cases, modern facilities generally perform better in such a comparison than average country data show, and as discussed above, technical progress is likely to further reduce production costs for biofuels.

Figure 3: Threshold prices for crude oil, 2004



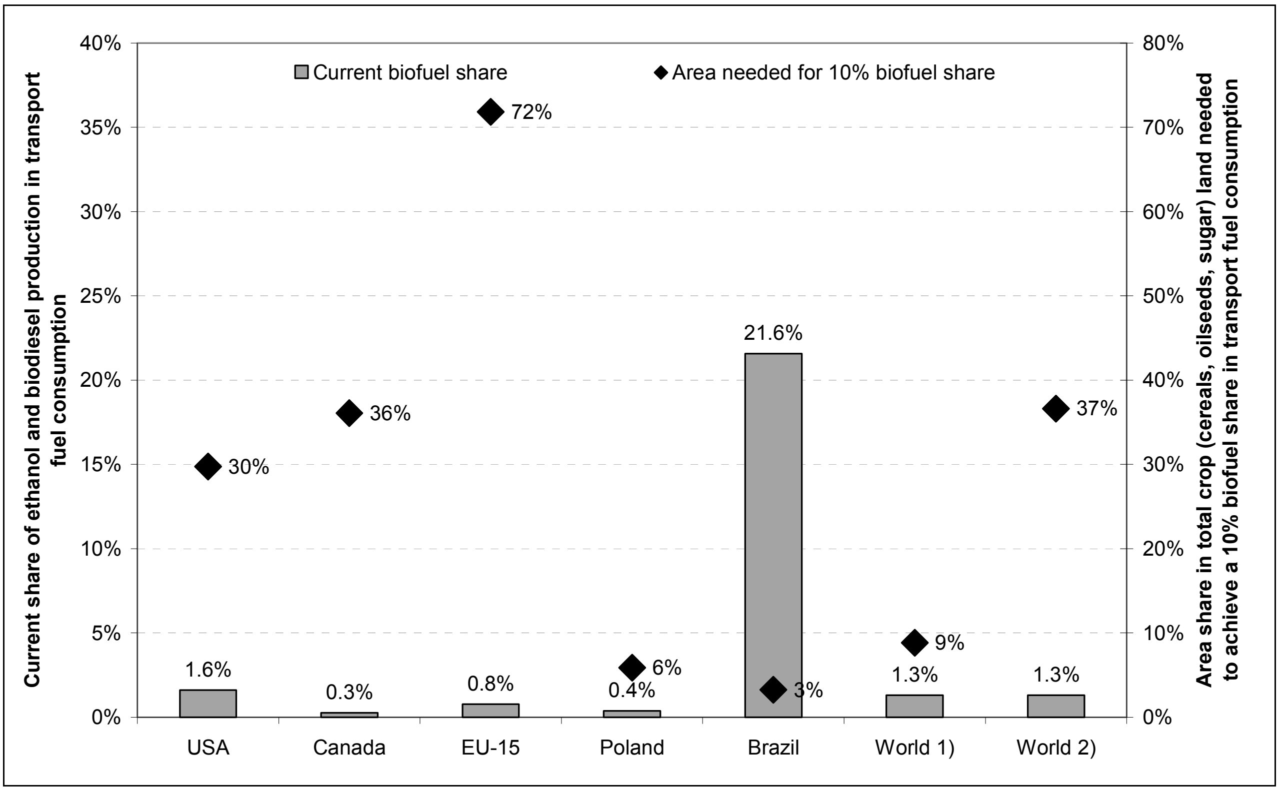
Note: Threshold prices represent estimated crude oil prices at which domestic tax-free gasoline and diesel prices are equal to the production costs of ethanol and biodiesel, respectively, taking into account the differences in their energy content. These calculations assume unchanged production costs at their calculated 2004 level and therefore do not consider changes in feedstock prices and costs for process energy due to changed crude oil prices.

More than half of total costs of ethanol production are represented by the value of the feedstock. Consequently, the price of the commodity used as feedstock, and their respective sugar and starch content is crucial for the viability of biofuel production. Similarly, the cost of vegetable oils used often represents more than three quarters of total production costs of biodiesel. Within the range of classic biofuels, *i.e.* without considering modern technologies that produce ethanol from cellulosis and hemi-cellulosis, the choice of using a relatively cheaper feedstock represents, therefore, the main option for reducing biofuel production costs in the medium term.[23]

Given information on the different content of sugars, starch and oil in the various feedstocks, and their yields per hectare of land, the land required to produce a certain quantity of ethanol and biodiesel assuming unchanged production technologies and constant shares of individual feedstocks can be calculated. Obviously such simple calculations ignore the technical progress likely to continue both in agriculture and in biofuel production as well as changes with respect to the feedstock mix and area use. In addition, the possibility and further potential to use land otherwise not used for crop production is not considered here, nor is possible international trade in biofuels taken into account. While these calculations give a useful indication of relative land efficiency of current biofuel production in different countries, they therefore cannot be taken as projected land use for higher biofuel production quantities in the future and corresponding pressures on land markets. Details on the calculations can be found in Annex 2.

Currently, Brazil is producing about 22% of its total transport fuel energy consumed in the form of ethanol. Due to its vast agricultural area, but also because of relatively low transport fuel consumption per capita, only 3% of the available cropping area (total of cereals, oilseeds and sugar crops) is used per 10% of transport fuel consumption (Figure 4).

Figure 4: Biofuel shares in transport fuel consumption and land requirements for 10% biofuel shares in major biofuel producing regions

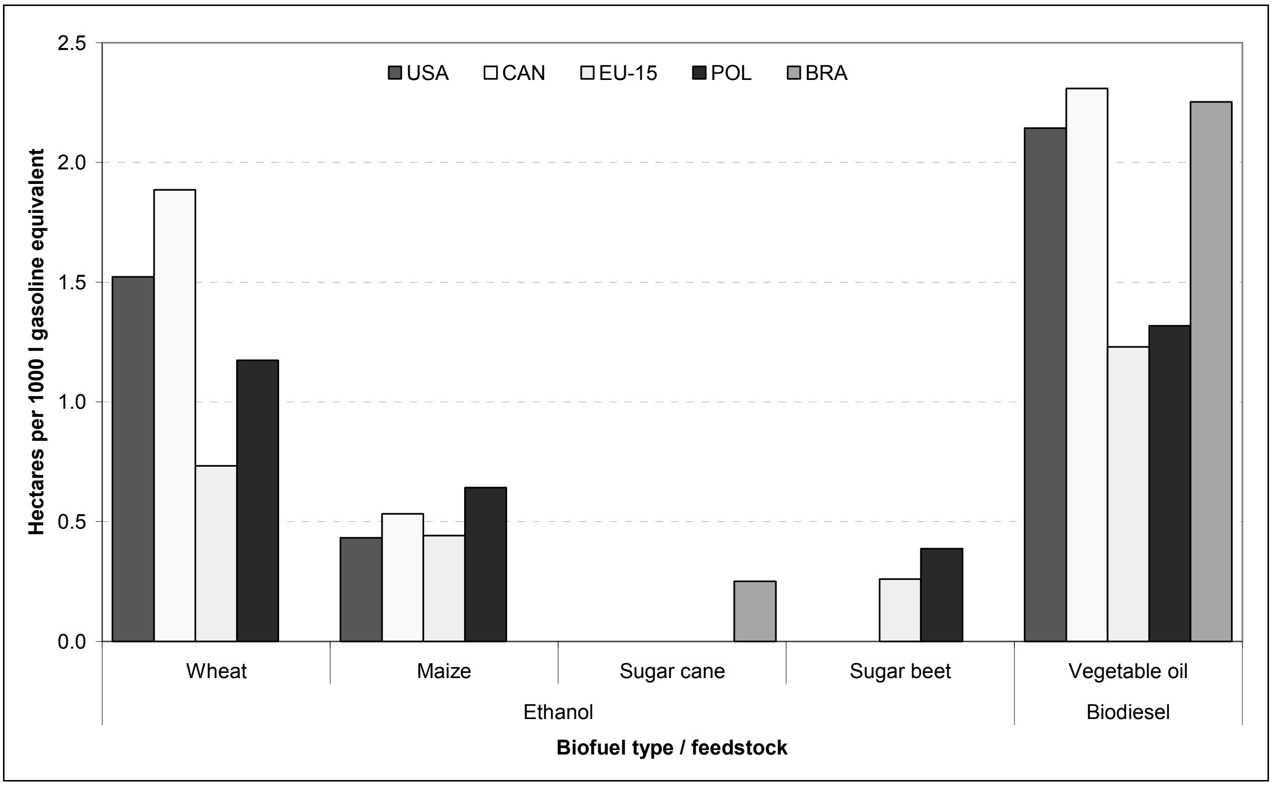


Notes: Current biofuel shares include ethanol and biodiesel only – shares are on an energy basis.
World area shares are calculated relative to land used for cereals, oilseeds and sugar globally (World 1)) and within the five major biofuel producing regions only (World 2)).
All areas requirements are calculated on the basis of average crop area and yield data for 2000-2004 and transport fuel consumption in 2004. For these calculations, the 2004 shares in the feedstock mix are assumed to remain unchanged. Details on the calculations can be found in Annex 2.
Note that calculations for the EU exclude ethanol transformed from wine which represented about 18% of EU ethanol production in 2004.

Source: OECD Secretariat.

All other countries meet only a small fraction of their total transport fuel consumption from biofuels. In the US, Canada and the EU (both EU-15 and Poland) production of ethanol and biodiesel is equivalent to less than 2% of total transport fuel consumed in 2004. While biofuel production is set to increase in all countries, the implied area requirements relative to land endowments are substantial with current technologies. In the US and Canada, about one third of all land currently harvested for cereals, oilseeds and sugar crops would be needed to produce biofuels equivalent to 10% of their transport fuel consumption, respectively. Whereas for the EU-15 more than two-thirds of the area currently used for these crops would be necessary.[24] These significant land requirements are related to the much lower biofuel yield per hectare of land compared to sugar cane based ethanol production in Brazil, as well as to the higher transport energy consumption in North America and the EU. In the EU-15, the lower land endowment per capita and in particular the large share of biodiesel in EU biofuels production adds to the relative land requirement. In general it takes much more land to produce biodiesel than to produce the equivalent amount of ethanol, particularly if the latter is produced from maize or sugar crops (Figure 5).[25]

Figure 5: Estimated land requirements for the production of 1000 l gasoline equivalent of biofuel energy



Note: Area requirements calculated from average regional crop yields and oil extraction rates in 2000-2004, assuming the following biofuel yields per ton of feedstock: wheat 362 l/t, maize 396 l/t, sugar cane 85 l/t, sugar beet 98 l/t, vegetable oil 1048 l/t.

Source: OECD Secretariat, based on production cost data from Smeets *et al.* (2005) and on OECD, FAO (2005): OECD-FAO Agricultural Outlook 2004-2014.

It is important to note that these calculations are based upon current crop yields and biofuel production technologies. With average crop and biofuel yields improving over time, area requirements for a given quantity of biofuels should decline gradually. At the same time, however, the demand for transport fuels is increasing, and projected growth rates are likely to exceed those of crop yields in most countries.[26] Consequently, in the medium term the supply of substantial amounts of biofuels with significantly lower area requirements than indicated by Figure 4 can be achieved only if the feedstock mix is adjusted in favour of commodities with a higher biofuel output per hectare, including imported feedstocks and biofuels where appropriate.

A more relevant factor for assessing the land needed for biofuels production in the longer run is the development of advanced production technologies. While the derivation of ethanol and biodiesel from starch, sugar and vegetable oil is relatively land intensive, ethanol is likely to become available from cellulosic and ligno-cellulosic material, be it dedicated biomass crops such as grasses and trees or waste material from crop production. Similarly, BTL-fuels are expected to become available from a large variety of biomass sources. These generally come with significantly higher yields per hectare of land. Consequently, both land requirements and feedstock costs can be substantially lower for ethanol from cellulosic material or for BTL. While currently conversion costs are much greater than for “conventional” ethanol from sugar and starch crops, further research could reduce total production costs to levels below those for grain-based ethanol within the next ten years (IEA, 2004a: Biofuels for Transport, pp. 77 ff.). When exactly advanced biofuels will become competitive remains open. In the quantitative analysis further below, neither ethanol from cellulosic material nor BTL are considered, assuming that these fuels will not account for significant shares in biofuels within the 10-years period analysed.[27]

4. Biofuel policies

A number of factors are motivating governments around the world to create policies to encourage the development of renewable energy sources as alternatives for finite supplies of oil-based fuels that currently dominate motor vehicle transportation. These include a desire to improve overall energy security and lower dependence on increasingly expensive petroleum fuels, to decrease motor vehicle contributions to growing air pollution in urban centres as well as lowering or eliminating their contribution to greenhouse gas emissions. For several countries, a key driver for policy initiatives in the transport sector is the greenhouse gas (GHG) abatement targets of the Kyoto Protocol for developed countries. Indeed, most studies available show that, apart from reducing other pollutants, net greenhouse gas emissions per kilometre would be reduced by between 20% and 90% for ethanol from crops and by around 50% for biodiesel from oilseeds.[28] For the Protocol signatory countries, the abatement targets require a total cut in greenhouse-gas emissions of at least 5% from 1990 levels in the commitment period 2008-12. Apart from these environmental objectives of reducing greenhouse gas emissions by replacing fossil transportation fuels, public support for biofuel production, consumption and trade will also likely be influenced by the environmental sustainability of biofuel production chains and other socio-economic factors. These include whether biofuel production and imports have a negative impact on food production at home and in developing countries. Finally, the generation of new markets with increasing demand for agricultural produce causes farm associations and other interest groups to favour growth in biofuel production on a local and regional basis.

In most countries, and prior to the recent rise in oil prices, bio-ethanol and bio-diesel are more expensive to produce than oil-based sources of these fuels. As a consequence, governments have tended to rely on regulatory mechanisms, tax concessions or some form of production subsidy to encourage the development and commercialisation of renewable biofuels. In setting up such measures for biofuels, governments will likely try to support biofuels from crops that have a potential in achieving high productivity and sustainability in the longer term. The following section provides a brief review of the biofuel policies of a select group of countries that are currently the main producers of bio-ethanol and biodiesel.

