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International Transport Forum

TRANSPORT RESEARCH CENTRE

BIOFUELS: LINKING SUPPORT TO PERFORMANCE

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TRANSPORT RESEARCH CENTRE

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INTERNATIONAL TRANSPORT FORUM

The International Transport Forum was created under a Declaration issued by the Council of Ministers of the ECMT (European Conference of Ministers of Transport) at its Ministerial Session in Dublin on 17 and 18 May 2006. It reflects the Ministers' will to transform the ECMT into an international forum whose specific objective is to help political leaders and a larger public better understand the role of transport as a key element in economic growth, as well as its effects on the social and environmental components of sustainable development.

Established under the legal authority of the Protocol of the ECMT signed in Brussels on 17 October 1953, as well as the appropriate legal instruments of the OECD, the Forum is considered an international entity endowed with all the necessary support structures and financing mechanisms. Its administrative headquarters is located in Paris.

The International Transport Forum is a global body with world-wide reach. The topics addressed by the Forum are strategic in nature and over-arching in scope, as they can cover all modes of transport. The International Transport Forum is above all a place for discussion and negotiation.

The full member countries and associate member countries of the ECMT are the *founding members* of the Forum, namely: Albania, Armenia, Australia, Austria, Azerbaijan, Belarus, Belgium, Bosnia-Herzegovina, Bulgaria, Canada, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, FRY Macedonia, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Mexico, Moldova, Montenegro, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, the United Kingdom and the United States. Morocco has *observer* country status. Corporations, organisations, institutions and leading figures from civil society may be asked to enter into *partnerships* with the Forum.

The International Transport Forum organises an Annual Conference attended by Ministers as well as leading figures from civil society and representatives of organisations involved in transport policy. As of May 2008, the meeting will take place each year in Leipzig, Germany. The theme chosen in 2008 is: "Transport and Energy: the Challenge of Climate Change". In 2009, the theme will be: "Globalisation of trade and its impact on transport and infrastructure".

In 2004, the ECMT and the OECD created the Joint Transport Research Centre. The Centre conducts co-operative research programs that address all modes of transport that in turn support policy-making in member countries. Through some of its projects, the Centre also makes contributions to the activities of the International Transport Forum.

Further information about the International Transport Forum is available on Internet at the following address:

www.internationaltransportforum.org

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SUMMARY OF DISCUSSIONS

SUMMARY CONTENTS

1. CONCLUSIONS AND MESSAGES FOR POLICY-MAKERS

Although this summary does not pretend to present a unanimous or negotiated position for the participants at the Round Table, a number of conclusions did enjoy broad support.

1.1 Performance of biofuels in reducing greenhouse gas emissions

Discussions at the Round Table underlined the wide range of performance of biofuels in terms of life-cycle energy and greenhouse gas emission balances. Performance differs between fuels and even for a single fuel and feedstock, performance varies greatly according to production process and farming practice. In the worst cases biofuels result in significantly higher emissions of greenhouse gases than gasoline or diesel.

The discussions also identified a wide range of uncertainty in the estimation of emissions of CO_2 from the soil and emissions of N_2O in the cultivation of feedstocks. These emissions vary according to soil type and farming technique and can account for a large part of the overall greenhouse gas emissions for some conventional biofuels.

For biofuels that provide relatively low greenhouse gas abatement (up to around 30%), such as ethanol produced from corn and many other grains, the range of uncertainty can be larger than the average expected benefit. Therefore there is a risk that such fuels provide no benefit or even produce higher rates of greenhouse gas emissions than oil products.

On a small scale, biofuels are currently produced from whey and waste cooking oil with relatively large greenhouse gas savings compared to fossil fuels, of around 70%. The only large-scale production of biofuels to approach this level of performance is Brazilian sugar cane ethanol. However, it requires tax subsidies to be viable, amounting to around USD 1 billion a year.

Most other large-scale biofuel production (ethanol from sugar beet and sorghum; biodiesel from rape, soy and palm oil) achieves around 30% to 50% greenhouse gas savings, but requires large subsidies.

1.2 Costs and alternative policies

Views differed over just how much biofuel could be produced sustainably. But most biofuels are expensive, particularly when environmental costs are factored in. Only at sustained high oil prices are biofuels likely to be produced commercially. With subsidies restricted to a level that reflects their contribution to greenhouse gas mitigation, much production would cease.

Improving energy efficiency in transport has much greater potential, and at lower cost, than promoting biofuels for reducing energy supply vulnerability and reducing greenhouse gas emissions.

Taxes related to the carbon content of fuels, including for biofuels, would also be more cost-effective than subsidies or biofuel targets as they target CO_2 emissions directly. Fuel excise tax systems are very similar to a tax on the carbon content of fuels, albeit at a high rate in some cases. In Europe, current excise rates are roughly equivalent to a carbon tax on petrol and diesel of around EUR 200/t $CO_{2\text{-eq}}$, around ten times the current cost of CO_2 in the European emissions trading system. Support for ethanol in the USA is currently estimated to cost double this level at the country's best performing ethanol plants. The same is true for rapeseed biodiesel produced in the EU.

1.3 Advanced biofuels

Future generations of biofuel feedstocks and production processes are likely to have lower greenhouse gas emissions and may be more cost-effective. Such biofuels may be able to meet up to 10% or 20% of current transport energy demand, but no more than this without major advances in technology (Jones 2007).

Ligno-cellulosic ethanol produced from some feedstocks in pilot plants already performs much better than most conventional biofuels in terms of greenhouse gas emissions and performs as well as the best Brazilian sugar cane ethanol. However, the economics are unproven and for large-scale production the potential supply of ligno-cellulosic ethanol is limited by cost and the land available for energy crops. There is a rationale for supporting research on advanced biofuels but this does not extend to open-ended support.

1.4 Effectiveness of subsidies

Subsidising large-scale production and consumption of conventional biofuels fails to deliver a significant contribution to the strategic goals of reducing greenhouse gas emissions or improving the security of supply of fuels for transport. It is an inefficient way of providing income support to rural communities and it consumes large amounts of taxpayers' money (USD 4 billion in 2007 in the USA in tax subsidies alone; USD 4 billion in 2006 in the European Union in tax subsidies; and between USD 13 billion and USD 15 billion in the OECD as a whole for support overall), without commensurate benefits. Germany has now begun to reduce subsidies for biofuels and the United Kingdom is expected to reduce the current excise duty differential of 20p/litre (EUR 0.29/litre) over time.

1.5 Policy reform

Volumetric production targets for biofuels fail to provide incentives to contain costs, to avoid environmental damage or even to ensure greenhouse gas emission reductions are delivered. Carbon content targets for fuels, accompanied by certification, are a better alternative.

California, the Netherlands, Germany, Switzerland, the United Kingdom and the European Commission are developing systems of certification to regulate the market for biofuels. These systems are aimed at improving environmental outcomes. If governments continue to promote biofuels, then greater selectivity is needed in the choice of producers and processes to be subsidised. Without this refinement of policy, through certification linked to subsidies, although there may be progress towards targets for production and consumption of biofuels, there will be disappointment in the higher level objective of reducing greenhouse gas emissions. Moreover there are likely to be unwelcome side effects for other sustainability goals.

It should be noted that certification systems are not well suited to addressing the indirect impacts of biofuel production. Certification can only guarantee to influence the supply chain. It can be used to modify farming and biomass harvesting methods in order to limit the environmental impacts of farming. But certification can not be used to control any displacement of existing farming activities induced by an expansion of biofuel production, with consequent land-use change outside the area farmed to produce biofuel. Separate measures will be required to protect valued natural and semi-natural ecosystems, from all kinds of development.

The range and sometimes poor performance of today's biofuels in terms of greenhouse gas emissions is in part a result of the absence of regulations or incentives to select biofuels according to their environmental profile. The challenge for the development of biofuel certification systems is to provide such incentives cost-effectively.