European Union

Biodiesel represents the biggest share of biofuel production in the European Union, with a market share of nearly 80% compared to bio-ethanol with just over 20% of the market. The European Union currently leads the world in the development of a biodiesel sector. Germany is the largest producer of biodiesel followed by France and Italy. For bio-ethanol, Spain France, Poland and Sweden are the leading producers within the European Union. In the Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport, the European Commission has set indicative targets for renewable fuel as a share of total transport fuels use in the EU. A guideline has been established of 2% of all transport fuels used by 2005, and rising to 5.75% of total use by 2010. Individual member states were given flexibility under the directive to choose the best way to implement the target guideline for biofuel use. Member states are required to report back to the Commission by 1 July of each year on their implementation strategies under the Council's Biofuel Directive. Only 15 of the 25 countries met the reporting deadline for 2005 and, overall, there appears to be significant differences between them on the way in which biofuel schemes will be implemented. The Commission can propose to the Council to change its indicative targets on biofuel use to mandatory ones, for a decision by the Council, if it finds that member states are not implementing the target guidelines and do not have compelling reasons for non-compliance. A second Council directive (No. 2003/96/EC) relevant to biofuels concerns taxation of energy products. Under this directive, member states are able to exempt biofuels from the tax applied to mineral oil products to encourage biofuel production. Furthermore, a biomass action plan has been published in December 2005, while a communication on biofuels is expected to be published in February 2006.

Germany

Germany is the leading biodiesel producer among the European Union countries. The Mineral Oil Duty Act was amended on 1 January 2004 in Germany to allow for full exemption from duty of biofuels and heating oils produced from biomass and blended with fossil fuels until 2009. No production quotas apply. Three production plants for fuel ethanol were put into operation in 2005.

France

Production quotas are established by the government for biofuel production which benefit from advantageous fiscal measures in France, such as exemption from excise tax on petroleum products at the rate of EUR 0.35/litre of biodiesel and EUR 0.37/litre of ethanol in 2003. For 2003, the global amount of tax exemption assigned to biofuels is about EUR 180 million. In September 2004, the French Prime Minister announced to increase the biofuel production approvals by 800 000 tons (compared to 400 000 tonnes in 2003) to reach 1.2 million tons in 2007. From 1 January 2005, a general tax on polluting activities has been implemented to encourage petrol distributors to incorporate blends of biofuels in fossil based fuels. A progressive tax rate has been established (of 1.2% en 2005 rising to 5.75% in 2010), with the level of tax applied reduced according to the volume of biofuel incorporated in the different transport fuels (diesel or petrol).

Italy

Quotas or approvals for biofuel production are established by the government in Italy which benefit from fuel excise tax exemption.

Spain

Spain is the leading EU producer of bioethanol. The government provides a tax exemption on biofuel use and has adopted a 5.75% target for biofuels share in total transport fuel use by 2010. In the summer of 2005, the Spanish government approved a Programme for Renewable Energy in Spain, 2005-2010. Under this programme, an energy objective for biofuels was established at 2.2 million tonnes equivalent to petrol (TEP), compared with a situation of 228 200 tonnes TEP in 2004.

Sweden

Provides full exemptions from excise duties applied to petroleum products for biofuels and has set a target of 3% for biofuel use in total transport fuel for 2005.

Poland

A Biofuels Law is being proposed by the government to encourage biofuels production. This law provides for a tax exemption for the production of ethanol mixed with petrol (with the tax exemption amount per litre of biofuel progressively depending on the blending rate), and with blending percentages and the amount of the tax exemption to be determined on a yearly basis after approval of the annual budget. The law is currently being revised following the Constitutional Court's 2004 rejection of the provisions regarding the obligation to use biocomponents in the volumes set annually by the Council of Ministers.

United States

The United States is the second major producer of biofuels in the world, after Brazil. Maize-based bio-ethanol production is the principal biofuel product and has been expanding rapidly in recent years. The Federal government provides tax incentives to promote ethanol production and a number of ethanol producing states have provided additional incentives as well. Excise tax exemptions for alcohol fuels were initially established by the Energy Tax Act of 1978 with full exemption for 10% blended gasoline (gasohol) of the then USD 4¢-per-gallon (USD 1¢-per-litre) federal gasoline excise tax, an effective subsidy of USD 40¢ per gallon (USD 11¢-per-litre) of ethanol. A 1980 law added an alternative blenders credit of USD 40¢ per gallon (USD 11¢-per-litre) applicable to other blend levels including E85 (an ethanol-gasoline blend including 85% ethanol in volume terms – see glossary for explanations). Various subsequent acts either raised (as high as USD 60¢ per gallon, USD 16¢-per-litre) or lowered and extended the subsidy. The most recent adjustment in 2004 eliminated the previous partial fuel excise tax exemption and created a "volumetric ethanol excise tax credit" against fuel tax liabilities. In addition, a tax credit for biodiesel, USD 1.00 per gallon (USD 26¢-per-litre) if made from virgin oil or USD 50¢ per gallon (USD 13¢-per-litre) if made from recycled oil such as cooking grease, is provided under the 2004 amendment. A variety of state-level incentives and targets also exist for ethanol and bio-diesel production and use in the United States.

A further boost to renewable fuel development in the United States is likely to come from a *Renewable Fuels Standard (RFS)* as part of a comprehensive US Energy Bill that has been passed by the US Congress and signed into law recently. The RFS provisions do not provide any liability protection for the use of MTBE (methyl tertiary butyl ether, an additive made from petrol and alcohol) and thus, discouraging its use, eliminates the reformulated gasoline oxygen standard,[29] enhances clean air rules and mandates minimum renewable fuels consumption of 4 billion gallons (15.1 bn litres) in 2006 rising to 7.5 billion gallons (28.4 bn litres) in 2012. Fuel ethanol would be the main beneficiary of the RFS and the MTBE phase-out, although other renewable transport fuels such as biodiesel and biogas would also benefit.

Brazil

Brazil is currently the world's largest producer of biofuels, predominately bio-ethanol from sugarcane. In the 1970s the government of Brazil established a National Fuel Alcohol Program known as Proálcool to increase the share of domestically produced fuel used in the transport sector. This program, with considerable government support, was highly successful and lead to fuel ethanol gaining a larger market share than gasoline in the Brazilian transport sector. The Proálcool program was effectively eliminated in the 1990s with the liberalization of hydrous alcohol prices. However, the government still provides a measure of support to ethanol production through a combination of market regulation and tax incentives. Support through market regulation takes the form of an official blending ratio of anhydrous alcohol with gasoline of between 20-25% in transport fuel, with a permitted variation of +/- 1%. In addition, other support is given through the provision of credits for storing ethanol, by setting a lower excise tax on ethanol use than for gasoline and through periodic purchases and sales from its strategic reserves. An *ad-valorem* duty of 20% is also applied to imports of ethanol by Brazil. The government has enacted a law establishing a biodiesel obligation: 2% by the end of 2007 (800 million litres per year), 5%

by 2013 (2 billion litres per year), and a goal of 20% by 2020 (12 billion litres per year). To produce the required vegetable oil, in February 2005 the Brazilian government has made USD 41.9 million (BRL 100 million) available for loans to several thousand families to produce oil from castor-oil plants for biodiesel production.[30]

India

A pilot programme was launched by the Indian government in December 2001 to test the feasibility of blending ethanol with gasoline as a way to absorb a burgeoning sugar surplus and assist the country's distillery sector that is burdened with overcapacity. In early 2002 the government approved the sale of E5 (5% blend of ethanol with gasoline) across the country and mandated that a number of states and territories would be required to sell E5 from 1 January 2003. This is expected to be extended to all states at some stage. In February 2003 the government introduced a RS 0.75 excise duty exemption for ethanol sales. However differences in excise duty and sales taxes across states complicate ethanol pricing in India. Biodiesel production is less well developed in India than bioethanol.

Thailand

The government of Thailand since 2002 has shown interest in supporting the establishment of a large scale bio-ethanol industry using cassava, sugar cane and rice as the preferred feedstock The nation's rising import bill for oil and the role of ethanol in replacing MTBE have been used as justification for the ethanol programme. To encourage the production and marketing of E10 fuel mixes the government has announced it will waive the excise tax on gasohol as well as contributions to the State Oil Fund and Energy Conservation fund, provide investment concession for new plant construction, allow duty concessions on machinery imports and give an eight year corporate tax holiday to ethanol production.

China

Fuel ethanol as a blend with gasoline has been on trial use in China as a way to create a new market for surplus grain in major Chinese corn-producing areas and to reduce its rising oil import bill that has accompanied the rapid development of the economy. The government currently subsidises production at four ethanol plants. In June 2002 ethanol was mixed with gasoline in 5 test cities, 3 in Henan Province and two in Heilongjiang Province. There are now mandates for E10 ethanol blends in Jilin province as of October 2003 and Heilongjiang, Liaoning, Hernan and Anhui provinces since October 2004. The government plans to expand the E10 program in 27 cities of Shandong, Jiangsu, Hebei and Hubei by the end of 2005.

Australia

In Australia, the Federal government in 2000 exempted ethanol from fuel excise tax of around AUD 0.38/litre (USD 0.21) and set a target of 1%, or at least 350 million litres, of total fuel supply in 2010 to be fuel ethanol and biodiesel produced from renewable sources. The government also supported two ethanol projects with capital subsidies under the Greenhouse Gas Abatement Program. In September 2002, the government changed the way it was supporting the nation's infant ethanol industry. The fuel excise exemption was ended and replaced with an ethanol production subsidy at the same rate for one year. In March 2004, the government extended the subsidy for ethanol producers to June 2011. From 1 July 2011 to 1 July 2015, government support for biofuels will be partially wound back through the phase-in of excise taxes for alternative fuels (including biofuels). Some support will continue in the form of a 50% discount on excise payable after 1 July 2015. It also set a 10% limit on the blending of ethanol in petrol as part of mandatory labelling of ethanol blends. The Federal Government has also implemented an AUD 37 m grants scheme to kick-start new and stimulate existing biofuel production initiatives. This Capital Grants Program has now been fully allocated to nine projects. The Australian government has reached agreement with oil companies and car manufacturers to develop voluntary agreements aiming to secure market share for biofuels. The government has also decided to simplify ethanol fuel labelling and, pending technical evaluation, to allow the sale of up to 5% ethanol blends without label.

Canada

The Federal government has established a target under its Climate Change plan, in the framework of its Kyoto commitments on greenhouse gas abatement. Under this target, by 2010, 35% of the national gasoline supply will be E10, and that 500 million litres of bio-diesel with be produced and consumed. The Federal government's Ethanol Expansion Program is intended to provide up to CAN 118 million in repayable contributions to 11 projects across the country. These 11 projects, in combination with existing production of about 200 million litres, will allow Canada to meet its climate change target for ethanol two years earlier. The Federal government provides a fuel excise tax exemption of USD 0.10/litre on fuel ethanol use and CAN 0.4 per litre on bio-diesel. A number of provinces offer road tax exemptions. In addition, three provinces have passed legislation for renewable fuel standards that will come into force when domestic production of biofuels is available.

Japan

Japan is the world's second largest consumer of gasoline after the United States. The government has permitted the sale of gasoline containing a 3 ethanol blend (E3) since August 2003. The "Kyoto Protocol Target Achievement Plan" provides goals to use 500 million litres fuel derived from biomass in fuel for transport by 2010. The government plans to increase domestic ethanol production in stages. For this purpose, the government is promoting the development of ethanol-processing technologies through field demonstration of those productions, and the use of domestic unused biomass and energy crops.

5. Baseline projections for agricultural commodity markets

The analysis of the implications for agricultural markets of an expected growth in biofuel production as well as of higher crude oil prices is based on a quantitative model and a set of baseline projections generated with it. This section briefly describes these two important elements. The Aglink model, a recursive-dynamic multi-region multi-commodity partial equilibrium model of regional and world markets for temperate-zone agricultural products, has recently been extended by the Cosimo model developed by FAO to explicitly cover a number of countries and regions in the developing world. In addition, it has been merged with the existing OECD World Sugar model.

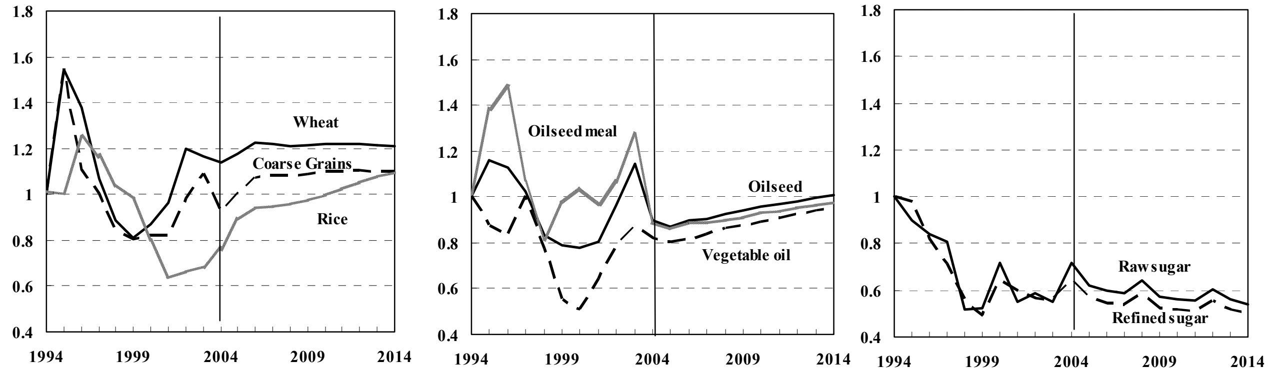
A set of baseline projections have been generated for the *OECD-FAO Agricultural Outlook 2005-2014* (OECD and FAO, 2005). These projections represent a plausible scenario of the future development of supply, demand, prices and trade of agricultural commodities in OECD and non-Member Economies (NMEs) and for international markets over a ten year horizon under a set of assumptions, covering macroeconomic developments, continuing "*status quo*" agricultural policies and normal weather patterns. While the projections should not be taken as market forecasts, they represent a useful basis for examining the market impacts resulting from changes in some of the driving factors. The baseline projections used in this analysis are summarized in Box 1.

Box 1. Brief summary of the baseline projections 2005-2014 underlying this analysis

Demand for food, feed and fibres should strengthen due to improved world economic performance. In a context where world agricultural production is expected to increase at a slower pace than in the last decade, rising consumer demand provides the foundation for increasing trade in agricultural products. With the growing developing country imports set to be partly met by rising exports from low cost producing and exporting countries in the developing world and transition economies, much of the additional trade will occur within the developing world (*i.e.* growing south-south trade).

With increasing production and exports from some developing and transition economies, competition in world commodity markets is set to intensify over the coming ten years. When coupled with continuing productivity gains at the world level, this situation should result in a further drop in real prices for most agricultural products to 2014, with nominal prices remaining largely stagnant or increasing only a little (Figure 6)

Figure 6: Outlook for world crop prices to 2014 (index of nominal prices, 1994 = 1)



Source: OECD – FAO (2005)

The rate of productivity growth is one of the important drivers for the commodity projections. Projected growth in crop yields vary by commodity between 0.9% and 1.3% p.a. globally, implying for most crops a slowdown in yield growth compared to the previous decade. With the exception of coarse grains, yields generally grow less rapidly - though on a higher level – in OECD countries than outside the OECD.

For this analysis, the combined Aglink/Cosimo/Sugar model has been modified in two important ways:

- The feedback from changes in international crude oil prices to domestic production decisions has been ensured by taking into account an energy costs element in the supply equations, mainly for crop products.

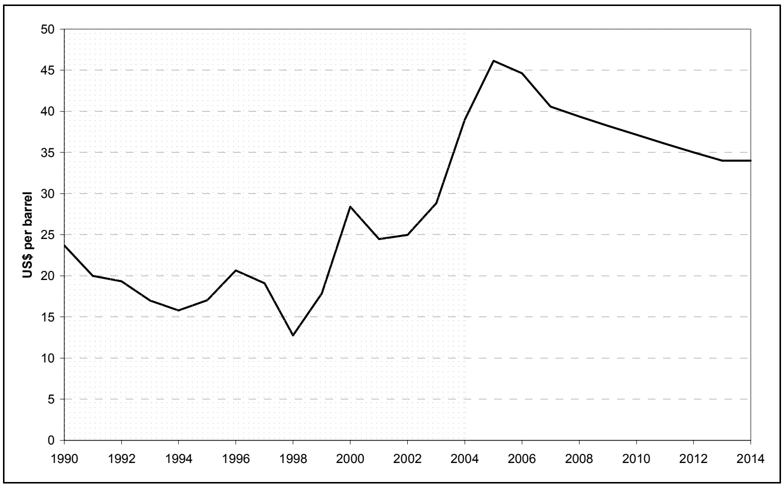
- Where relevant, the country modules have been extended to endogenously represent ethanol and biodiesel production, their cost calculation, the shares of different feedstocks in their production, total feedstock use and by-product production. By-products considered include distillers dried grains with solubles (DDGS) from the dry milling process, corn gluten feed (CGF) and corn gluten meal (CGM) from the wet milling process, which in practice substitute for feed grains and oil meals in animal feeds and are modeled as such. In addition, glycerin as a by-product of biodiesel production is considered in value terms. While the Brazil sugar module already covered ethanol production, extended modules have been developed for the US, Canada, the EU-15 and Poland.[31]

Due to the lack of empirical data, the representation of biofuel production is fairly *ad hoc*. Production capacities are assumed to respond inversely to a three-year average of the ratio of net production costs (taking into account total production costs, byproduct values and eventual taxes) to gasoline and diesel pump prices, scaled to the same energy content. Short-term adjustments are possible in the capacity use rate that directly responds to the cost-fuel price ratio of the same year.[32] Annex 3 to this report provides detailed information about the modifications made to the model used. It also shows the technical coefficients and cost parameters used in this analysis. Both these coefficients and much of the data on biofuel production is taken from Smeets *et al.* (2005). It should also be noted that, for this analysis, trade in biofuels is not taken into account. In particular, growth in biofuel consumption is assumed to be linked to an equivalent growth in biofuel production within the same country or region, such that the growth in demand for feedstocks is assumed to occur in the country or region where the increase in biofuel use occurs.[33]

No detailed information about the taxation of biofuels was available for this analysis. It is therefore generally assumed that all biofuels are exempt from fuel taxes in all countries with the exception of Brazil, where no specific assumption is needed due to the different way in which ethanol production is modelled.

The *OECD-FAO Agricultural Outlook* takes into account – exogenously – a significant increase in biofuel production in the US, as well as further growth in Brazil.[34] In contrast, no biofuel growth is considered in the outlook for Canada and the EU. Crude oil prices are explicitly taken into account only in the context of Brazil ethanol production, but for the purpose of this analysis, the same development of crude oil prices is assumed for the baseline projections. As can be seen from Figure 7, in the baseline oil prices are assumed to decline to USD 34 towards the end of the projection period after peaking at about USD 46 in 2005.

Figure 7: Annual crude oil prices in the baseline scenario



6. Implications of alternative developments on biofuel and crude oil markets

Given that only partial growth in biofuels production is taken into account in the *OECD-FAO Agricultural Outlook*, the published baseline described in the previous section cannot serve as a useful base of comparison. Instead, a set of scenarios is simulated with the amended Aglink model, and the results of the scenarios are compared with each other. In particular, the following scenarios were simulated:

- A **constant biofuels scenario** includes an exogenous assumption of biofuel production, crop demand for biofuels, and by-product generation at their 2004 level throughout the projection period. This scenario can be read as a no-change scenario with respect to biofuels and will be used as the base scenario to compare with the results of the other scenarios.

- A second scenario includes growth of biofuel quantities in line with officially stated goals given baseline prices for agricultural commodities. This scenario can be read as a **policy-target scenario** with respect to biofuels, although, as will be seen below, these targets are not fully met due to the feedback to commodity markets. This scenario will be compared to the constant biofuels scenario to analyse the direct impacts of the anticipated biofuel production growth on agricultural markets.

- A third scenario adjusts energy and fuel prices as drivers for costs of agricultural production, for relative biofuel prices and for the profitability of biofuel production. It assumes crude oil prices at a constant level of USD 60 per barrel from 2005. Compared to the policy-target scenario, the higher oil prices in this **high oil price scenario** can be expected to impact on agricultural commodity markets in two ways. First, agricultural production costs will increase with higher energy costs, leading to higher feedstock prices and making the production of biofuels more expensive. Second, domestic prices for petrol-based fuels will rise and trigger increased demand for biofuels. Therefore, it will be necessary to analyse the scenario in two steps: first, the impact of the higher oil price on agricultural markets will be discussed, ignoring the likely changes in domestic transport fuel prices. Impacts of increased prices for gasoline and petrol-diesel on production of ethanol and biodiesel, and the subsequent implications for agricultural markets, will be discussed in a second step.

Constant biofuels scenario: Market developments with no growth in biofuels production

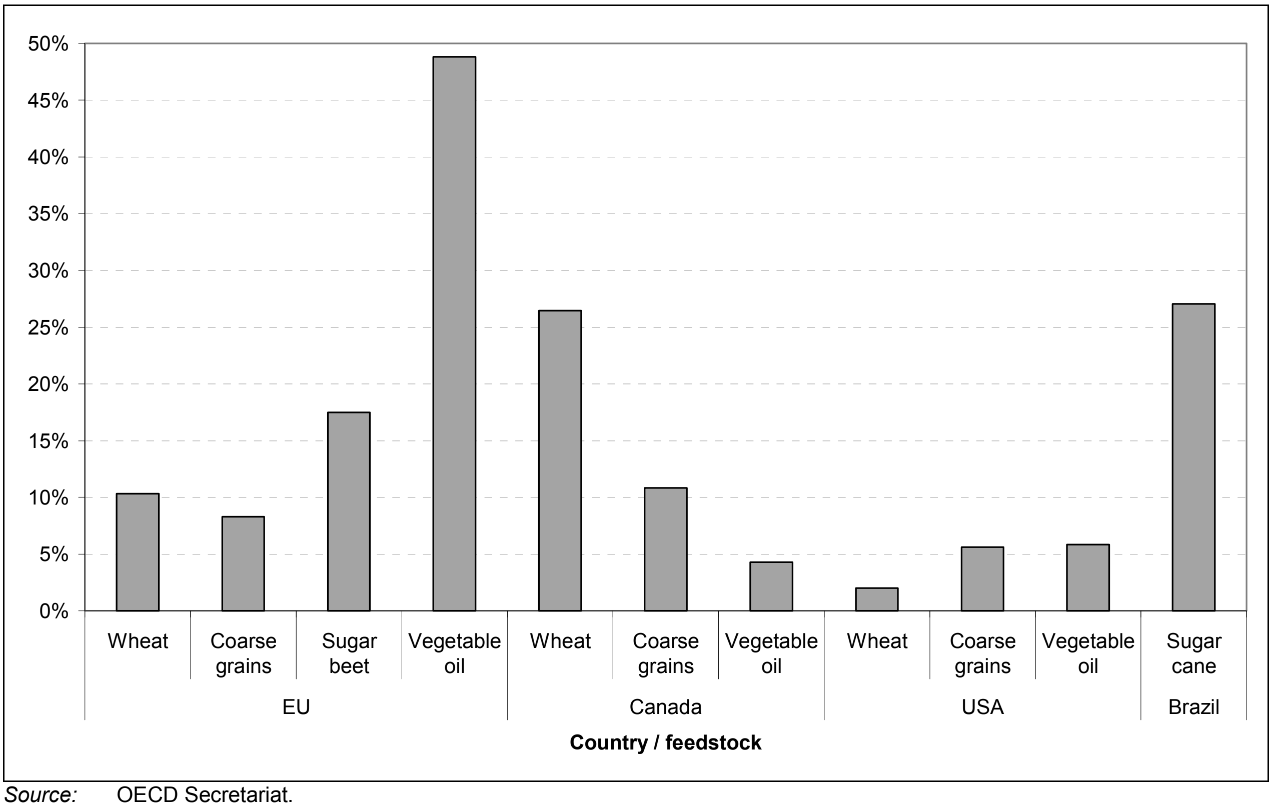
The **constant biofuels scenario** shows the hypothetical developments of agricultural markets without any changes triggered by additional demand for feedstock crops or additional supply of by-products used as animal feed. Given that the baseline considers growth in biofuel production only for the US and Brazil, the principal differences are found in those countries. In the US, the expected growth in ethanol production would require an additional 14 million tons of coarse grains to be used by 2014 for this purpose. Without that growth, total coarse grains use would be lower in 2014 by 10 million tons or 4%, resulting in an 11% or 7.6 million tons increase in US coarse grains exports. With lower biodiesel production, US exports of vegetable oil would almost double in 2014, when compared to the baseline, although absolute levels are relatively low. At the same time, US oil meal exports would fall by 6% in 2014 due to the reduced supply of protein-rich by-products, in particular of corn gluten meal that is co-produced with ethanol in the wet mill production process, as well as due to the reduced crush of soya beans as biodiesel production remains at low levels. Consequently, world prices for coarse grains and wheat would end 2.5% and 1% lower compared to the baseline, while the reduction of vegetable oil prices in 2014 would be about 1.5% (see Figure 9 below for world price projections for crops across scenarios). In contrast, world prices for oilseed meals would increase by about 0.7% in 2014. Markets for livestock products would be affected only little. Pigmeat markets would show the largest impact, with pork prices lower by up to 1.2%, while prices for other meats and dairy products would fall by less than 1% relative to the baseline. In summary, while US projections for grains and oilseed markets would be altered to some degree, the implications on a global scale would be rather limited, with the principal market outcomes of the Outlook remaining valid.

Implications for the Brazil sugar cane industry would be more significant. Despite a reduced cane output by 7% in 2014, sugar exports would be 54% higher at the end of the projection period.[35] These additional 13 million tons represent 8% of projected global sugar production and would cause world sugar prices to fall by up to 37%, when compared to the baseline projections. Rather than remaining almost flat as projected in the baseline, world sugar prices would fall to levels that have not been observed for the past two decades.

Policy-target scenario: Biofuel growth along publicly stated goals

Compared to the constant biofuels scenario, the **policy-target scenario**, which assumes biofuel developments are in line with stated national goals, would have substantial effects on most agricultural markets. Biofuels production would largely follow the baseline projections for Brazil and the US, with corresponding increasing use of cereals and sugar cane when compared with the constant-biofuels scenario. However, additional biofuel production quantities are expected for the EU and Canada, requiring additional quantities of sugar beet, grains and vegetable oils as feedstocks. In the EU, wheat and coarse grains use for ethanol production would increase by about 24 million tons between 2004 and 2014, more than 9% of total projected grain use (see Figure 8 for data on individual commodities). An additional 19 million tons of sugar beet would be used for expanded ethanol production as well, equivalent to about 17% of projected beet production in the EU. Vegetable oil demand for biodiesel production would increase even more by 7 million tons or 49% of projected consumption.[36] In Canada, cereal use for ethanol production is set to increase by more than 5 million tons, representing 15% of projected domestic cereal use in 2014, while oil use for biodiesel would increase domestic consumption of vegetable oils by 4%.

Figure 8: Growth in commodity use for biofuel production between 2004 and 2014 in the policy-target scenario relative to total domestic consumption projected in the constant-biofuels scenario for 2014



Source: OECD Secretariat.

Following the substantial additional demand for crop products in these countries, trade patterns change significantly. EU imports of vegetable oils would increase three-fold, while wheat exports would fall by up to 41%. Canadian wheat and coarse grains exports would be reduced by 13% and 34% in 2014, respectively. As visible from Figure 9 below, world prices for most commodities, therefore, increase substantially. This is particularly the case for vegetable oils, where the stronger EU imports cause world prices to increase to USD 697 per ton by 2014, 15% higher than without an increase in biofuel production (see Figure 9). Conversely, world prices for oilseed meals would fall significantly, ending up about 6% lower than with constant biofuel production. For sugar markets, developments would be similar to those projected in the original baseline, but the additional sugar demand for ethanol production in the EU would trigger higher world prices, almost 60% above those with constant biofuel production.[37] Similarly, world grain prices would be somewhat higher, when compared to the original baseline, due to the additional demand from ethanol production in the EU and in Canada. World wheat prices would rise to USD 167 per ton, more than 4% higher than under the constant biofuel production scenario.

Meat markets do not see a large response to the changes taking place in crop markets. Most international meat prices would be somewhat higher than without growth in biofuels production – and more for pork than for beef. Implications are more significant for dairy markets, where butter prices tend to increase by up to 3% relative to the constant biofuel production scenario. In contrast to the meat markets, however, this is not predominantly caused by higher feed prices. Instead, the higher prices for vegetable oil raise demand for butter. That in turn increases SMP output, and in consequence, SMP prices fall by up to 0.7% relative to the no-change scenario.

While this scenario assumes policy target oriented developments in biofuel quantities with baseline commodity prices, the higher prices for feedstock products lead to somewhat slower growth in ethanol and biodiesel production than stated in the official goals. The share of transport fuel in the EU-15 that would be replaced by ethanol and biodiesel would increase from just under 1% in 2004 to 5.2% in 2010 and 5.5% in 2014, thus just failing to meet the objective of 5.75% set for 2010 by the Commission Directive. In the US and Canada, these shares would increase from 1.6% in 2004 to 2.2% in 2014, and from 0.3% to 3.0%, respectively, while in Brazil the share is estimated to increase from 22% to more than 26% during that period.

In summary, it becomes clear that the expected or announced growth in biofuel production in major producing countries has an important impact on both national and international markets for agricultural commodities. Prices for most crop products would develop much more strongly than without this source of additional demand, with the markets for sugar and vegetable oils are affected most significantly. The implications for livestock markets are generally moderate, with the notable exception of butter due to its link to vegetable oils. These results assume that the increase in biofuels mainly is due to growth in first-generation fuels, *i.e.* crop-based ethanol and biodiesel. If advanced biofuels become available on a large scale within the simulation period, that would replace some of the growth in ethanol and biodiesel based on grains, sugar crops and vegetable oils, and the implications on agricultural markets would likely be less pronounced than shown here (see section 7).