2. INTRODUCTION

Government support for the production of biofuels has been motivated primarily by agricultural and energy policies with the aim of substituting biofuels for imported oil and supporting farm incomes and agricultural sector industries. More recently support for biofuels has become a core part of many national policies for reducing transport sector CO_2 emissions. The relative importance of each driver differs between governments.

Subsidies for biofuels are growing rapidly and are estimated to have reached around USD 15 billion in 2007 for the OECD as a whole. Many governments have also imposed biofuel quotas for oil distributors. The European Union requires Member States to take measures to ensure that biofuels account for 2% of the demand for transport fuels, rising to 5.75% in 2010. The European Commission proposes increasing the target to 10% by 2020[1]. The US Government set a target of 4 billion gallons of ethanol for 2006, nearly 3% of the gasoline market, and has proposed a target of 35 billion gallons of biofuels production by 2017, which is expected to account for about 9% of transport sector fuel consumption.

However, all biofuels are not equally effective in substituting for oil or in cutting greenhouse gas emissions and promoting their production can have unintended consequences. Subsidies for biofuels, and the resultant increase in demand for grain and oil seeds, appears to have contributed to sharp increases in food and livestock feed prices in world markets, in a context of rising demand for these commodities for traditional uses. Also, depending on feedstock and farming practices, biofuels production can have significant environmental costs. These include degradation of biodiversity and soil fertility and increased rates of soil erosion, excessive water abstraction and water pollution. In some circumstances, biofuel feedstock production can even result in a net increase in greenhouse gas emissions.

The Round Table brought together 50 leading researchers on the science and economics of biofuels to examine the potential for these fuels to fulfil the policy expectations underlying their promotion, to analyse the economics of biofuels supply and to assess the potential to limit the environmental costs of large-scale production. In this context the Round Table reviewed progress on certification systems designed to limit unintended environmental damage from producing and promoting biofuels.

The discussions, chaired by Lyn Martin of the Australian Bureau of Transport and Regional Economics, focused on the following themes:

- *The energy and greenhouse gas impacts of producing biofuels and substituting them for oil products in the transport sector;*
- *The economics of biofuels;*
- *The potential of second generation fuels;*
- *The potential for Brazilian ethanol exports;*
- ***Certification and the potential for linking support to performance**;*
- *The policy implications of the discussions.*

The debate was structured around five papers, each addressing one of these themes. Presentations based on each of the papers are available at

http://www.internationaltransportforum.org/jtrc/roundtables.html

3. ENERGY AND GREENHOUSE GAS IMPACTS

The Round Table began with a review of the research on the life-cycle energy balance and greenhouse gas emissions of producing biofuels for transport markets. Discussions were launched by Professor Alex Farrell of the University of California Berkeley who highlighted the mixed results of the research and identified the critical parameters on which the results depend.

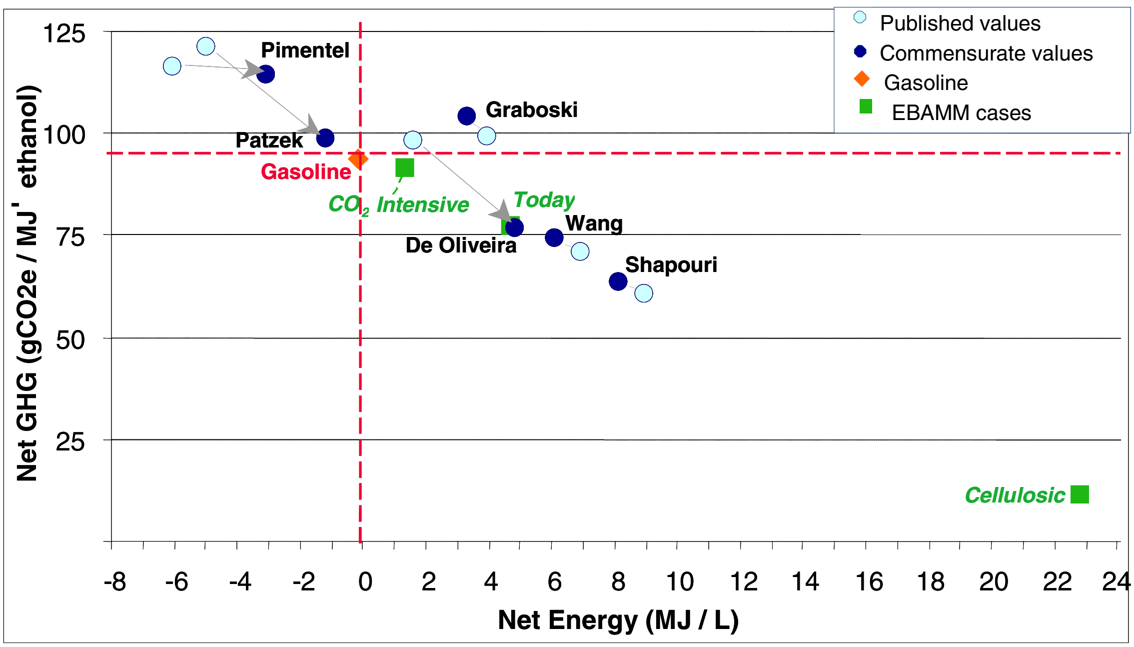
The team at Berkeley's Energy and Resources Group (ERG) undertook a detailed comparison of six representative studies of US corn-ethanol greenhouse gas and energy balances (Farrell *et al.,* 2006), with the results first reported in the journal Science in 2006. Four of the six studies found that producing and consuming biofuels for transport results in higher greenhouse gas emissions than producing and consuming gasoline (see light coloured circles above the horizontal line in Figure 1). Average impacts ranged from a 20% decrease to a 32% increase in greenhouse gas emissions. In terms of net energy balance, two of the studies found that corn ethanol required more fossil fuel to produce than the energy it contains (light circles to the left of the vertical line in Figure 1). Though all of the studies found net oil savings, a lot of gas or coal was consumed in processing biomass to produce ethanol.

The comparison set out to standardize the reported results by normalizing the assumptions on which the studies were based. The key differences identified concern the boundary conditions employed in the studies (i.e. decisions on which parts of the overall production system to include or exclude from the analysis) and assumptions regarding:

- the prime energy used in bio-refineries – natural gas, oil, electricity or coal, with widely differing thermal efficiencies and associated CO_2 emissions;
- soil erosion and oxidation of soil carbon as a result of crop cultivation;
- lime application on crop land; and
- the treatment of co-product energy (the energy content of non-fuel co-products).

The primary energy source used in the production of biofuels, and particularly for distilling ethanol, is a major determinant of greenhouse gas impact. Boiler efficiencies, which vary widely, also account for some of the variation in performance. In most locations natural gas or electricity provides the energy for process heat. However, high prices for gas have resulted in some new ethanol facilities using coal in the American Midwest, with large associated greenhouse gas emissions. In Brazil, bagasse (sugar cane waste) is burnt to provide process heat and electric power and this is in large part responsible for the superior performance of Brazilian ethanol production (see the paper prepared for the Round Table by Professor Almeida)[2].

Figure 1. **Greenhouse gas and energy balances for corn ethanol production pathways, as reported in the literature and adjusted for consistency**



Note: EBAMM = UC Berkeley Energy Resources Group (ERG) Biofuel Analysis Meta-Model. The EBAMM model is available as open source software online and can be downloaded from: http://rael.berkeley.edu

Source Farrell *et al., Science* 2006 (see References for original study sources).

The ERG team developed a meta-model to compare the results of all the studies on the basis of consistent assumptions. Adjustments were made in relation to:

- primary energy inputs;
- system boundaries (by adding missing parameters such as effluent processing energy and dropping some extraneous parameters); and
- co-product energy content.