High oil price scenario: Sustained world crude oil prices at USD 60 per barrel

With sustained higher crude oil prices, there are two main forces at play that affect world markets for agricultural commodities. First, due to higher agricultural production costs that lead to lower quantities of production, commodity prices increase. At the same time, higher oil prices – and higher oil-based fuel pump prices – increase incentives to produce more biofuels (even though partially dampened by higher feedstock prices), which creates an additional demand for feedstock products. Again, this causes prices of agricultural commodities to increase.[38]

It should be noted that the impact of higher oil prices on crop production largely depends on the share of energy (including energy-dominated inputs such as fertilisers and pesticides) in total crop production costs. At the time this report was written, these data were available only for two countries, *i.e.* for the US and Argentina. As outlined in more detail in Annex 3, cost data for these two countries indicate energy shares in total crop production costs of some 25% for the US and 43% for Argentina. These shares are applied to all OECD countries and NMEs respectively. Clearly, it is unlikely that these shares will represent actual production costs in all countries, even though the orders of magnitude may be correct. Results of the high-oil price scenario therefore need to be read with some care.

Direct implications through higher production costs in agriculture

With crude oil prices at a sustained level of USD 60 per barrel from 2005 to 2014, oil costs between 30% in 2005 and 76% in 2014 more than assumed in the baseline. Higher agricultural production costs result in a global reduction of crop supply. Compared to the policy-target scenario, and keeping oil-based fuel and hence biofuel prices unchanged for the moment, global wheat and coarse grains production would be 1.5% and 1.7% lower in 2014, respectively, while the reduction of oilseed production would be 2.8%. Despite significant reductions of sugar cane production in developing countries, global sugar supply would be less than 2% below the policy-target scenario in each year of the projection period, and less than 1% below those levels by 2014. Sugar production remains largely unchanged in the highly protected and regulated markets of some of the major OECD sugar producing countries.

With 25% and 43%, respectively, the shares of energy in total crop production costs in developed and developing countries are assumed to be relatively high.[39] Nevertheless, the comparatively small supply responses and hence price changes are caused by generally small effects of increased production costs on crop area. As production costs for all crops are affected, reallocation of area is limited in most cases, so the supply response mainly comes from production intensity changes and hence yield effects. Consequently, compared to the policy-target scenario, world crop prices would be higher by between 10% (wheat) and 17% (oilseeds) at the end of the simulation period (Figure 9). In consequence of the higher commodity prices, biofuel production costs would increase as well. Still assuming no change in biofuel prices in this hypothetical scenario, ethanol and biodiesel production would decline by about 8% and 6% in 2014, respectively, compared to the policy-target scenario.

Indirect implications through higher biofuel production

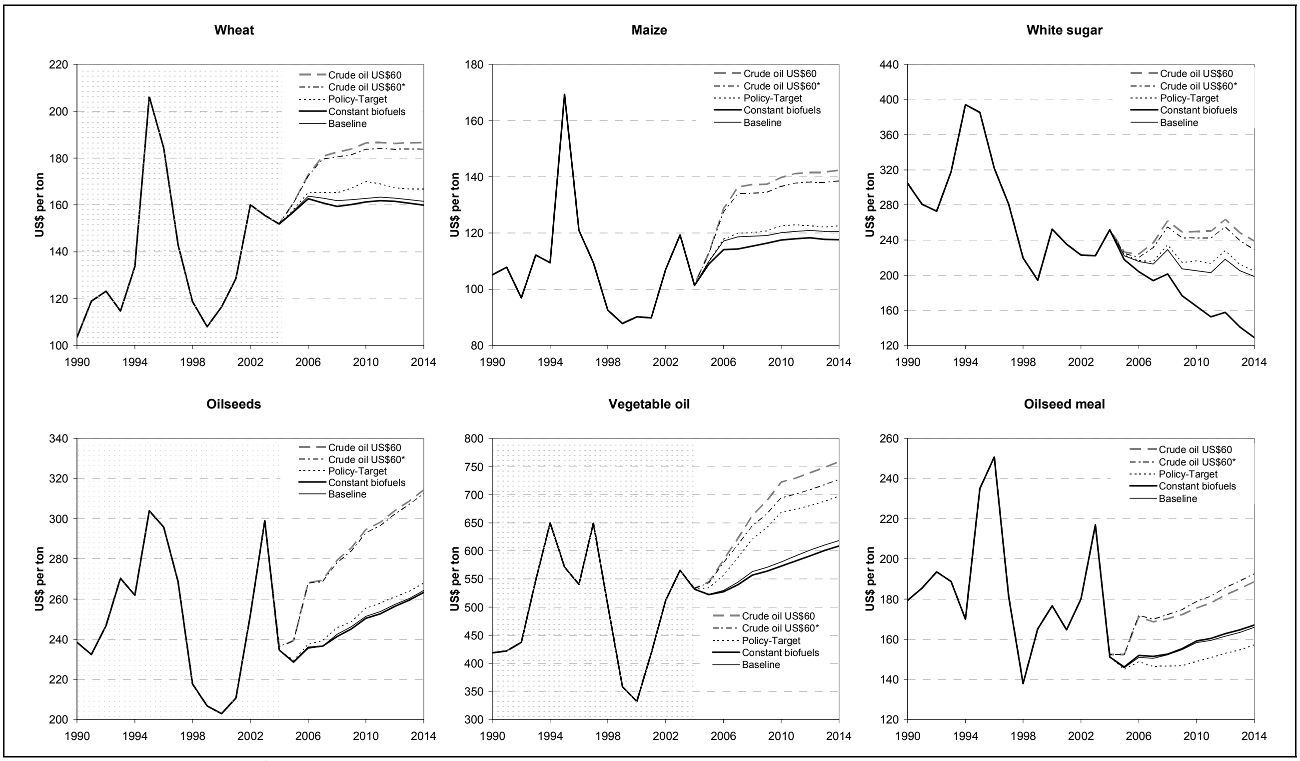
Following the increased pump prices for oil-based fuels, however, biofuel producers would have additional incentives to expand their output, even though dampened by the higher crop prices.[40] Global production of ethanol – dominated by the response in Brazil and the US – would increase by 8.1% in 2014 relative to the policy-target scenario, while production of biodiesel – dominated by the EU – is simulated about 16% higher in that year. These changes strongly depend on the assumed responsiveness of national biofuel production capacities and their usage rates to improvements in the ratio of net production costs and oil-based fuel prices.[41] In addition, with higher crop prices and declining crude oil prices, some of the biofuel production capacities are expected to remain unused in the policy-target scenario – the improved incentives following the higher oil prices would increase these use rates as well.[42]

Higher biofuel production should further stimulate world commodity prices, but with the exception of sugar, vegetable oils and oilseed meals, the impact of the additional biofuel production is relatively small: 0.6% to 2.8% by 2014 on top of the impact through higher production costs in agriculture. World sugar prices, however, would benefit by up to 4.2% from higher ethanol production in Brazil, a major exporter to world sugar markets. The stronger increase in biodiesel production should lead to a further increase in prices for vegetable oils, too, which would end another 4.3% higher than with unchanged gasoline and diesel prices. In contrast, with the stronger demand for vegetable oils and consequently higher crushing, and lower feed demand due to higher protein-rich by-product supplies, oil meal prices are 2% lower in 2014.

Higher production of biofuels also would increase their shares in total transport fuel consumption. In the EU-15, this share would increase to 6.0% in 2014, compared to 5.5% in the policy-target scenario. Shares in the US and Canada would remain lower at 2.6% and 3.0% lower, respectively, in 2014, changed only little from the policy-target scenario. In Poland, the transport fuel share replaced by biofuels would increase to 2.3% in 2014 compared to 1.9% with oil price levels of the policy-target scenario.

Price projections for crops and oilseed products are depicted in Figure 9. These projections suggest that biodiesel production, in particular, has the potential to boost world vegetable oil prices to levels that have not been observed during the past two decades.

Figure 9: World crop market prices under alternative scenario assumptions



Note: "Crude oil US$60*" denotes a scenario assuming higher crude oil prices, but unchanged petrol-based fuel prices – and hence unchanged biofuel prices – relative to the policy-target scenario.

Source: OECD Secretariat.

Biofuels in other countries

As shown in section 4 above, biofuels are not restricted to the four regions taken into account in this quantitative analysis. Instead, many other countries promote – or intend to promote – the production and use of ethanol and biodiesel, as well. While 77% of global ethanol, and almost all biodiesel, were produced in the four regions covered in this analysis in 2004, China and India need to be mentioned here in particular, as these two countries have produced 9% and 4% of global ethanol supplies in 2004, and both countries envisage a significant growth in their biofuel industries. Other countries are expected to start or expand their biofuel production as well.

For many developing countries that depend on imports for both food and crude oil, it is an important issue to discern to what degree increased domestic biofuel production can replace imported oil – and to what degree this would drive land and other resources out of food production in these countries. Clearly, the answers to these two important questions will differ across countries as they strongly depend on domestic conditions: resource constraints not only in terms of agricultural land, but also in terms of labour and capital availability need to be considered as well as the regional climate conditions, to mention only a few. Driving land out of food production may not always be a necessary consequence of producing biofuels if marginal or otherwise unused land can be made productive. It may even be an economically viable option if the reduction in the import bill for crude oil (or oil-based fuels) exceeds the costs for additional food imports. On the other hand, if access to international food markets is constrained, for instance due to lack of infrastructure, even a substantial reduction in the oil import bill may not justify a reduction in domestic food production. In the longer run, advanced biofuels may reduce the competition between biofuel and food production (see section 7); but this may require substantial investments and know-how.

In many cases, developing countries that intend to produce ethanol or biodiesel will likely require foreign aid to do so, either in the form of capital and foreign investment, or in terms of know-how, training *etc.* If the above-mentioned conditions for economic viability of increased biofuel production are met in these countries, such help can be considered as effective development aid. However, even if economically desirable it may be very difficult for political reasons to replace food production with biofuels feedstock production in countries that are most heavily dependent on food imports and where the population suffers from hunger and malnutrition on a regular basis.

To what degree individual developing countries will eventually further engage in biofuel production remains largely unclear at this stage, even though substantial quantities of ethanol and biodiesel are already being produced in the developing world, particularly in India and China. In case there would be substantial growth in biofuel production in developing countries, the results shown above are likely to underestimate the actual impact of global biofuel developments on agricultural markets. Compared to the four countries considered in the quantitative assessment above, however, biofuel quantities in other countries, perhaps with the exception of India and China, and hence the degree of underestimation of market impacts are likely to remain small. Given the larger importance of developing countries in global supply and demand of sugar compared to cereals, impacts on sugar markets are probably underestimated to a larger degree than those on cereal markets.

7. Longer-term implications of “advanced” biofuels

The analysis of the impact of biofuel developments on agricultural markets so far has almost exclusively focused on biofuels made from food and feed commodities. Cereals, sugar crops and vegetable oils currently represent the bulk of the feedstock used in ethanol and biodiesel production, and given their relative costs, this is likely to remain the case for the next decade or so. In the longer run, however, modern technologies to produce ethanol from cellulosic and ligno-cellulosic material or synthetic fuels from biomass (BTL) may change the economics of biofuels supply significantly, as mentioned above.[43]

These technologies are expected to make biofuels production cheaper than cane-based ethanol – which is economically viable without any support at current crude oil prices; however, they would have very different and probably much less pronounced impacts on agricultural markets. Rather than representing an additional demand for food commodities these technologies would, in many cases, for example based on the use of switchgrass or dedicated wood, divert land from food and feed production and hence reduce agricultural supply, but to a lesser extent compared to the additional demand from first-generation biofuels. In other cases, where materials currently considered as waste are utilised, no additional land may be required at all, as is the case of straw or forest waste (where these are not already used to produce heat and electric energy). In any case, the amount of land needed to produce a certain quantity of biofuel energy will certainly be well below the numbers presented in section 3 of this report. Similarly, the impacts on agricultural markets will be smaller than those presented in section 6 assuming everything else the same, in addition to the effects of using marginal or fallow land, which has not been taken into account in the analysis above.

Due to the expected economic advantages of advanced biofuels technologies, however, production of renewable fuels may well increase substantially in the longer run. When compared to the quantitative analysis presented above, two main effects may arise from this growth. First, it is impossible to make an *a priori* assessment on whether the lower land requirements per unit of biofuel energy would be under- or overcompensated by the overall change in biofuel production quantities, and hence whether the eventual market implications would be smaller or larger than those shown above. Nevertheless it seems quite likely that overall effects on agricultural commodity markets will be less pronounced in the longer run than shown in this analysis. Second, the assumption of exogenous crude oil prices may no longer hold: if biofuels are taking substantial shares of total transport fuel energy and, eventually, of total energy consumption, the resulting reduction (or slower growth) of demand for crude oil may impact on oil prices as well. Quite obviously, the assessment of such a question goes far beyond the scope of this paper and would require a different analytical approach than the partial-equilibrium modelling framework employed in the current analysis.

8. Summary and conclusions

Biofuels represent a significant and growing source of demand for agricultural commodities. Cereals, sugar beet and sugar cane are currently used to produce ethanol, which has become a ready substitute for oil-based gasoline. On the other hand, biodiesel is produced from vegetable oils and has the potential to be used instead of oil-based diesel. While both ethanol and biodiesel require some modifications in the engines of normal transport vehicles, both blending and the sale of modified engine vehicles give rise to the expectation that these fuels can gain non-trivial shares in total transport fuel consumption, particularly as it is widely supported by public measures in a number of countries. The economics of biofuel production and the likely impacts of an expected growth in biofuel-related demand for agricultural products on commodity markets therefore represent the main questions looked at in this report.

The present study describes the economics and policies in biofuel markets by bringing together available information on production technologies, costs and policy measures in major biofuel producing countries. Additionally, based on assumptions where data are missing, production costs are calculated for the year 2004 (the base year for the impact analysis below) and compared across countries and production processes as well as with oil-based fuel prices to show the relative competitiveness of biofuel production. Impacts on agricultural markets are analysed using the OECD partial equilibrium model for temperate zone agricultural commodities, Aglink, in connection with the FAO-counterpart, Cosimo, and the OECD World Sugar Model. A number of modifications are made to the models to allow for this type of analysis, as well as to model the impact of changes in crude oil prices on agricultural production costs. Model results of a set of scenarios are compared in order to identify the specific impacts of expected growth in biofuels production as well as those of changes in world crude oil prices.

Production costs vary considerably across the main biofuels producing countries as well as across feedstocks. Although estimates of biofuel production costs are subject to substantial uncertainty, the available data suggest that costs per unit of Brazilian ethanol from sugar cane are far below those of most other production systems. Consequently, only Brazil would be able to produce ethanol in an economically viable manner with world crude oil prices of around USD 39, which was the prevailing price in 2004, the base period used in this report. Production cost estimates for the US, Canada and the EU suggest that economic viability without public support can be expected only at higher oil prices. While US ethanol production from maize would become viable – according to these calculations – at oil prices above USD 44, i.e. at prices lower than those observed in 2005, other estimates range between USD 65 and USD 145. A number of caveats apply for these estimates. First, production costs are calculated for all countries largely based on literature data found for one specific country, assuming the same technology but taking into account regional crop and energy prices. Second, biofuel production costs are kept at their calculated 2004 level while crude oil prices are adjusted to balance net fuel prices with net production cost of biofuels. Third, the EU-15 is treated as an aggregate block. Differences between Member States in terms of productivity in both agriculture and biofuel industries are therefore not taken into account, which might bias results in terms of biofuel competitiveness. Nevertheless, it appears that the oil prices that would allow national biofuel production to become profitable without subsidies vary widely across countries, but also across feedstock products. Important variables determining the relative comparison across countries and feedstocks particularly include the domestic crop prices which are driven by regional supply and demand conditions, as well as by domestic and trade policies.

Similar results can be found with respect to the area requirements for a given share of domestic transport fuel consumption. The three OECD regions, the US, Canada and EU (15) require between 30% and 70% of their respective current crop area if they are to replace 10% of their transport fuel consumption by biofuels, assuming unchanged production technologies and crop yields, and in the absence of international trade or use of marginal or fallow land. However, only 3% would be required in Brazil due to not only the high ethanol yield per hectare of land, but also because of the relatively low per capita fuel consumption in this country. This latter factor results in a relatively low area share of 6% for Poland, too. Both production costs and area requirements suggest a substantial comparative advantage of Brazil relative to OECD countries in the northern hemisphere. As similarly favourable agro-climatic conditions hold for other tropical and subtropical countries as well, countries such as India, China and other Latin American countries in addition to Brazil could also be able to produce biofuels which are comparatively cost effective, but further work is needed in this area.

The additional demand for agricultural commodities is likely to substantially affect the outlook for their markets. The major producers of biofuels – Brazil, the US, the EU and Canada are covered explicitly in this analysis – are expected to significantly reduce their exports of the respective feedstock commodities or to increase their imports. The strongest impact on international price levels can be expected for sugar, where world prices could increase by up to 60% in 2014 compared to a situation with unchanged biofuel quantities at their current levels. Other prices would respond less dramatically, but could still gain some 4% in the case of cereals, and up to 20% in the case of vegetable oils.

While for the baseline underlying this analysis a declining world oil price from its 2005 peak is assumed, recent developments suggest that crude oil could remain valued above USD 60 per barrel. Assuming unchanged policies, higher crude oil prices would further stimulate biofuels production. The degree to which biofuel quantities would increase strongly depends on parameters that are yet unobserved. Nevertheless, the results of this analysis suggest that the impacts of high oil prices on agricultural markets may well be dominated by their direct effects on agricultural production costs rather than by the increased demand for agricultural commodities.

A number of policy questions have been left aside in this analysis. The biofuel producing countries in this analysis mostly apply various measures to domestically support their biofuel industries and/or biofuel consumption (see section 4). Without such support, biofuel quantities would likely develop less dynamically as in many countries and for most production processes biofuel production is more expensive than the tax-free prices for gasoline and diesel when taking into account the energy contents of the different fuels, although this clearly also depends on the further development of crude oil prices. Public support for biofuel production and consumption undoubtedly results in increased demand for starchy and sugar crops as well as for vegetable oils, at least in the near future. Higher prices certainly are in the interest of producers of such commodities, but are likely to be less welcome to their consumers, in particular to livestock producers both in biofuels producing countries and elsewhere. Biofuel policies may therefore be considered an important element in the agricultural policy debate.

Related to domestic biofuel policies, trade in ethanol and biodiesel is facing a number of barriers in several countries that prevent low-cost producers from fully exploiting their export potential. Reducing such barriers (including the set up of international product standards) would not only allow these countries to better sell their product, but would also help to meet the environmental objectives behind many of the national biofuel policies of (potentially) importing countries, provided the fuels are produced in the exporting countries in an environmentally sound manner. The environmental implications and sustainability of biofuel production and use in different countries are subject to intensive debate and represent an important area of further research that could not be covered in the present study, but that will need to be taken into account in the evaluation of policies and their market impacts.

Linked to international trade in biofuels, limitations of the Aglink model with respect to commodities used in the biofuel production also need to be acknowledged. This not only concerns biomass cultivations to be used in advanced biofuels, but also commodities already used in current biofuel production, such as cassava, potatoes and other commodities rich in starch to be used in ethanol production. It also concerns oil crops other than rape seed, sunflower seed, soyabeans, and palm oil, that can be used in biodiesel production.[44] A similar limitation has to be mentioned with respect to the country coverage, as biofuels of potentially important producers, such as China and India, are not considered.

Apart from domestic and trade policies in biofuel markets, there is a number of other questions that have been touched upon in the present analysis, but where more in-depth research is required. Two questions are directly related to the development of biofuel production: first, it is assumed that oil-based fuel prices are the driving factor for biofuel production. But this can only be regarded as a first step. One alternative could be to determine ethanol and biodiesel prices by means of an inverse demand function (as it is used by, *e.g.* FAPRI). Another one could be to develop a full sub-module for ethanol and biodiesel markets in the model that then could also take into account international biofuel markets and trade policies explicitly. Clearly, the latter option would involve a much greater task with substantial resource costs.

Second, the functional relationship between fuel prices, production costs and biofuel production has been only roughly approximated in this study based on scarce data and simple assumptions. With biofuel production becoming a longer-term development, statistics on both production and cost data should improve, allowing for a better assessment of the behavioural relationships. This would also allow a reduction in the exogenous adjustments made to the biofuel production capacities in the model which in some cases in this analysis have become quite important. Similarly, the link between biofuel use and its driving forces is not well known yet. Thus, better data should allow for better analysis of the demand side of the biofuel market as well.

In addition to the assessment of agricultural market impacts, regional questions such as the potential contribution of biofuels to economic development in developing countries are important, too. However, such questions cannot be discussed on a global scale in isolation and need to take into account in-depth analyses of individual countries and regions, including their resource endowment, climatic conditions, political situation *etc.*

Finally, and independent of the specific analysis of biofuels, further work is needed to refine the representation of crop and livestock production costs. With detailed cost data for countries other than Argentina and the US, the analysis of changes in crude oil prices should become more precise.

Furthermore, the current assumption of equal cost shares across crops – and across livestock products – excludes the reallocation effects that are likely to occur between commodities with different intensities of inputs in general, and of energy inputs in particular.

A number of caveats on the quantitative analysis in this study need to be mentioned. First, data availability for biofuel production costs and quantities is relatively poor in numerous countries that are or may become important players in this area. Consequently, several simplifying assumptions are made with respect to production technologies across countries, and some potentially important biofuel producers, most notably China and India, as well as a number of feedstock commodities are not taken into account. Second, both the calculation of production costs and area requirements as well as the model-based impact analysis ignore the potential benefits of “advanced” biofuels. Third, the calculation of area requirements remains perfectly static as opposed to projections into the future in that it represents unchanged 2004 conditions in terms of technology, feedstock mix and area use. In addition, neither the potential use of currently unproductive land nor the implications of international trade are taken into account

ANNEX 1: PRODUCTION COSTS FOR BIODIESEL AND ETHANOL FROM DIFFERENT FEEDSTOCKS, MAIN PRODUCING COUNTRIES

Table 1.1: Production costs for biodiesel and ethanol from different feedstocks, main producing countries, 2004

Country:		EU			EU			USA			EU			Brazil	
Biofuel:		Biodiesel			Ethanol			Ethanol			Ethanol			Ethanol	
Feedstock:		Vegetable oil			Wheat			Maize			Sugar beet			Sugar cane	
	Quant.	LC/t	USD/t	Quant.	LC/t	USD/t	Quant.	LC/t	USD/t	Quant.	LC/t	USD/t	Quant.	LC/t	USD/t
Feedstock use, t	1.06			3.49			3.20			12.90			14.87		
Feedstock price		463.16	573.40		103.73	128.41		76.57	76.57		23.87	29.55		32.75	10.95
Feedstock costs		**490.95**	**607.80**		**362.11**	**448.30**		**244.66**	**244.66**		**307.82**	**381.08**		**486.98**	**162.80**
Processing costs excl. energy		**69.29**	**85.78**		**347.99**	**430.82**		**130.18**	**130.18**		**288.96**	**357.74**		**339.49**	**113.50**
Energy use: methanol, kg	145.33														
Energy: methanol, price per kg		0.23	0.28												
Energy use: heat, GJ				13.90			16.43			13.90					
Energy: heat, price per GJ					3.46	4.29		4.29	4.29		3.46	4.29			
Energy use: electricity, kWh	315.94			353.85			303.30			353.85					
Energy: electricity, price per kWh		0.031	0.039		0.031	0.039		0.031	0.031		0.031	0.039			
Total energy costs		**43.10**	**53.36**		**59.18**	**73.27**		**79.86**	**79.86**		**59.18**	**73.27**			
Gross production costs		**603.34**	**746.95**		**769.28**	**952.39**		**454.71**	**454.71**		**655.96**	**812.09**		**826.47**	**276.30**
Energy feed by-product; t cg-eq.				1.63			0.80			0.75					
Domestic price coarse grains					112.96	139.85		76.57	76.57		112.96	139.85			
Protein feed by-product; t om-eq.							0.16								
Domestic price oil meals								178.50	178.50						
Other by-product credit (glycerin)		50.00	61.90												
Total by-product credit		**50.00**	**61.90**		**183.90**	**227.67**		**89.82**	**89.82**		**84.72**	**104.88**		**0.00**	**0.00**
Net production costs		**553.34**	**685.05**		**585.38**	**724.72**		**364.89**	**364.89**		**571.24**	**707.21**		**826.47**	**276.30**
Net costs, per litre of fuel		***0.438***	***0.542***		***0.463***	***0.573***		***0.289***	***0.289***		***0.452***	***0.560***		***0.654***	***0.219***
Net costs, per litre GE		***0.395***	***0.489***		***0.702***	***0.869***		***0.437***	***0.437***		***0.685***	***0.848***		***0.991***	***0.331***

Note: Cost calculations for combinations of countries and feedstock commodities other than those shown in this table which are used in the cost comparison are based on the technical coefficients used in this table, whereas domestic commodity prices and regional shares of energy sources in the generation of electricity cause biofuel production costs to differ across countries. Given the implicit assumption of equal technologies and technical coefficients across countries, production cost figures used in the report for country/commodity combinations are indicative only and might differ from specific studies on biofuel production in these countries once these become available.

Source: OECD Secretariat based on data provided in Smeets *et al.* (2005), Aglink database

ANNEX 2: CALCULATION OF LAND REQUIREMENTS FOR 10% BIOFUEL SHARES IN TRANSPORT FUEL CONSUMPTION IN MAJOR BIOFUEL PRODUCING REGIONS

Land requirement estimates are calculated from 2004 data and therefore do not take into account the likely increase in productivity both in agriculture and in the biofuel production technology. Similarly, no changes in the allocation of various feedstocks to biofuel production are accounted for. Finally, trade of biofuels is not considered either, *i.e.* the 10% share of biofuels in domestic transport fuel consumption is assumed to be produced domestically only. Consequently, the shares calculated here and shown in Figure 4 should not be read as projected land use estimated once higher levels of biofuel use should be achieved.

The calculation itself is based on a number of data and parameters. The following explanations on data sources and calculation methods refer to Table 2.1 below, which contains the data used and the results (both intermediate and final) obtained. Line numbers are given in the first column to facilitate the reading of the explanatory text.

Data sources and methods in the calculation of land requirement estimates

Lines 1 and 2:Production quantities of biofuels in 2004 are estimates based on Smeets et al. (2005).[45]

Line 3: Data on transport fuel consumption are taken from the World Energy Outlook 2004. 2004 data are calculated as a linear interpolation of 2002 and 2010 data provided in that source.

Line 4: 2004 shares of biofuels in total transport consumption are calculated on an energy basis, using the following parameters: density of ethanol 0.7913 kg/l; density of biodiesel 0.9 kg/l; energy content of one litre of ethanol relative to one litre of gasoline: 0.66; energy content of one litre of biodiesel relative to one litre of gasoline: 0.89.

Lines 5 to 9: Data on the feedstock composition of ethanol production is not always available. However, Smeets et al. (2005) say that in the USA most of the ethanol is produced from maize (p. 29). A 10% share is assumed to be produced from wheat. In Canada ethanol is mainly produced from wheat (p. 31) – a 10% share is assumed to be produced from maize. In the EU (15), feedstocks mainly include wheat, coarse grains and sugar beet. Based on data on ethanol from sugar beet taken from CGB (2005), about 15% of ethanol are assumed to be made from sugar beet; 45% of ethanol are assumed to be produced from wheat, the remainder (40%) from coarse grains. For Poland, it is assumed that wheat and coarse grains are used for 5% and 85% of ethanol production, respectively, with the remainder produced from sugar beet (this abstracts from the fact that a non-trivial share of ethanol is produced from potatoes in Poland). All biodiesel is assumed to be made from vegetable oils. Conversion rates from agricultural commodities to ethanol and biodiesel are presented in Table 3.1 below.

Lines 10 to 15: Data on average crop yields and on oil extraction rates are taken from the Aglink data base. Oilseed data refer to soyabeans for the USA and to rape seed for Canada, the EU (15) and Poland.

Lines 16 to 20: Crop area is calculated from crop use for biofuels (lines 5 to 9) and crop yields and oil extraction rates (lines 10 to 15) (area = use / yield for grains and sugar crops; area = use / (yield*extraction rate) for oilseeds).

Line 22: The area needed to meet the 10% share of biofuels is a simple extrapolation of the data above and hence is calculated from the total crop area in lines 16 to 20 multiplied by the 10% target share and divided by the actual 2004 share in line 4.

Line 23: Data on the total area harvested for grains, oilseeds and sugar crops are taken from the Aglink data base.

Line 24: Finally, the area share needed to meet the target share of biofuels is the simple ratio of the area needed in line 22 to the total area harvested in line 23.

World data (last column in Table 2.1) largely represent the sum of the countries represented in this table, with the exception of transport fuel consumption (line 3) and total area harvested for grains, oilseeds and sugar crops (line 23) which are actual global figures. The area needed (line 22) and the area share needed (line 24) are calculated as in the cases of individual countries, but given the higher transport fuel consumption the area needed is higher than the sum of the five countries.