Adjusting for the different assumptions brings the results of the US corn-ethanol studies closer to convergence (see dark circles in Figure 1). However, it does not alter their absolute position. Except in one case, studies that found negative energy balances and higher greenhouse gas emissions compared with producing and using gasoline (to the left of and above the red lines) maintain these negative results after correction. Half the studies show negative greenhouse gas emission balances after correction.

The ERG team selected what it viewed as the best data from the original studies to create three case-studies with their model (Figure 1):

- *Ethanol Today* using typical values for current US corn-ethanol production;
- *CO_2-Intensive* based on plans to ship Nebraska corn to a lignite-powered ethanol plant in North Dakota;
- *Cellulosic* using data from Wang's study for ligno-cellulosic ethanol produced from switchgrass.

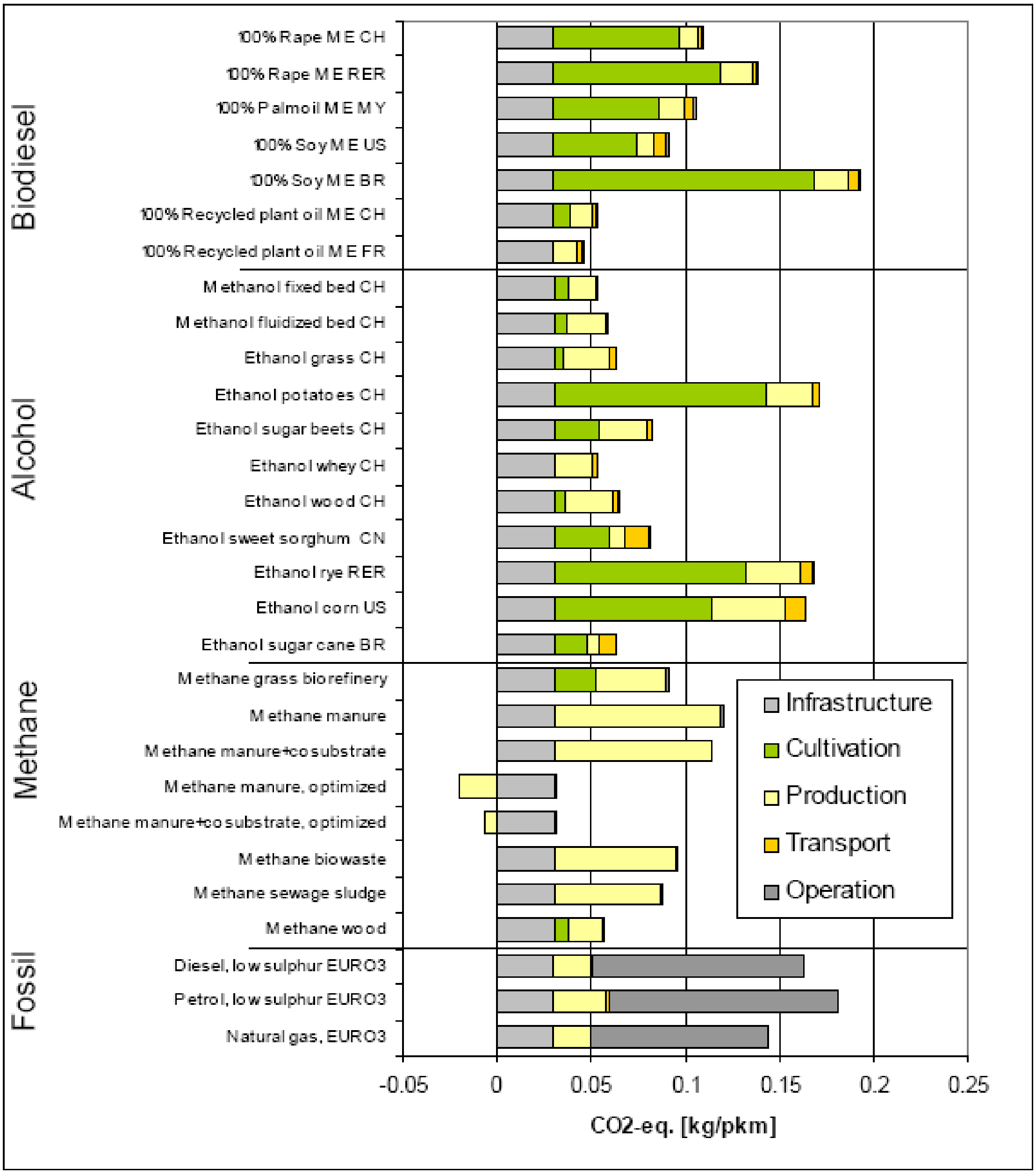
These additional points were used to show that greenhouse gas emissions can differ tenfold according to the feedstock used to produce ethanol. The case studies also illustrate the strong sensitivity of the results to the carbon intensity of the fuel used to heat the processing and distillation processes, with coal-fired and transport-intensive production labelled "CO_2 intensive". This scenario includes the long-distance shipping of corn by rail with diesel traction. Transport becomes an increasingly important aspect of life-cycle analysis as the size of biofuel plants increases and feedstock has to be transported from an increasingly large area. For instance, some of the large plants on the Gulf of Mexico rely on corn brought from the Midwest by rail. Residual animal feedstock (distillers' grain) also often has to be transported long distances to cattle farms.

More generally, the average results presented in Figure 1 from each of the original studies masks a very wide range of results at the level of individual production sites.

One of the most recent and most comprehensive environmental assessments of biofuels was prepared for the Swiss Government by the Empa Research Institute (Zah *et al.*, 2007). This developed comprehensive indicators for environmental impacts along with life-cycle assessments for greenhouse gas emissions for a wide range of biofuels and biofuel production systems. Biofuels produced in a range of countries were examined. The study assumed the fuels were for use in Switzerland but, as the transport-to-market component of overall greenhouse gas emissions for finished fuels is relatively small, this affects the figures only slightly.

The results, summarized in Figures 2 and 3, illustrate the importance of emissions during cultivation in determining life-cycle greenhouse gas emissions, together with the amount of carbon in the organic matter returned to the soil after harvesting.

Figure 2. **Comparison of the greenhouse gas emissions from biofuels and oil products, broken down by process in the production and distribution chain**



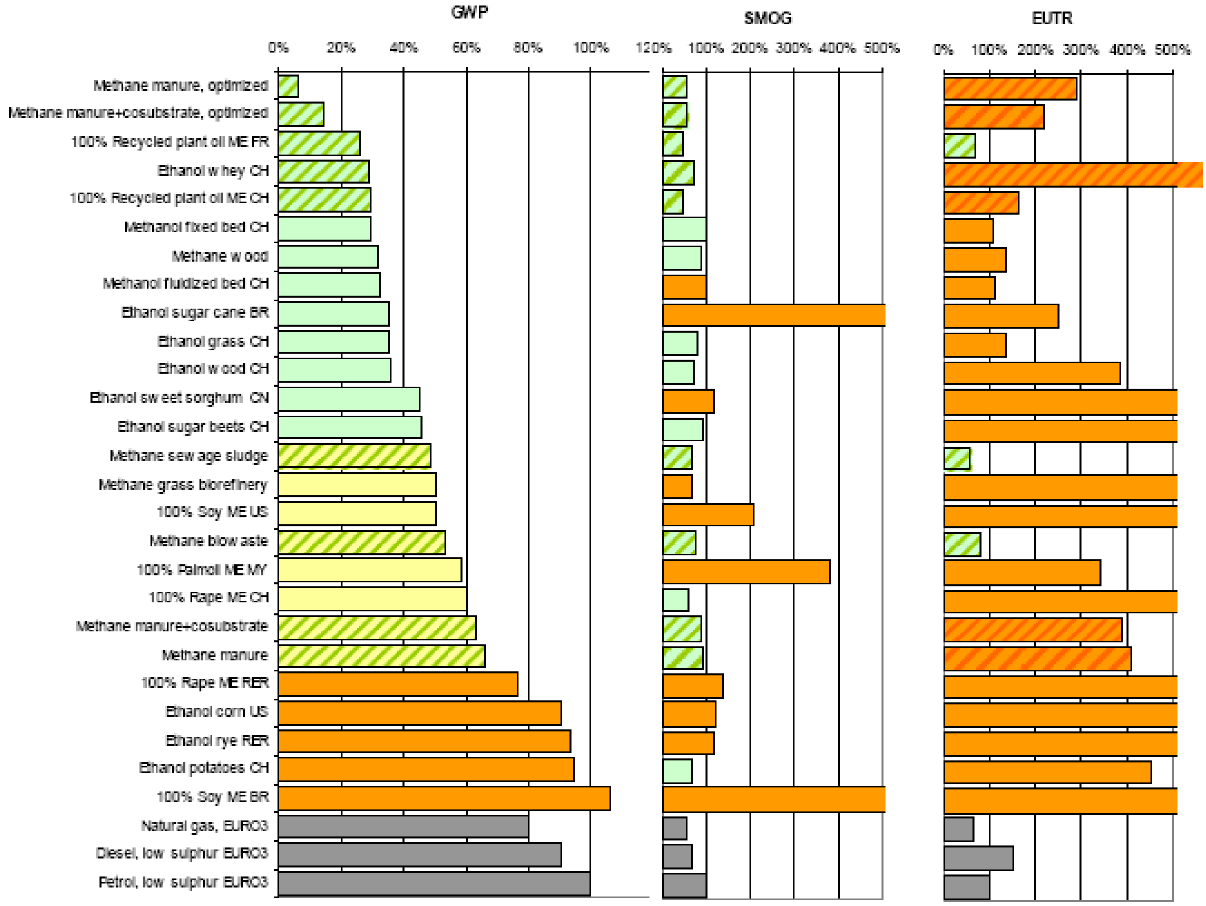
Notes: Vehicle operation is CO_2 neutral in the case of the pure biofuels because the CO_2 emitted in combustion is absorbed from the atmosphere during plant growth.

Global warming potential is here expressed as kilograms CO_2-equivalent per passenger km using a load factor of 1.59 passengers per vehicle. The infrastructure figures include emissions from the production and maintenance of both the car and of the road.

RER = European Union.

Source: Zah *et al.*, 2007.

Figure 3. **Environmental life-cycle assessments of biofuels in comparison to reference oil products**



Notes: GWP = greenhouse warming potential, SMOG = summer smog potential, EUTR = excessive fertilizer use. RER = European Union.

Biofuels are ranked by their respective GHG emission reductions. In the left-hand diagram, fuels with total GHG emission reductions of more than 50% compared to petrol are shown in green, those with GHG emissions reductions of more than 30% in yellow, those with GHG emissions reductions of less than 30% in orange. In the other diagrams, green = better than reference; orange = worse than reference. Cross-hatched fields = production paths from waste materials or residues.

Source: Zah *et al.*, 2007.

The Empa study confirms a number of the points made by Farrell *et al.*:

- The large range in greenhouse gas performance between different fuels and feedstocks;
- Corn-ethanol and ethanol produced from rye and potatoes appears to provide no greenhouse gas benefits; and
- Ligno-cellulosic ethanol produced from both grass and wood offers potentially far superior greenhouse gas benefits.

The study also finds favourable greenhouse gas performance for ethanol produced from whey and for biodiesel produced from recycled vegetable oil. The other fuels that provide unambiguous greenhouse gas benefits (over 50% reductions compared to gasoline or diesel) are ethanol from Brazilian sugar cane, from Canadian sorghum and from sugar beet. Biodiesel from US soy, Malaysian palm-oil and Swiss rapeseed also perform reasonably well with 30-40% reductions of greenhouse gas emissions compared to conventional diesel. Rapeseed biodiesel produced in the European Union performs less well according to the study (indicated as 100% Rape ME RER in Figure 3).

3.1 Uncertainties

Discussions at the Round Table confirmed the wide range of uncertainty in the estimation of life-cycle energy and greenhouse gas emission balances for biofuels. Most of the uncertainties relate to feedstock production, whilst processing of feedstock into fuel is much better understood and can be more readily measured.

Almost all biofuels today are produced on fertile land that competes with other agricultural production. Many Round Table participants felt that the uncertainties surrounding greenhouse gas emissions from this type of biofuel are so large that no firm conclusions can be drawn on the climate costs and benefits of biofuels.

Other participants concluded that large uncertainties concern only a few parameters (mainly land-use change and emissions of nitrous oxide) and that emission ranges can be adequately quantified. In their view, for biofuels offering only small greenhouse gas emission benefits (such as corn-based ethanol) the uncertainties are sufficient that greenhouse gas emissions may in fact exceed those associated with gasoline. Most biofuels, however, achieve net emissions reductions, even if these are sometimes small.

A recent study by Tad Patzek, using an estimate of the impact of typical US corn farming practices, finds that emissions from humus oxidation in soil eroded by wind may be the second largest component of emissions from corn ethanol production, after emissions from the fuel used for biorefinery process energy (Patzek, 2007). New scientific research will be essential in order to produce figures specific to other crops and farming practices. New crops and new farming methods might reduce greenhouse gas emissions and other environmental impacts significantly.

A large part of the difference between the highest and lowest values for greenhouse gas emissions in the data analysed by Farrell and the ERG team are due to differences in the assumed rate of lime application in farming corn and they observe that the data on lime application is poor.

Much of the uncertainty in the analysis of life-cycle greenhouse gas emissions concerns land-use change. Changes in land use due to the production of biofuels can result in large changes in the amount of carbon in biomass and soils. There is a great deal of variation in soil-carbon levels but forest, wetland, and grassland soils generally contain significantly more carbon than do typical agricultural soils (Delucchi, 2006). Converting forests or grasslands to agriculture for the purpose of producing biofuel crops can result in emissions of soil carbon equivalent to several decades of emissions from fossil-fuel use.

Another large source of uncertainty arises in estimating emissions of nitrous oxide (N_2O) from cultivated soil and indirectly from fertilizer application. This may account for as much as 50% of total greenhouse gas emissions on a CO_2 equivalence basis for some biofuels production. A recently completed, unpublished report for the German Environment Agency found that when N_2O emissions are included, biodiesel produced from rapeseed in Germany is associated with three times the greenhouse gas emissions of conventional diesel. Mark Delucchi at University of California, Davis found similar results for soybean biodiesel in the USA (Delucchi, 2006).

Farming practices are an important determinant of emissions and the difference between "good" and "bad" practice can be sufficient to shift the balance from positive to negative. Soil types also matter. Emissions of greenhouse gases from the soil from farming crops on humus rich soils, such as prevail in northern Europe, are estimated to be around a hundred times emissions from farming crops on the more mineral soils typical of Spain or the main sugar cane areas of Brazil. Crop yields also have a major impact on life-cycle energy and greenhouse gas emissions balances.

3.2 Ecosystem impacts

Using waste products as the raw material for biofuel production avoids many of the problems associated with cultivating biofuel crops. At the same time many agricultural wastes have an opportunity cost and sustainable agricultural practices would see them returned to the soil to maintain organic matter content. As it is, levels of soil humus are diminishing rapidly in many regions of the world with current agricultural practices. Extracting straw, manure and other biomass for vary large scale production of ligno-cellulosic fuels could exacerbate the trend depending on the proportion of residues removed.