Table 2.1: Calculation of land requirement estimates

		Unit	USA	CAN	EU-15	POL	BRA	WLD
	Representation of the 2004 situation							
1	Ethanol production quantity	1000 t	10 208	138	386	36	11,732	22 500
2	Biodiesel production quantity	1000 t	90	5	1 853	1		2 029
3	Transport fuel consumption	bil. l GE	535.4	45.8	279.5	8.2	45.4	1 604.2
4	Bio-share in transport fuel		1.6%	0.3%	0.8%	0.4%	21.6%	1.3%
5	Use of wheat	1000 t	1,069	435	606	6		2 167
6	Use of coarse grains	1000 t	31 638	44	491	97		32 226
7	Use of sugar cane	1000 t					188 291	188 291
8	Use of sugar beet	1000 t			755	46		801
9	Use of vegetable oil	1000 t	95	6	1 965	1		2 151
10	Wheat yield	t / ha	2.75	2.22	5.71	3.57		
11	Maize yield	t / ha	8.88	7.19	8.68	5.96		
12	Sugar cane yield	t / ha					71.42	
13	Sugar beet yield	t / ha			59.34	39.97		
14	Oil extraction rate (main seed)	T / t	0.19	0.32	0.28	0.36		
15	Oilseed yield (main seed)	t / ha	2.58	1.43	3.08	2.25		
16	Wheat area for ethanol	1000 ha	389	196	106	2		707
17	Coarse grain area for ethanol	1000 ha	3 564	6	57	16		3 636
18	Sugar cane area for ethanol	1000 ha					2 636	2 636
19	Sugar beet area for ethanol	1000 ha			13	1		14
20	Oilseed area for biodiesel	1000 ha	191	12	2 254	1		2 561
	Extrapolation of 2004 data							
21	Target bio-share in transport fuel		10%	10%	10%	10%	10%	10%
22	**Area needed to meet target bio-share**	**1000 ha**	**25 790**	**8 139**	**31 518**	**542**	**1 222**	**73 784**
23	Total area harvested (grains, oilseeds, sugar)	1000 ha	86 702	22 563	43 888	9 236	37 514	830 433
24	**Area share needed to meet target bio-share**		**30%**	**36%**	**72%**	**6%**	**3%**	**9%**

ANNEX 3: MODELLING BIOFUELS AND CRUDE OIL PRICES IN AGLINK

Aglink is a dynamic partial equilibrium model for agricultural product markets developed and applied by the OECD Secretariat and Member Countries. Together with the Cosimo model, developed by FAO based on the Aglink modelling methods, it covers the global markets by representing all OECD countries (two of which are exogenous and with EU members aggregated into a common market) and 36 countries and regions outside the OECD. Designed for temperate-zone products, the model covers the markets for some 15 commodities, including cereals, oilseeds, oilseed products, meat, and dairy products. A special emphasis is given to domestic and trade policies which are represented in detail. The model is regularly used to create medium-term projections (baseline) for supply, demand, trade and prices, as well as for the forward-looking analysis of policy changes and other factors.

Normally run as a separate model next to Aglink / Cosimo, the Aglink Sugar Model specifically covers the regional and international markets for sugar cane, sugar beets and raw and white sugar. Using similar modelling methods and having a similar focus on agricultural policies, the sugar model has a different regional disaggregation. Aglink / Cosimo and the Aglink Sugar Model have been combined for the purpose of this analysis.

Model representation of biofuels

The representation of biofuels in the model is based on the methods already applied for a similar, but more restricted, analysis of biofuel developments in the OECD Agricultural Outlook 2002-2007 (OECD, 2002). In the model, biofuel production represents an additional demand for agricultural products, particularly for wheat, coarse grains, vegetable oils, sugar cane and sugar beet. At the same time, depending on the feedstock used, biofuel production provides additional supplies of feed commodities used in the livestock production process, and, hence, substituting for other feed products represented in the model. The model analysis considers the production of both ethanol and bio-diesel.[46] Depending on the country, ethanol is produced from wheat, coarse grains and/or sugar, with different conversion rates across feedstock types.[47]

$$(1)\quad BF_{r,t}^{i,j} = \alpha_{r,t}^{i,j} * QP_{r,t}^{j} * BFS_{r,t}^{i,j}$$

$$(2)\quad EF_{r,t} = \sum_{i} \delta_{r,t}^{i,EF} * QP_{r,t}^{ET} * BFS_{r,t}^{i,ET}$$

$$(3)\quad PF_{r,t} = \sum_{i} \delta_{r,t}^{i,PF} * QP_{r,t}^{ET} * BFS_{r,t}^{i,ET}$$

with:	
$BF^{i,j}$	quantity of feedstock i used for production of biofuel j
QP^{j}	quantity of biofuel j
$BFS^{i,j}$	share of biofuel j produced on the basis of feedstock i in total production of biofuel j
EF	quantity of energy-rich feed by-produced with ethanol
PF	quantity of protein-rich feed by-produced with ethanol

$\alpha^{i,j}$	quantity of feedstock i needed to produce one tonne of biofuel j
δ^{EF}, δ^{PF}	quantity of energy- (protein-)rich feed produced with one tonne of ethanol
i	product index {sugar cane, sugar beet, coarse grains, wheat}
j	biofuel index {ethanol, biodiesel}
r	region index
t	time index

Production of ethanol and bio-diesel in turn is modelled in a double-log form depending on time, the cost ratio between biofuel and petroleum-based fuel and an exogenous adjustment factor to take into account politically determined growth. The cost ratio is calculated from net production costs and crude oil prices.

$$(4)\quad QP^{j}_{r,t} = QPC^{j}_{r,t} * QPS^{j}_{r,t}$$

$$(5)\quad \ln\left(QPC^{j}_{r,t}\right) = QPC^{j}_{r,t-1} + \chi^{j}_{r} + \phi^{j}_{r} * \ln\left(\left(CRT^{j}_{r,t-1} + CRT^{j}_{r,t-2} + CRT^{j}_{r,t-3}\right)/3\right) + \ln\left(R.QPC^{j}_{r,t}\right)$$

$$(6)\quad QPS^{j}_{r,t} = QPSL^{j}_{r,t} + \frac{1 - QPSL^{j}_{r,t}}{1 + LOGA^{j}_{r} * e^{\left(LOGB^{j}_{r} * \left(CRT^{j}_{r,t} - 1\right)\right)}}$$

$$(7)\quad CRT^{j}_{r,t} = \frac{NC^{j}_{r,t} / \lambda^{j,j'}}{CP^{j'}_{r,t}}$$

$$(8)\quad CP^{j'}_{r,t} = a^{j'}_{r,t} + b^{j'}_{r,t} * XP^{OIL}_{t} * XR_{r,t} + TAX^{j'}_{r,t}$$

with:

QPC^j	production capacity of biofuel j
$R.QPC^j$	exogenous adjustment factor for production capacity of biofuel j
QPS^j	production capacity use share of biofuel j (i.e., average utilisation rate of biofuel production plants)
$QPSL^j$	lower limit of production capacity use share of biofuel j[48]
CRT^j	cost ratio of biofuel j
NC^j	net production costs of biofuel j
LOGA, LOGB	parameters in logistic function
$CP^{f'}$	retail price of fossil fuel j’
XP^{OIL}	world crude oil price
XR	exchange rate
$TAX^{j'}$	tax on fossil fuel j’
χ^j_r	trend annual growth rate of production capacity for biofuel j
ϕ^j_r	elasticity of production capacity for biofuel j with respect to its cost ratio
$\lambda^{j,j'}$	energy content of biofuel j relative to the respective petrol-based fuel j’
$a^{j'}$, $b^{j'}$	constant and slope parameter in the functional relationship between crude oil price and the price of fossil fuel j’
j’	fossil fuel index {gasoline, diesel}

Net production costs can be defined as the sum of feedstock costs (directly linked to market prices for grains, sugar and vegetable oils), energy costs (assumed to be a function of crude oil prices) and other costs (assumed to be exogenous,[49]) minus the value of by-products used in the livestock industry (linked to market prices for the respective feed substitutes grains and oilseed meal), less subsidies (*e.g.* by means of tax concessions). These costs may differ across processes using alternative feedstocks.

$$(9)\quad \begin{aligned} NC_{r,t}^{j} &= \sum_{i} NC_{r,t}^{i,j} * BFS_{r,t}^{i,j} \\ &\quad + TAX_{r,t}^{j} \end{aligned}$$

$$(10)\quad \begin{aligned} NC_{r,t}^{i,j} &= \alpha_{r,t}^{i,j} * PP_{r,t}^{i} \\ &\quad + \beta 0_{r,t}^{i,j} + \beta_{r,t}^{i,j} * XP_{t}^{OIL} * XR_{r,t} \\ &\quad + \gamma_{r,t}^{i,j} \\ &\quad - \delta_{r,t}^{i,j,EF} * PP_{r,t}^{CG} - \delta_{r,t}^{i,j,PF} * PP_{r,t}^{OM} - \delta_{r,t}^{i,j,OBP} \end{aligned}$$

with:

PP^i	domestic price for commodity i
TAX^j	tax on biofuel j
$\beta 0^j$	constant parameter of net production costs of biofuel j reflecting energy costs independent of crude oil prices
β^j	slope parameter of net production costs of biofuel j with respect to crude oil prices
γ^j	intercept of net production costs of biofuel j
δ^{OBP}	value of other by-products per tonne of biofuel
CG, OM	coarse grains, oil meals

Finally, shares of feedstocks in ethanol production[50] where several feedstocks are used are determined assuming constant elasticities of substitution (where s and d are scale and distribution parameters of the CES function, and σ is the elasticity of substitution). If the elasticity of substitution is known, the scale and distribution parameters can be calibrated to any base set of data. Given that the shares of a CES function not always add up to exactly unity when net costs change, a second set of scaling equations is applied.

$$(11)\quad BFSE_{r,t}^{i,j} = \frac{1}{s_r^j} * \left[d_r^{i,j} + \sum_{i' \neq i} \left(d_r^{i,j}\right)^{(1-\sigma)} * \left(d_r^{i',j}\right)^{\sigma} * \left(\frac{NC_{r,t}^{i',j}}{NC_{r,t}^{i,j}} \right)^{(1-\sigma)} \right]^{\frac{\sigma}{(1-\sigma)}}$$

$$(12)\quad BFS_{r,t}^{i,j} = {BFSE_{r,t}^{i,j}} \Big/ {\sum_{i'} BFSE_{r,t}^{i',j}}$$

with: $BFSE^{i,j}$ unscaled share of biofuel j produced on the basis of feedstock i in total production of biofuel j

Parameters are largely taken from Smeets *et al.* (2005). As information about biofuel production processes generally are available only from one country each, many of the parameters applied in the analysis are equal across countries. The following table lists the parameters applied, as well as their changes over time assumed.

Table 3.1: Parameters used in the model analysis

	Products	Value 2004	Change p.a.	Found for	Used for
$\alpha^{i,j}$	**quantity of feedstock i needed to produce biofuel j, t/t**				
	Coarse grains	3.20	-0.53%	USA	all countries
	Wheat	3.49	-0.50%	EU	all countries
	Sugar beet	12.90	-0.25%	EU	all countries
	Sugar cane	14.87	-0.50%	BRA	Cost calculations BRA
	Veg. Oil	1.06	0.00%	EU	all countries
δ^{EF}	**quantity of energy-rich feed produced with ethanol, t/t**				
	Coarse grains	0.8	-0.53%	USA	all countries
	Wheat	1.628	-0.50%	EU	all countries
	Sugar beet	0.75	-0.25%	EU	all countries
	Sugar cane	0	-0.50%	BRA	Cost calculations BRA
	Veg. Oil	0	0.00%	EU	all countries
δ^{PF}	**quantity of protein-rich feed produced with ethanol, t/t**				
	Coarse grains	0.16	-0.53%	USA	all countries
	Wheat	0	-0.50%	EU	all countries
	Sugar beet	0	-0.25%	EU	all countries
	Sugar cane	0	-0.50%	BRA	Cost calculations BRA
	Veg. Oil	0	0.00%	EU	all countries
χ^{j}_{r}	**trend annual growth rate of production capacity for biofuel j**				
	Ethanol	5.00%			CAN, POL, EU
	Ethanol	3.00%			USA
	Biodiesel	5.00%			CAN, USA, EU, POL
ϕ^{j}_{r}	**elasticity of production capacity for biofuel j with respect to its cost ratio**				
	All products, all biofuels	-1			all countries
$\lambda^{jj'}$	**energy content of biofuel j relative to the respective petrol-based fuel j', ratio**				
	Ethanol	0.66			all countries
	Biodiesel	1.1096			all countries
aj'	**constant parameter in the functional relationship between crude oil price and the price of fossil fuel j', LC/l**				
	Gasoline	0.240			CAN
	Gasoline	0.131			EU
	Gasoline	0.168			POL
	Gasoline	0.134			USA
	Diesel	0.170			CAN
	Diesel	0.173			EU
	Diesel	0.156			POL
	Diesel	0.118			USA
bj'	**slope parameter in the functional relationship between crude oil price and the price of fossil fuel j', USD/l per USD/barrel**				
	Gasoline	0.00410			CAN
	Gasoline	0.00751			EU, POL
	Gasoline	0.00682			USA
	Gasoline	0.00629			Viability calculation BRA
	Diesel	0.00629			CAN
	Diesel	0.00620			USA
	Diesel	0.00652			EU, POL

	Products	Value 2004	Change p.a.	Found for	Used for
	Diesel	0.00629			Viability calculation BRA
$\beta 0^j$	**constant parameter of net production costs of biofuel j reflecting energy costs independent of crude oil prices, LC/t**				
	Coarse grains	7.282	-0.53%		EU
	Coarse grains	28.183	-0.53%		POL
	Coarse grains	7.320	-0.53%		USA
	Coarse grains	11.807	-0.53%		CAN
	Wheat	8.495	-0.50%		EU
	Wheat	32.880	-0.50%		POL
	Wheat	8.540	-0.50%		USA
	Wheat	13.775	-0.50%		CAN
	Sugar beet	8.495	-0.25%		EU
	Sugar beet	32.880	-0.25%		POL
	Sugar cane	0.000	-0.50%		Cost calculations BRA
	Veg. Oil	32.964	0.00%		EU
	Veg. Oil	127.581	0.00%		POL
	Veg. Oil	31.526	0.00%		USA
	Veg. Oil	50.850	0.00%		CAN
β^j	**slope parameter of net production costs of biofuel j with respect to crude oil prices, barrel equivalent/t**				
	Coarse grains	1.877	-0.53%		EU, POL
	Coarse grains	1.862	-0.53%		USA, CAN
	Wheat	1.611	-0.50%		EU, POL
	Wheat	1.593	-0.50%		USA, CAN
	Sugar beet	1.611	-0.25%		EU, POL
	Sugar cane	0.000	0.00%		Cost calculations BRA
	Veg. Oil	0.064	0.00%		EU, POL
	Veg. Oil	0.050	0.00%		USA, CAN
γ^j	**intercept of net production costs of biofuel j (labour, maintenance, overheads, capital), LC/t**				
	Coarse grains	137.91	-0.53%		EU
	Coarse grains	533.76	-0.53%		POL
	Coarse grains	130.18	-0.53%		USA
	Coarse grains	209.98	-0.53%		CAN
	Wheat	332.08	-0.50%		EU
	Wheat	1286.34	-0.50%		POL
	Wheat	313.65	-0.50%		USA
	Wheat	508.48	-0.50%		CAN
	Sugar beet	288.96	-0.25%		EU
	Sugar beet	1118.36	-0.25%		POL
	Sugar cane	339.49			Cost calculations BRA
	Veg. Oil	69.29	-2.00%		EU
	Veg. Oil	268.17	-2.00%		POL
	Veg. Oil	65.41	-2.00%		USA
	Veg. Oil	105.50	-2.00%		CAN
	Veg. Oil	223.87			Cost calculations BRA
δ^{OBP}	**value of other by-products biofuel, LC/t**				
	Veg. Oil	50	-8.76%		EU
	Veg. Oil	192.64	-8.76%		POL
	Veg. Oil	47.21	-8.76%		USA