Where excess manure concentrations from intensive farming are currently a problem, conversion to biofuel would be beneficial, even if a comparison with resolving the problem through less intensive production is difficult to make. More generally, producing biofuels from wastes that would otherwise be dumped in landfill sites might be expected to show net environmental benefits given a shortage of suitable landfill sites.

The potential for the use of degraded lands, normally abandoned agricultural land, for biofuel feedstock production was discussed briefly at the Round Table. This is not common practice today and when degraded lands have been converted to biofuel production, such as on some Conservation Reserve Program lands in the United States, traditional crops such as maize have usually been used, causing all of the problems discussed above. Alternatives have been proposed that would establish perennial crops to restore land quality and sequester carbon in soils at the same time as producing biofuels, using existing species such as prairie grasses or genetically modified biofuel crops such as elephant grass (miscanthus). These approaches have not yet been demonstrated and would produce biofuels on only a limited scale because of the relatively low productivity of such land and feedstocks.

The categorisation of almost all biofuels as "renewable" was challenged at a fundamental level. Turning biomass into fuels takes material out of natural ecosystems (when wild growing plants and trees are converted into fuel), replaces a natural ecosystem with crop land or intensifies production from existing farmland. The net result, as with much modern farming, is the destruction of natural ecosystems, a loss of biodiversity and a simplification of modified farmland ecosystems that is irreversible except on a geological time-scale. Increased production of biomass represents consumption of a resource that can not be replaced. With even present-scale production of biofuels these losses are not trivial. Taking a very long-term perspective it was argued that large-scale biofuel production is not "sustainable" and biofuels cannot be regarded as "renewable" fuels (see Patzek, 2007a for a full discussion of this point). Of course the same holds for the "renewability" of much food production.

4. SUBSIDIES, COST-EFFECTIVENESS OF SUPPORT TO BIOFUELS AND INDIRECT ECONOMIC IMPACTS

Debate was launched by a presentation from Ron Steenblik, Director of Research for the Global Subsidies Initiative of the International Institute for Sustainable Development, which examined:

- the size and extent of subsidies;
- prospects for commercial viability in relation to oil and feedstock prices;
- market interactions and the impact of biofuel subsidies on food and animal feedstock markets.

He began by noting that if it were not for the existence of large and growing subsidies and volumetric production targets for biofuels, the complicated and costly task of calculating life-cycle performance for the certification of fuels would probably not be required. Few if any biofuels are currently produced without direct or indirect government support.

In the United States, the cost to taxpayers of just the federal volumetric tax credits for biofuels is expected to be almost USD 4 billion in 2007 (Table 1), equivalent to one-third of the total USD 12 billion expected to be paid out in farm support in 2007. Federal tax credits for biofuels could grow to USD 16 billion if the US Congress were to adopt the Bush Administration's proposed expanded "alternative fuels" target of 35 billion gallons (132 billion litres) a year by 2017 (Figure 4).

In the European Union, reduced excise tax rates for biofuels are estimated to have cost around EUR 3 billion (USD 4 billion) in tax revenues foregone in 2006, up from EUR 1.8 billion in 2005 (Kutas *et al.*, 2007).

Table 1. **Estimates for the major tax subsidies for biofuels in the USA in 2007**
(billion USD)

	Federal blender's tax credits (Revenue loss from Volumetric Excise Tax Credits)	**Federal small-producer income tax credits**	**State fuel excise tax exemptions**	**Total**
Ethanol	3.2	0.1	0.2	3.5
Biodiesel	0.5	0.1	0.1	0.7
Total	**3.7**	**0.2**	**0.3**	**4.2**

Source: Koplow, 2007.

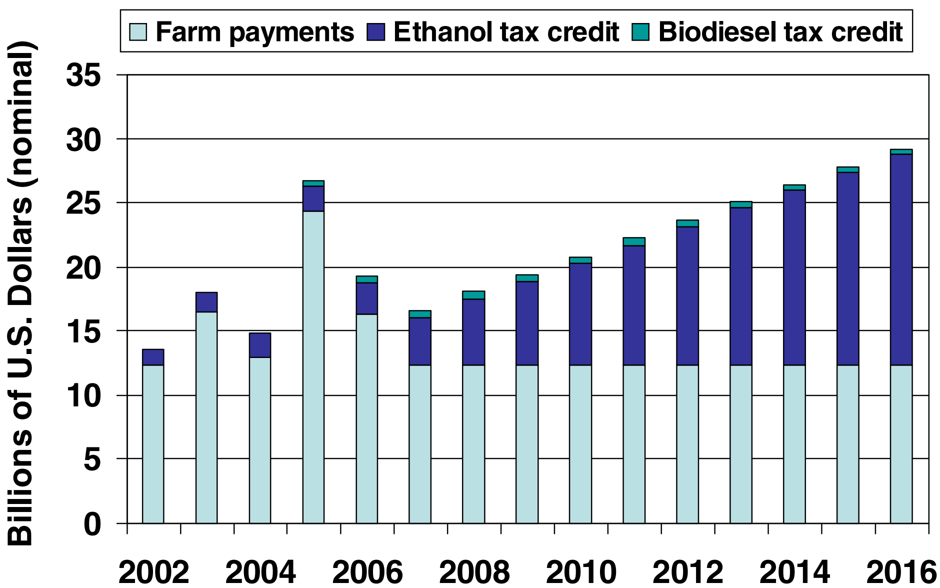
Table 2. **Estimates for major tax subsidies in the European Union**
(Excise tax exemptions - revenue loss)

	2005		2006	
	Billion EUR	***Billion USD***	**Billion EUR**	***Billion USD***
Ethanol	0.5	*0.7*	0.8	*1.2*
Biodiesel	1.3	*1.8*	2.1	*3.0*
Total	**1.8**	***2.5***	**3.0**	***4.1***

Notes: Euros in current prices; Dollars converted from Euros at interbank exchange rate of 12 September 2007.

Source: Kutas *et al.,* 2007.

Figure 4. **Projected farm payments and biofuel tax subsidies in the USA**



Note: Projection based on the Bush Administration's 35 billion gallon ethanol target for 2017, assuming farm support payments remain constant in nominal value; the peak in support in 2005 was due to price support and counter-cyclical payments triggered by low crop prices in the wake of Hurricane Katrina.

Source: Prepared by Ron Steenblik, GSI, for this report.

For the OECD as a whole, Mr. Steenblik estimated overall support for biofuels at between 13-15 billion dollars in 2007.

Much cheaper ways of saving fuel and CO_2 emissions are available in the transport sector and elsewhere in the economy. Putting to one side those circumstances where the use of ethanol increases, rather than reduces, greenhouse gas emissions, support for ethanol was estimated to cost USD 520/t$CO_{2\text{-eq}}$ (EUR 390) for the greenhouse gas emissions saved through production of ethanol at the best performing US plants[3]. The cost of emissions avoided rises to over USD 10 000/t$CO_{2\text{-eq}}$ (EUR 7 400) in the case of hypothetical production of ethanol in Oregon from feedstock transported from the Midwest. At these levels of cost it is inconceivable that using life-cycle analysis to help improve even the best performing US ethanol plants and corn production practices could make ethanol a more cost effective way of reducing greenhouse gas emissions than alternatives such as supporting improved vehicle fuel efficiency.

Research for the Global Subsidies Initiative (Kutas *et al.,* 2007) suggests that the same is true for biofuels produced in Europe, even though greenhouse gas emission balances are generally much better than is the case for US corn ethanol. For ethanol produced from sugar beet in Europe the cost of subsidies per ton of $CO_{2\text{-eq}}$ avoided is estimated to lie between EUR 450 and EUR 620; for biodiesel produced from rapeseed the range is estimated to be EUR 750 to EUR 990; and for biodiesel produced from used cooking oil around EUR 270 (USD 370).

Table 3. **Greenhouse gas mitigation costs: Subsidies per ton of $CO_{2\text{-eq}}$**

Average performance	EUR per ton $CO_{2\text{-eq}}$	USD per ton $CO_{2\text{-eq}}$
US corn-ethanol	390	520
EU sugar-beet ethanol	450-620	610-840
EU rapeseed biodiesel	750-990	1 000-1 340

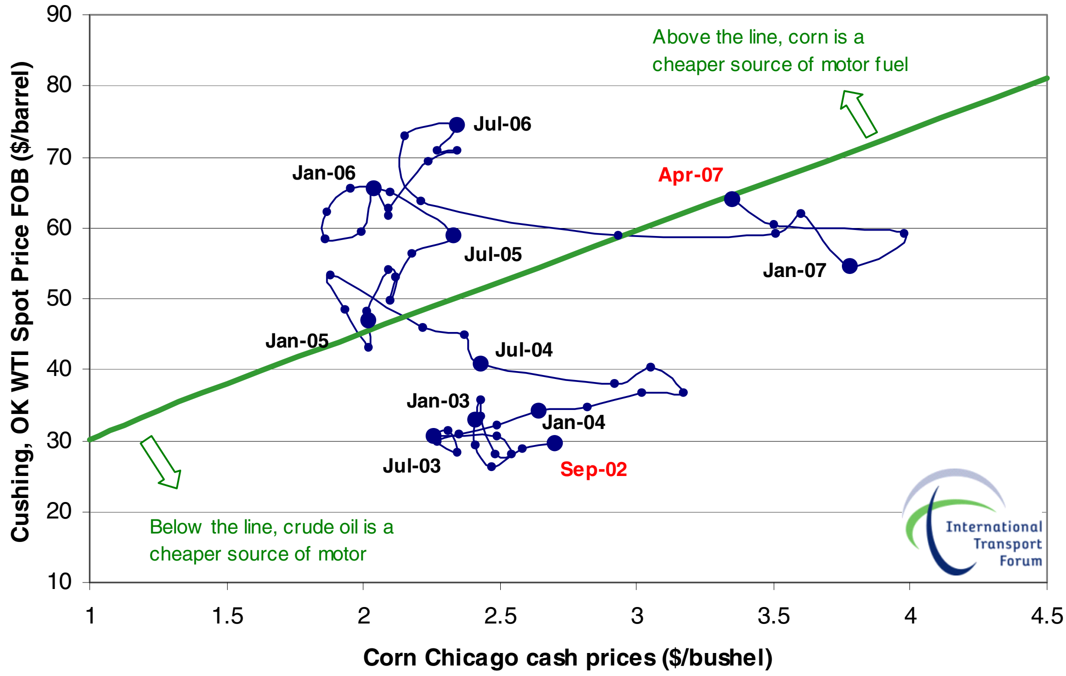
Note: Currency conversions at interbank exchange rates of 7 September 2007.

Sources: Koplow, 2007; Kutas *et al.,* 2007.

These subsidies for biofuels are an extremely costly way of reducing greenhouse gas emissions. For example, the implicit subsidy from the excise tax exemption for biodiesel of EUR 0.70 per litre in Germany is equivalent to 10 000 EUR (USD 13 000) per car on the basis of average kilometres driven over a car's lifetime. Investing this amount in improved vehicle efficiency could massively improve the fuel efficiency of average cars.

In some cases biofuel subsidies can significantly exceed the price of the fossil fuel for which they substitute. Pennsylvania, for example, is contemplating providing subsidies for biodiesel that, combined with federal subsidies, would amount to USD 2.37 per gallon against a pre-tax price for mineral diesel oil of around USD 2.00 per gallon. Fossil fuels also receive subsidies, but not at such high rates per unit of fuel produced. In OECD countries there are tax subsidies to oil production but these have only a small effect on prices at the pump. (Fuel subsidies tend to be found mainly in OPEC member countries and a few lower income countries.)

Figure 5. **The impact of corn and crude oil prices on the competitiveness of corn-ethanol and gasoline**



Data sources: Corn price, USDA; Oil price, US EIA; Break-even line, Tyner, 2007.

Food and fibre production is also heavily subsidised in many countries, but biofuels subsidies are particularly poorly structured, with no cap and no differentiation according to performance. Although the purpose of biofuel subsidies might be expected to be to make biofuels competitive with oil products, they are only rarely linked to the price of oil, and subsidies continue to be paid when oil prices rise to levels that should make biofuels competitive. It was noted that biofuel subsidies in France are currently calculated on the basis of an oil price of USD 30 a barrel. With current prices at USD 60 a barrel this represents a massive transfer from the taxpayer to the biofuels industry. Whilst capital grants for building biorefineries can be terminated relatively easily, subsidies to production always prove very difficult to reform.

Few markets have been as distorted by government intervention as biofuels. Moreover, biofuel subsidies are lending legitimacy to calls for subsidies for other “alternative” fuels. US politicians that would like to see new coal-to-liquid plants located in their States are arguing for a production tax credit (51 cents per litre) that matches that currently benefiting ethanol. Two bills were presented to Congress and defeated in June 2007 seeking similar subsidies for coal-to-liquid fuels production. The logic is that other fuels providing the same environmental or energy security benefit should be accorded the same level of subsidy. In this way subsidies tend to proliferate. A simple increase in fuel excise duty to reflect its carbon content would be a more direct, less open-ended and more transparent way of encouraging the development of low-carbon fuels.

There were suggestions that Brazil demonstrates that subsidies can be temporary. Brazilian ethanol production comes closest to commercial viability. However, as explained in detail in Professor de Almeida's paper, it is exempt from fuel excise duty, and in sugar cane growing states it is also exempt from VAT. Without these tax subsidies production would not be viable. Support amounts to around USD 1 billion a year.

Any notion that conventional ethanol production requires infant industry support is difficult to accept as the production process is identical to the fermentation of grain for ethanol in making beer and other alcoholic beverages, a process operated commercially over thousands of years. Moreover, ethanol for gasoline blending has been produced in the USA for twenty years. Support for wind power generation was advocated on an "infant" industry basis because costs are on a trajectory towards commercial viability. Biofuels, however, appear to be on the opposite trajectory with land and grain prices increasing as a consequence of subsidizing their production.

It was suggested that the lack of substitutes for liquid hydrocarbon transport fuels justifies specific support to biofuels, but given the large potential for reducing CO_2 emissions and saving oil in other sectors at much lower cost, this view did not command general support. Moreover, transforming biomass into complicated hydro-carbon molecules is inevitably much less efficient than simply burning it for heating or electricity generation.

The strategic goals of subsidies to biofuels production are:

- reducing greenhouse gas emissions;
- improving energy security; and
- promoting rural employment.

Much greater contributions to all of these goals can be achieved at much lower cost by other means: promoting energy efficiency, developing transport demand management strategies and providing direct income support to farmers.

Support to commodity production has proved an ineffective way to deliver social policy in the farm sector as any benefits are almost always captured by large agro-industrial companies rather than the targeted farm labourers or small farmers. The same is true with biofuels production where most production is accounted for by large corporations.

In relation to energy security, price volatility is usually a good indicator of supply security problems. Prices increase in times of shortage and fall when there is a glut. Grain prices fluctuate more widely than oil prices due, in part, to dependence on the weather. Even if all arable land were diverted to the production of biofuels it would not ensure energy security and could increase price volatility.

The high cost of subsidies to biofuels has the potential to divert resources from energy efficiency measures with much higher returns in terms of greenhouse gas emission reductions. Overall, the current level and structure of support for biofuel production would appear to weaken our ability to achieve any of the strategic goals.