	Products	Value 2004	Change p.a.	Found for	Used for
	Veg. Oil	74.11	-8.76%	CAN	
	Veg. Oil	137.90	-8.76%	BRA	
s^{j}_{r}	**scale parameter of the CES function determining feedstock shares in ethanol production**				
	n.a.	2.893		EU	
	n.a.	2.673		POL	
	n.a.	1.633		USA	
	n.a.	1.410		CAN	
$d^{i,j}_{r}$	**distribution parameters of the CES function determining feedstock shares in ethanol production**				
	Coarse grains	0.323		EU	
	Coarse grains	0.518		POL	
	Coarse grains	0.751		USA	
	Coarse grains	0.168	+24%[1)]	CAN	
	Wheat	0.428		EU	
	Wheat	0.195		POL	
	Wheat	0.249		USA	
	Wheat	0.832	-10%[1)]	CAN	
	Sugar beet	0.249		EU	
	Sugar beet	0.287		POL[2)]	

Note: [1)] Distribution parameters d^{ij} for coarse grains and wheat in Canada have been adjusted to become 0.394 and 0.606 in 2008. respectively, to account for new ethanol plants using US maize.

[2)] In Poland, sugar beets are generally not processed into bioethanol, but sugar beet molasses is.

Parameters are largely technical coefficients quoted in literature rather than results of econometric analyses.

Source: Technical parameters from Smeets *et al.* (2005). Parameters of CES share functions obtained by calibration to 2004 data.

Modelling production effects of changes in crude oil prices

Energy prices – as approximated by world crude oil prices – clearly have an impact on international markets for agricultural products that is independent from the biofuels markets. In fact, there are at least two direct links between energy prices and agricultural markets. First, and most directly, production costs for both crops and livestock products are highly dependent on energy costs. Fuels for tractors and other machinery, as well as heating and other forms of energy are directly used in the production process. In addition, other inputs such as fertilisers and pesticides, have a high energy content, and costs for these inputs are driven to a significant extent by energy prices. Second, energy prices have an important impact on transport costs, both within a country and in international trade. Consequently, price differentials across producing and consuming countries depend on energy costs.

Production costs for crops and livestock products are not represented explicitly in Aglink/Cosimo. Instead, a cost index is used to deflate gross production returns. This cost index – one each for crops and for livestock products, respectively, to account for the different shares of input groups in total production costs – is currently constructed from two sub-indices representing tradable and non-tradable input, respectively, and while the tradable sub-index is linked to global inflation (approximated by the US GDP deflator) and the country's exchange rate, the non-tradable sub-index is approximated by the domestic GDP deflator. This relationship is shown in the following equation:

$$(13)\ CPCI^{I}_{r,t} = CPCS^{I}_{r,t} * GDPD_{r,t} + \left(1 - CPCS^{I}_{r,t}\right) * XR_{r,t} \big/ XR_{r,bas} * GDPD_{USA,t}$$

with:		
with:	$CPCI^{I}$	commodity production cost index for commodity group I
	$CPCS^{I}$	share of non-tradable input in total base commodity production costs for commodity group I
	GDPD	deflator for the gross domestic product

XR	nominal exchange rate with respect to the US Dollar
I	commodity group (crops, livestock products)

The basic construction of the cost index is maintained and the sub-index for tradable inputs is divided into an energy component and a component representing other tradable inputs:

$$\begin{aligned} CPCI^{I}_{r,t} &= CPCS^{NT,I}_{r,t} * GDPD_{r,t} \\ &+ CPCS^{EN,I}_{r,t} * \left(XP^{OIL}_{t} * XR_{r,t}\right) \big/ \left(XP^{OIL}_{bas} * XR_{r,bas}\right) \\ &+ \left(1 - CPCS^{NT,I}_{r,t} - CPCS^{EN,I}_{r,t}\right) * XR_{r,t} \big/ XR_{r,bas} * GDPD_{USA,t} \end{aligned} \tag{14}$$

with:	$CPCS^{NT,I}$	share of non-tradable input in total base commodity production costs for commodity group I
	$CPCS^{EN,I}$	share of energy in total base commodity production costs for commodity group I

Detailed data on the composition of production costs are available to the OECD Secretariat for Argentina and the United States. These data, shown in the table below, suggest energy shares in crop production costs of about 43% on average for Argentina and 25% on average for the US; these figures are applied for all non-OECD and OECD countries, respectively, given that detailed data on other countries are not available. US energy shares for livestock production costs are calculated at 3%; this figure is applied for all countries.

Table 3.2: Composition of crop and livestock production costs for Argentina and the United States of America

Commodity group		**Crops**	**Crops**	**Hogs**	**Dairy**
Country		**ARG**	**USA**	**USA**	**USA**
Cost element:	**Cost category:**	Pesos/ha	USD/acre	USD/cwt gain	USD/cwt sold
Seed	Tradable	21.13	22.16		
Fertilizers, Chemicals	Energy	57.16	53.71		
Irrigation	Non-Tradable	0.77			
Fuels etc.	Energy		15.48	1.05	0.48
Other operating costs	Non-Tradable		28.58	12.4	2.4
Labour	Non-Tradable		23.14	7.59	4.68
Capital	Non-Tradable		51.10	10.32	3.23
Field work, Harvest	30% Energy, 70% Non-Tradable[1)]	102.54			
Interest	Non-Tradable	4.29			
Land, Other Fixed Costs	Non-Tradable	20.65[2)]	85.94	1.47	0.73
Tradable feed	Tradable, excluded from shares[3)]			22.19	2.8
Non-tradable feed	Non-Tradable				3.68
Total costs:		206.54	280.11	55.02	18.00
Total excl. tradable feed[3)]		206.54	280.11	32.83	15.20
Total Non-Tradable		97.49	188.76	31.78	14.72
Share:		*47%*	*67%*	*97%*	*97%*
Total Tradable Non-Energy		21.13	22.16	0.00	0.00
Share:		*10%*	*8%*	*0%*	*0%*
Total Energy		87.92	69.19	1.05	0.48
Share:		*43%*	*25%*	*3%*	*3%*

Notes:
1) Split according to information provided by USDA
2) Land and other fixed costs not included in original data assumed to represent 10% of total crop production costs in Argentina
3) Tradable feed costs excluded from the share calculation to avoid double-counting as the majority of the marketable feed and related costs is represented explicitly in the Aglink model.

Sources: Data for Argentina kindly provided by the USDA Economic Research Service. US data downloaded from the USDA ERS website, May 2005. http://www.ers.usda.gov/Data/CostsAndReturns/testpick.htm

ANNEX 4: CONCLUSIONS DRAWN IN SMEETS *ET AL.*, 2005

In preparing the present report, the Secretariat commissioned a study from the Copernicus Institute of the University of Utrecht, the Netherlands, which provides a review of the following:

1. A description of the technical and economical performance of biofuel production systems, and
2. An overview of current and planned strategies, policies and outlooks for biofuels in various key countries and regions.

The following section reproduces the main summary and conclusions of the consultant's report. The complete report will be made available as an unclassified report on the OECD website.

Biofuels policy

Three regions are likely to be dominant in biofuel production until 2013: These are the EU-25, the US and Brazil. The EU directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport established a goal of 2% of domestic transport fuel consumption as the target for EU biofuel use by the end of 2005. As several European Union states had failed to implement rules promoting biofuels by the stipulated date of July 2005, the European Commission has indicted an intention to commence or advancing legal action against the offending countries. The European Commission said the bloc's 25 governments had an obligation to turn EU rules on biofuel usage into national law in 2004.[51] In addition, they had to send a report to the Commission with "an indicative target for the share of the petrol and diesel market that will be taken by biofuels at the end of 2005." In terms of member state compliance, Estonia, Finland, Greece, Italy, Luxembourg, the Netherlands, Portugal and Slovenia had not yet notified the Commission of the national law. Italy, Luxembourg, and Slovenia had not submitted reports, while France and Estonia's reports lacked concrete targets, the Commission said. The Commission also rejected targets submitted by seven states, ranging from 0.0% to 0.7%, saying they did not comply with EU rules. Those countries were Denmark (0.0% target), Ireland (0.06%), Finland (0.1%), the UK (0.3%), Hungary (0.4-0.6%), Poland (0.5%) and Greece (0.7%).

So far, the EU-25 has basically been the sole major producer of bio-diesel. This may change over the next 10 years: Brazil has plans to produce 2000 million litres biodiesel (approximately the volume produced by the EU in 2004) by 2013, mainly from soyabeans, but also from other oil crops such as Castor and Dende. Also India and China are experimenting with Jatropha as a feedstock for biodiesel production, and other South-East Asian countries are starting to experiment with diesel from palm oil or coconut oil. However, it is very hard to estimate how biodiesel production may develop over the next decade in most South-East Asian countries, as in most countries, no (information on) government policy and targets are available.

Regarding ethanol, it can be expected that in 2013, over 80% of the global fuel ethanol production will take place in Brazil, the US and Europe. These expectations are based on the EU white paper, the US Energy Bill that recently was signed into law, and the growth expectations of the Brazilian ethanol sector, based on a large domestic demand and export opportunities to *e.g.* Japan and South Korea. Also Peru, Colombia or the Central American states may become large ethanol producers with markets in North America, and possibly also for Japan and possibly South Korea and the European Union. While South-East Asian countries such as Thailand and India may have reasonable potential to increase their fuel ethanol production, it is again difficult to forecast their production levels due to (limited information on) current biofuels policies and targets.

Given the fact that developments in the EU, the US and Brazil are relatively transparent, a close eye should be kept on the developments in promising Latin American countries, South East Asian countries like India, China, Thailand and Malaysia, and Australia, Southern African countries (especially South Africa, but possibly also Zimbabwe, Madagascar, Malawi, Mozambique etc.) as well as Eastern Europe (such as Romania, Ukraine and Russia).

In addition, it must be remarked that most of the growth expectations are based on policy-based incentives. In the longer term, market factors such as global (rising) oil prices, prices for competing products (*e.g.* for sugar, vegetable oils, fodder), (removal of) trade barriers and technology development of (advanced) biofuels options may become more important than policy incentives alone to determine the growth of global biofuels markets. Given the fact that European ethanol is a factor of 2-3 times more expensive than ethanol from Brazil, domestic agricultural policy reforms might influence domestic production levels of ethanol in Europe and removal of trade barrier could encourage production in regions such as Latin America and (in a negative way) Europe.

Technical and economical performance of biofuel production systems

Numerous studies exist on the technical and economic performance of biofuel production systems that focus on the total production costs and the greenhouse gas balance of biofuel production systems. Most studies present aggregated results in costs per unit of fuel produced or in avoided greenhouse gas emissions per unit of fuel. Large differences exist between results from various studies.

The large range in technical and economic performance reported in various studies is caused by differences in system boundaries, scope, definitions or conversion factors, as well as differences in assumptions on feedstock costs, interest rate, labour costs, economic lifetime, type of technology and scale of the plant, load factor, value of co-products and whether production subsidies are included or excluded. For example, the scale of the plant is a crucial factor for total investment costs. The total investment costs per unit capacity decreases with increasing scale, although the rate of decline levels off with increasing plant size. The combined impact of the scale effect and the interest rate, lifetime and load factor, is one of the reasons for the large differences and large uncertainties related to capital and O&M costs.

In practice, it is usually very difficult to distinguish between the impact of the various factors included in the literature, due to a lack of disaggregated (detailed) data on the technical and economic performance. Similarly, it is also very difficult to derive one representative set of data on the technical and economic performance. It is also difficult to differentiate between various regions, particularly because at this moment most biofuel production systems are geographically concentrated in regions: ethanol from sugar cane is mainly used in Brazil, biodiesel from rapeseed in Europe and ethanol from maize in the US.

Therefore, the data must be regarded with caution and may represent only a fraction of the available literature. Although data on the technical and economic performance of various biofuel production systems comes with a certain degree of uncertainty, the overall impact on the total biofuel costs is limited, because processing costs generally account for only a fraction of the total processing costs (between 20% and 50% depending on the product and on the country). Further research is required to compose a more detailed and accurate set of data with specific attention to the technical and/or economic performance due to regional circumstances, scale effects, type of technology, differences in key data and co-products.

This goes particularly for the ‘advanced biofuels’, which are produced from lignocellulosic biomass via gasification-synthesis or via hydrolysis-fermentation. These advanced biofuels are projected to have a better technical and economic performance, but for which at this moment more limited data are available. Such an exercise requires in-depth analysis and comparison of existing data in combination with bottom-up calculations. The result of such an exercise would be a detailed set of data in which the impact of various assumptions is clearly visible.

General discussion, conclusions and recommendations

The production of bio-diesel and bio-ethanol is based on traditional processes that have been researched and applied over the last decades. With the exception of ethanol from sugar cane, the energy and CO2 balances of these ‘first-generation’ biofuels are in general not so beneficial. In some cases, when total production chains are poorly managed (*e.g.* ethanol from maize), the energy balance can in some cases even be negative.

It is generally expected, that in the midterm future, the share of advanced biofuels which use lignocellulosic biomass (*e.g.* wood waste, residues, wood from dedicated crops, grasses *etc.*) as feedstock will increase. Lignocellolosic biomass can (partly) be produced from different land areas than agricultural land, including forest areas and marginal lands no longer required for food production. To allow for meaningful (macro-economic) analysis, considerable expansion of the current modelling work is needed. Competition of wood use with power and heat production as well as biomaterial applications (*e.g.* timber, pulpwood) should then also be considered. This would probably require an extension of the Aglink model, and we would recommend to give some attention to this, especially for the longer-term (*e.g.* from 2015 onwards).