5. SECOND GENERATION FUELS – PERFORMANCE AND POTENTIAL

Discussions followed a presentation by Professor Birgitte Ahring of the Technical University of Denmark, founder of the BioGasol Company that produces ligno-cellulosic ethanol from a pilot plant in Denmark. The paper covers:

- energy performance by feedstock and process;
- economic performance to date;
- design of subsidies; and
- future performance and scale of production from wastes and dedicated crops.

Ligno-cellulosic ethanol demonstration plants are under development in Denmark with production expected to start in the next year or two at a scale of around 10 million litres a year per plant. These plants will be designed to demonstrate flexibility of feedstock capability rather than produce fuel at the lowest cost. Around 2010 the next generation of small, full-scale plants of around 70 million litres a year capacity is foreseen. Fully commercial plants would be bigger again, around 100 million litres per year, and expected to break even at an oil price of USD 35/bbl. Despite that, Professor Ahring's paper argues for continuing subsidies for production.

The capital costs of ligno-cellulosic plants were reported to be around 50% higher than for conventional ethanol production; nevertheless the critical factor for commercial viability is the cost of biomass feedstock. The main feedstock in Denmark will be straw, despite its relatively high price of USD 85/t, but a variety of feedstocks are expected to be used eventually including waste paper, household wastes and the fibrous residues of pig manure. The potential value of diverting wastes from landfill was stressed against a background of rapid growth in the generation of household waste. Producing fuels from some kinds of waste reduces land use impacts to zero but the potential volume of production from these kinds of waste remains to be quantified.

The great variety of feedstocks that can potentially be used for ligno-cellulosic ethanol production provides for a very wide range of performance in terms of life-cycle greenhouse gas emissions. Results are more likely to be positive than with much conventional ethanol production. For straw fed plants in Denmark, emission reductions of 80% compared to gasoline are expected. There is no figure available for the cost per tonne of CO_2 saved.

The relatively high capital costs of producing ligno-cellulosic ethanol imply important scale economies. Large plants, processing large volumes of biomass, are therefore probably required for commercial viability. This means either that large quantities of feedstock have to be available locally or feedstock has to be brought to the plant over long distances. This is the case for low yield crops such as switchgrass grown on marginal land. Transporting feedstock, however, has a cost in both financial and energy terms and severely undermines the greenhouse gas balance of producing ethanol this way. Large-scale plantations of dedicated crops on reasonably fertile land would be required to produce quantities of ethanol sufficient to substitute for more than one or two percent of transport sector oil demand. Ethanol yields from ligno-cellulosic production are higher per hectare of land used than conventional ethanol production because more of the feedstock is converted to fuel. Substituting for conventional production could reduce pressure on land to some degree, albeit at the expense of higher production costs.

Distiller's grain, a co-product in conventional ethanol plants, could be used as feedstock for ligno-cellulosic production (although it is 30% protein and 9% fat and probably more valuable as animal feed) and could be used to increase overall ethanol output 20% in an integrated production system. Professor Ahring thought that producing ethanol from bagasse in Brazil would enable it to become competitive with gasoline without tax subsidies. It was noted that in Australia sugar cane is selected for greater leafiness and cane burning[4] is being reduced to provide more material for bagasse.

Again a number of questions were raised about the material and energy balances of diverting some waste streams for ethanol production. Bagasse in Brazil is usually used to fire the boilers for distilling ethanol whilst co-producing ethanol, diverting it to ligno-cellulosic ethanol production would sacrifice income from electricity sales to the grid and require other (fossil) fuels to provide process heat and electricity. Since straw normally gets ploughed back into the soil, using large quantities to produce ethanol would be detrimental to soil quality.

It was reported that prospects for commercial operation of the world's first large-scale demonstration ligno-cellulosic ethanol plant, the Iogen plant in Canada, continue to be uncertain. There was speculation that early starts like Iogen might not prove to be the way forward in the long run. A number of small private companies are developing new enzymes that could reduce costs, and the costs of the enzymes themselves are falling. One technology being trialled in the USA is to feed algae in tanks with carbon dioxide sequestered from fossil-fuel power stations. Although this doesn't dispose of the CO_2 it results in some incremental energy production through photosynthesis. A note of caution was sounded with regard to the potential of bioengineering to radically increase the efficiency of producing biofuels. Although enzymes are superior to chemical catalysts in their selectivity, this comes at a cost in terms of speed and thermal efficiency, where catalysts do much better.

Small scale subsidies for technical innovation were regarded as generally useful, with a role in supporting research into the technologically innovative forms of second generation biofuels. But some second generation biofuels are counterproductive. Converting wood to liquids by processes generally known as BTL (biomass-to-liquid) is around 50% efficient whereas burning the wood directly in an efficient boiler can achieve 80% efficiency; 30% of the energy content of the wood is foregone by converting it to liquid instead of burning it. Replacing domestic heating oil with wood for industrial and domestic heating would release oil for motor diesel at four times the efficiency of producing biodiesel.

There are potentially other fuels that might be produced from second generation technologies, including other alcohols (e.g. biobutanol), hydrocarbons and hydrogen. These alternatives were not discussed in detail at the Round Table but a variety of pathways need to be explored.

6. POTENTIAL FOR BRAZILIAN ETHANOL EXPORTS

Discussions were launched by Professor Edmar de Almeida of the Institute of Economics of the Federal University of Rio De Janeiro, examining:

- the performance of current production;
- environmental issues;
- the potential size of exports;
- the impact on energy, environment and economic performance of scaling up for export; and
- trade and trade barriers.

Professor de Almeida's paper examines the performance of Brazilian ethanol and biodiesel in detail, including energy and CO_2 balances, quantifying subsidies and examining the direct and indirect environmental impacts of producing biofuels. The discussions focused on ethanol, reflecting the relative significance of ethanol and biodiesel in Brazil.

The most comprehensive body of research on ethanol in Brazil, led by Professor de Macedo, finds ethanol produced from sugar cane achieving 30% to 80% greenhouse gas savings compared with gasoline, depending on the efficiency of feedstock production and the operation of plants, with most towards the upper end of performance. Professor Almeida's thorough review of the literature confirms the superior performance of Brazilian ethanol production, although the he was not able to assess all of the uncertainties discussed above surrounding such estimates. The advantages for Brazilian ethanol production are as follows:

- Sugar is a better feedstock than starch (from grain) as starch must first be broken down with enzymes into sugar before it can be fermented, which requires heat;
- The use of bagasse (cane residue) to produce process heat and electricity avoids the use of fossil fuel;
- Co-generation of surplus electricity sold to the grid, improving both financial and energy balances;
- At least some of the soils used for sugar cane in Brazil are low in organic matter and produce relatively little N_2O and CO_2 when cultivated;
- Cane is largely rain-fed in Brazil rather than irrigated, reducing the need to pump water and reducing stress on water resources;
- Farm labour costs are low, aiding financial performance;
- A sustained government funded research effort into plant breeding and selection has improved yields substantially, a trend that is set to continue.

Ethanol prices have traditionally been closely linked to sugar prices because of the flexibility of producers to switch production between sugar and ethanol. However, high oil prices mean that ethanol prices are increasingly linked to the price of oil.

The potential indirect impacts of cane growing on greenhouse gas emissions through the displacement of agriculture as a result of the expansion of cane growing are not well documented. There is likely to be some effect because of interconnections between land markets. Expanding cane plantations onto land famed for other purposes will create pressure for more intensive production of the displaced crops or expansion into virgin lands somewhere in the world, if demand for these other crops remains unchanged.

There are a number of factors that complicate the picture. Incremental cane plantations in Brazil generally replace extensive cattle rearing, which is associated with widespread soil erosion. In these conditions replacing cattle with cane may reduce soil carbon loss. Around Sao Paolo, in the heart of cane country, some cattle have been moved indoors as cane planting expands. Greenhouse gas emissions from stall-fed cattle can be much higher than from free-range herds depending on the feed types they are given. The overall impact of cane expansion on greenhouse gas emissions is difficult to determine. It is also possible that some cattle rearing has been displaced to the North where it encroaches on rainforest. The main incentive for felling forest in the Amazon is extracting timber, which has a very high cash value. Cattle-rearing yields very little, around USD 100 per hectare per year, and simply follows where timber has been exploited – legally or illegally.