NOTES

[1] IEA (2004a), p. 27.

[2] The term “biomass” is used in a more general sense to describe organic substances that can be used for the generation of bio-materials or bio-energy. The latter includes the production of fuels and power (electricity and/or heat). See Parris (2004), p. 28.

[3] Production of these organic materials, with the exception of by-products such as straw, could still draw agricultural land from potential food production. Two factors reduce their possible effects on agricultural markets, though: First, some of these materials can be produced on marginal land not profitably used for food production. Second, the yield of these materials in terms of energy output per hectare of land is generally much higher than in the case of food crops, thus reducing the amount of land needed to produce a given volume of fuel.

[4] Environmental friendliness is not an undisputed fact for all biofuel options. This paper does not try to discuss the ecological characteristics which include both greenhouse gas and other gas emissions and the environmental effects of agricultural production, but solely focuses on economic aspects.

[5] Smeets, E. *et al.* (2005)

[6] See section 4 for information about biofuel policies in Brazil and other countries.

[7] The levels of crude oil prices that would allow for subsidy-free production of biofuels in the different countries are of particular interest in this context and will be discussed below in Section 3.

[8] See the Glossary of Terms for explanations of technical and special terms.

[9] See section 7 for a discussion of possible implications of a widespread application of these technologies in the longer run

[10] Note that ethanol can also be used together with isobutene, a petrol-based co-product of the oil and chemical industry, to produce ethyl tertio butyl ether (ETBE), which can be used as an additive to gasoline in higher blending rates than pure ethanol without modifications.

[11] An important technological step in the spread of ethanol use as a fuel was the introduction of “Flex Fuel Vehicles” (FFV) in recent years. These vehicles can run on various blends of ethanol with gasoline ranging from pure gasoline to pure ethanol (FFVs sold in Europe have an upper limit at 85% of ethanol as pure ethanol is not sold in European countries) and allow the owners to freely choose between the fuels according to their relative prices.

[12] Data on actual biodiesel production is not available. Global production capacities, mostly within the EU, have increased from some 500 million litres in 1998 to around 1.7 billion litres in 2003, with an estimated two-thirds of capacities having been used.

[13] Note that these cost calculations are subject to a considerable degree of uncertainty. Cost estimates in the literature vary widely, and their applicability for other regions than those for which the estimates were obtained may be limited. For comparison, cost estimates provided for 2002 by the IEA (2004a, pp. 85 f.) are between USD 0.17-0.23 per litre of ethanol from sugar cane in Brazil, USD 0.26-0.40 per litre of ethanol from maize in the US, USD 0.33-0.53 per litre of ethanol from grains in the EU and USD 0.36-0.71 per litre of bio-diesel from rapeseed in the EU (values recalculated from data shown per litre of gasoline equivalent, using conversion rates of 0.66 for ethanol and 0.89 for bio-diesel).

[14] In November 2005 the EU adopted a reform of its sugar regime, resulting in a 36% reduction in intervention prices over four years. Neither the cost estimates nor the impact analysis in this study take the reform into account, which should make ethanol production from sugar beet less costly.

[15] Note that most of the ethanol produced in the US is made from maize, while in Canada the main feedstock for its ethanol production is wheat.

[16] Note that most of the ethanol produced in Poland is made from coarse grains (rye, maize), sugar beet molasses and potatoes. Commercial production of biodiesel (FAME) in 2004 was still very limited.

[17] It is interesting to note that at low blending rates of ethanol in conventional gasoline, synergistic effects in the combustion engines may occur, resulting in a better mileage per litre of blend fuel than what would be suggested by the difference in energy content. These effects depend on the exact specifications of the fuel as well as of the engines. Comparisons in this study are therefore made on the basis of the relative energy content, but costs expressed in gasoline equivalent may overestimate relative biofuel costs to some degree.

[18] It should be noted that Brazilian ethanol has not always been as cost efficient as today. Productivity has improved significantly both in sugar cane and ethanol production during the past decades, when ethanol production increased strongly supported by the Proalcool program. See IEA, 2004a, p. 60, and NOVEM (2003) p. 26 on technical progress in Brazilian ethanol production.

[19] At the time this report was written (September 2005), crude oil prices (Brent) fluctuated around USD 64 per barrel.

[20] For these calculations, the change in domestic fuel prices (in USD per litre) resulting from a change in crude oil prices by USD 1 per barrel is estimated on the basis of data provided by IEA (2005). Values for this price transmission range from USD 0.0041 in the case of Canadian gasoline to USD 0.0075 for European gasoline. For Brazil as well as for Canadian diesel a value equal to USD 0.0063 is assumed, which corresponds to a change of domestic net fuel prices by USD 1 per litre for a change in world crude oil prices by USD 1 per litre, as suggested by Metschies, G.P.: "International Fuel Prices 2005". It should also be noted that these calculations are based on biofuel production costs unchanged from their 2004 level. Higher crude oil prices, however, are likely to trigger higher production costs of feedstocks and prices for process energy, thus increasing production costs of biofuels as well (see below).

[21] It should be noted that the comparatively high threshold crude oil price for wheat-based ethanol in Canada is not related to higher production costs for ethanol relative to other countries - Figure 2 shows that these are calculated fairly similar to those in other countries. In fact, the higher threshold price comes from the significantly lower value for the oil price transmission estimated for Canada in comparison to other countries, as outlined in note 20. The lower transmission value results in a larger change in the world crude oil price needed to obtain a certain increase in domestic (net) gasoline prices and hence in higher threshold prices.

[22] Note that the EU has decided in November 2005 to reform its sugar regime, with intervention prices to be reduced by 36% within four years. This is likely to have a negative impact on production costs for ethanol based on EU sugar beet.

[23] Of course, other elements of the production costs also need to be considered. With further gains in technological efficiency transformation costs are likely to decline in the future. Similarly, sales of co-products can improve the profitability of biofuels production. See Table1.1 in Annex 1 for details on the cost elements.

[24] As mentioned above, these calculations should not be read as projected area requirements, as they are simple extrapolations of 2004 data. In consequence, they ignore likely technological improvements, possible changes in area use and feedstock shares, the possible use of marginal or currently unused land and the possibility of biofuels trade. They also do not take into account any rotational requirements that would become binding if the area share devoted to rapeseed increased significantly. See also the caveats laid out above. In particular, the area shares shown here are inflated to some degree by not including fallow land (such as CRP areas, set-aside land etc.) in the total land basis.

[25] This does not necessarily hold when biodiesel is made from oilcrops other than rape seed, sunflower seed or soyabeans. Palm oil in particular can have an oil yield of about five tonnes per ha (http://journeytoforever.org/biodiesel_yield.html#ascend), although the fatty acid composition of palm oil causing relatively high melting points makes it less suitable for biodiesel in low-temperature regions than some other oils.

[26] Projected growth rates in transport fuel consumption until 2010 range between 1.7% in North America and 7% in China (IEA, 2004b).

[27] For most countries, however, a 10% share of biofuels in total transport fuels consumption can be reached only in the long run at best. It is therefore, again, important to understand the illustrative meaning of the land requirement calculations above.

[28] IEA (2004), p. 13. These calculations, which take into account those emissions caused by crop production and fuel processing, show the highest reductions for cane-based ethanol. The net reductions in GHG emissions are linked to the net energy gains of biofuels. As shown in IEA (2004) pp. 53, 59, 63, most studies suggest that the energy contained in the biofuels exceeds the energy used to produce them, although for grain-based ethanol this gain is relatively small and, according to some studies, even negative.

[29] The 1990 Clean Air Act established a reformulated gasoline oxygen standard requirement that gasoline sold in “carbon monoxide (CO) non-attainment areas” must contain 2.7% oxygen. The reformulated gasoline (RFG) programme requires clean-burning reformulated gasoline (requiring 2% oxygen) to be sold in the nine worst ozone non-attainment areas of the United States (IEA, 2004a p. 148).

[30] Note that to date it remains unclear to what degree soya oil, the most important vegetable oil in Brazil, will be used to meet Brazil’s domestic demand for biodiesel, a question that is likely to have significant impact on global vegetable oil markets given the importance of Brazil’s soyabean exports on global markets.

[31] Other potentially important producers (such as China and India, see Figure 1 above) are excluded from this analysis, so the results of this quantitative impact assessment are likely not to show the full implications of further growth in biofuels production. See the discussion on biofuels in other countries further below in section 6.

[32] Using gasoline and diesel pump prices in the biofuel supply function implicitly assumes perfect substitution of biofuels with their respective oil-based equivalent and represents an important simplification.

[33] While international trade in biofuels does exist and is expected to grow, there are obstacles to biofuel trade as well, such as environmental concerns, different or lacking biofuel norms and tariff barriers.

[34] Note that the increase in US ethanol production is considered in the *OECD-FAO Agricultural Outlook* only implicitly in the form of a stronger increase in grain demand. The additional US demand for vegetable oils for biodiesel production is assumed to be implicit in the demand projections as well, although these would cause only small differences in the baseline. In contrast, the Brazil sugar baseline explicitly takes into account ethanol production from sugar cane as for Brazil the sugar cane-ethanol link was readily implemented in the sugar module of the model.

[35] Note that while in principle it is possible to produce ethanol from the sugar remaining in the cane molasses left over from the sugar extraction process, Brazilian ethanol production generally competes with sugar production for the cane used. Consequently, the projected growth in ethanol production uses up significant quantities of cane that would be processed to sugar in the constant biofuels scenario. It should also be noted that the changes to the Brazil and world sugar markets assumed in these scenarios are quite large, and this is a caveat relative to the likely exactness of the model results.

[36] Vegetable oils in the model include oils from soyabeans, rape seed and sunflower seed as well as palm oil. It is expected that at least a part of the additional vegetable oils demand would be sourced from imported oils. Note also that the possibility of biodiesel imports to the EU is not considered in this analysis, even though substantial investments in some developing countries such as Malaysia would indicate such a possibility.

[37] See the comments given in footnote 35. Compared to the constant biofuels scenario, sugar exports from both Brazil and the EU (25) decline by about one third in 2014.

[38] A third route of market implications is the food demand side: GDP growth is likely to be lower with higher crude oil prices for most countries, while it may be higher for oil producing ones. This may have an impact on food demand. This is ignored in the present analysis.

[39] Shares calculated from production cost data for two countries only. Those found for the US are applied to all OECD countries, while those found for Argentina are applied to all non-Member Economies. See Annex 3 for details.

[40] Note that due to the lack of detailed support data, this analysis assumes unchanged biofuel policies in the high-oil price scenario. This may be considered an unrealistic assumption, as governments may be inclined to limit overcompensation and hence to reduce the support for biofuel production as crude oil prices and hence domestic fuel prices increase.

[41] In these simulations, the elasticity of production capacities with respect to the average ratio of net production costs relative to oil-based fuel prices at the pump is assumed to be -1 for both biofuels.

[42] Data on production capacities are available only for the European Union. Available data suggest that ethanol production capacity use rates in 2003 ranged from 80% in France to 96% in Sweden (Biofuels Barometer, 2005). No capacity data is available for Poland, but the decline in ethanol production from 66 kt in 2002 to 36 kt in 2004 would suggest that capacities remained unused to a substantial degree in the latter year. Reported rates for biodiesel are also relatively low in some cases: While for Germany this rate was 95% in 2004, it was only between 57% and 76% in France, Italy, Austria and the UK, and less than 20% in Spain and Sweden. For the Czech Republic, data suggest a capacity use rate of 43%. The fact that data for Denmark suggest a use rate of 159% indicates, that these numbers should be taken with great care, however (European Biodiesel-Board 2005).

[43] See the end of section 3. More detailed information on these “advanced” biofuels can be found in IEA (2004a) as well as in Smeets *et al.* (2004).

[44] One example that deserves to be mentioned here is the current investments in the plantation of jatropha (physic nut, *jatropha curcas L.*), a plant that yields a toxic oil that however appears well suited for

biodiesel production. Plantation of jatropha is expanding rapidly in South and South-East Asia, largely as a response to growth in biodiesel demand.

[45] Note that commercial production of biodiesel in Poland has begun only in 2005. For 2004, a small amount of biodiesel is assumed to be produced on a non-commercial basis.

[46] Note that for this analysis, biofuel production is taken into account only for a subset of biofuel producers, namely the EU-15, Poland, USA, Canada and Brazil,

[47] Note that other commodities such as cassava are used in ethanol production as well, but are not reflected in this model analysis. Similarly, in terms of vegetable oils the model only takes into account soya, rape, sunflower and palm oil, while other oils such as jatropha are being used for the production of bio-diesel as well.

[48] For plausibility reasons it is assumed that the use rate of existing biofuel production capacities cannot fall below 50%.

[49] Note that this formulation ignores the likely negative impact of changes in capacities (see equation 5) on production costs, particular with respect to capital and other operating costs. Given the focus of the study, the representation of production costs of biofuels is much more detailed than that of agricultural commodities, where production costs are summarised in a cost index as explained further below in this annex.

[50] For biodiesel production, one could imagine a similar handling of various types of vegetable oils (or even other oils and fats such as waste oils(used as feedstock. Given that the Aglink model treats the markets for vegetable oils as an aggregate of individual oils, however, no differentiation across oilseed oils is made here either.

[51] Press release, available at http://www.planetark.com/dailynewsstory.cfm/newsid/31557/story.htm

GLOSSARY OF TERMS

Bxx (where xx is a number, e.g. B10): Biodiesel blend with petroleum diesel, with biodiesel volume percentage indicated by the number

Cellulose: A complex carbohydrate, $(C_6H_{10}O_5)_n$, that is composed of glucose units. Forms the main constituent of the cell wall in most plants.

Cetan number: A rating for diesel oil that indicates how easily the fuel ignites and how fast it will burn.

Exx (where xx is a number, e.g. E85): Ethanol blend with gasoline, with ethanol volume percentage indicated by the number

FAME: Fatty acit methyl ester.

Hemi-Cellulose: Any of several polysaccharides (molecules composed from more than one sugar molecule) that are more complex than a sugar and less complex than cellulose.

Lignin: A complex polymer, that binds to cellulose fibres and hardens and strengthens the cell walls of plants. Chief noncarbohydrate constituent of wood.

MTBE: Methyl tertiary butyl ether, a colourless, flammable, liquid oxygenated hydrocarbon containing 18.15 percent oxygen. A lead-free, petrol-based additive for gasolines used to increase their octane number.

Octane number: Numerical measure of the anti-knock properties of motor fuel. The higher the octane number, the stronger the resistance to detonation, which is important in high-compressing vehicle engines.

Transesterification: A chemical process which reacts an alcohol with the triglycerides contained in vegetable oils and animal fats to produce biodiesel and glycerine.

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