The link between forest destruction and biofuel production may be stronger in the case of soybeans for biodiesel as this crop is suited to the North and grown on very large plantations. Soybean production has expanded rapidly recently due to growing international demand. The spread of the crop is replicating the initial development of land for sugar cane plantations, which resulted in massive deforestation in earlier centuries. Whilst the government has passed laws to protect the Amazon rainforest, enforcement is difficult across the vast and sparsely populated territory of the North.

Biofuels subsidies in Brazil were initially aimed at providing jobs for unskilled labour in rural areas and at combating local air pollution. (Ethanol is used as an octane enhancer in lead-free petrol and as a fuel oxygenate to reduce carbon monoxide emissions). Although mechanisation is gradually reducing employment in sugar cane plantations, the industry provides one million jobs, and at a higher rate of pay than the rural average. There are similar motivations for supporting the development of biodiesel production. The first goal is rural development through support to small scale production in poor areas. Biodiesel is also free of sulphur and can be blended with conventional diesel to reduce emissions of both sulphur dioxide and particulates, which are major environmental health problems in Brazil's main cities. There has, however, been no analysis of whether subsidies for biofuels are an efficient way of encouraging rural development.

6.1 Trade in biofuels

Debate on trade in biofuels was initiated by a short presentation from Ron Steenblik noting an important distinction between the trade treatment of biodiesel and ethanol. The World Customs Organisation (WCO) classifies biodiesel as a chemical product and as such it attracts low tariffs. Ethanol is classified by the WCO as an agricultural good, as most production has been for beverages, and as such it can be subject to much higher tariffs. Import tariffs vary widely in OECD countries, from 6% in Canada to 51% in Australia on an *ad valorem* basis. The USA and EU levy tariffs with *ad valorem* equivalent rates of 23% and 38% respectively. Trade diplomacy on environmental goods under the World Trade Organisation (WTO) negotiations on access to markets for agricultural products only ever covered biodiesel, and biodiesel has now been removed from the list of proposed environmental goods. Negotiators are reluctant to address ethanol as they believe this would inevitably lead to demands for a wide range of agricultural products to receive special treatment.

The potential of Brazil to export ethanol is severely constrained by import tariff policies. Brazil's current 2 billion litres annual exports to the USA mainly enter the country via Central American and Caribbean countries under the Caribbean Basin Initiative trade agreement. Major expansion would require negotiation of favourable tariffs. There has been speculation that ethanol might provide a reason for reopening the current stalled round of WTO negotiations, but no country appears ready to change its present position.

7. CERTIFICATION – THE POTENTIAL FOR LINKING SUPPORT TO PERFORMANCE

Certification schemes have been developed for a variety of agricultural and forest products in order to differentiate products that meet certain environmental standards from others that do not. Organic food labelling is a familiar example. Some of the schemes are operated by government, some by voluntary consumer or producer organisations. All have to create confidence in the reliability of the endorsement they provide. This requires an assurance system that sets the standards to be met, inspects farms and processing plants to determine if standards are being met, and grants accreditation to independent bodies that issue certificates to producers confirming their products meet the standards. Confidence in the integrity of the assurance system may rely on government oversight, involvement of environmental campaign groups and public reporting of inspection activities and standard setting.

Certification and assessment of biofuels was introduced by a summary of developments in California from Professor Alex Farrell and a detailed presentation from Professor Jeremy Woods of Imperial College London, covering:

- the design of certification and assurance schemes;
- the environmental impacts of farming biomass;
- national and international certification schemes; and
- the cost-effectiveness and feasibility of auditing and inspection.

The very great range of performance in terms of greenhouse gas emissions of different biofuels production pathways was stressed in the presentations. Around 130 combinations of feedstock and process have been evaluated to date. Taking just one, ethanol produced from wheat, research suggests performance when compared to gasoline ranges from higher emissions to an 80% reduction in greenhouse gas emissions, on a life-cycle basis.

As noted already, the role of soil carbon is particularly poorly understood. This applies to both the soil-carbon content of natural ecosystems compared to farmland (for example if peat-lands or wetlands are cleared and drained for biofuel crops) and to the soil-carbon impacts of different farming techniques. Research suggests that good farming practice can result in an increase in carbon trapped in organic matter in the soil, in some cases even when grazing land or savannah is planted. Poor farming practice can result in significant emissions and loss of soil carbon. Poor practice currently dominates and farming practice is costly to monitor for certification purposes. At the same time, biofuels production is so far only a small sub-set of the different uses to which land is put. As knowledge about the impacts of soil-carbon on greenhouse gas emissions increases estimates for emissions from other types of land use will also need to be revised.

Certification is a difficult task, not least because of the effort required in building consensus over the methodologies employed and the validity of results.

Despite the difficulties and gaps in research certification is critical if subsidies and volumetric targets for biofuels production are to continue to be employed. Without certification, such targets are likely to result in a “race to the bottom”; producing the largest quantity at the lowest cost and at the lowest capital intensity, which tends to be associated with the highest greenhouse gas emissions. The first goal of certification is to counter this tendency.

In response to EU biofuel targets the UK Government will introduce a Renewable Transport Fuel Obligation (RTFO) from April 2008 under which fuel suppliers will be required to submit monthly carbon and sustainability reports to the Administrator of the scheme. The reports will identify the volume and type of biofuel supplied with detail on the feedstock type, any environmental and social standards to which the feedstock has been grown, any land use change that has occurred and the carbon intensity of the biofuel supplied. Targets have been set that indicate the level of performance government expects from suppliers but there will be no penalty or sanction for not meeting these targets. Companies will supply an annual report that provides a summary of this information which will be made publicly available. The Administrator will also publish an annual report that will include an assessment of each supplier’s performance against the targets.

Technical guidance is being developed (by E4tech) that will provide the information and instructions suppliers need in order to comply with these requirements. Direct land use change is included within the boundaries of the carbon intensity calculation. Indirect land-use change is not addressed within the well-to-wheel carbon intensity calculation but the Administrator will assess these potential impacts on an ex-post basis and report to Parliament.

In June, the UK Government announced that it intends to move to a scheme that rewards fuels on the basis of their greenhouse gas performance from 2010, and that only biofuels that meet specific sustainability standards will qualify for incentives from 2011. The proposals for a mandatory carbon-based RTFO with minimum sustainability standards are subject to a number of provisos. The changes must be: compatible with World Trade Organisation rules and EU Technical Standard requirements; consistent with the policy framework being developed by the European Commission as part of the review of the Biofuels Directive; subject to consultation on environmental and economic impacts; and subject to the appropriate development of sustainability standards for feedstocks. The scheme design must also be in line with the proposals developed under the European Fuel Quality Directive.

The Netherlands has scheduled introduction of a reporting system in 2008, similar to that adopted in the UK. Technical guidance is being developed (by Ecofys) in alignment, as far as possible, with UK guidance.

The German Government planned to introduce certification in June 2007. Although introduction has been delayed in Germany, certification there is expected to be compulsory without a long lead-in period of voluntary reporting. Germany plans to organise workshops in Asia and South America to build support for certification with local Non-Governmental Organisations (NGOs) and local communities as well as governments and biofuel producers.

A number of voluntary agreements between producers and environmental NGOs have improved farming practices for palm oil in mature plantations. However, such schemes are unlikely to be effective in preventing the destruction of primary forest for new plantations of palm oil. Certification systems are designed to influence the supply chain and are not well suited to addressing the indirect impacts of producing biofuel feedstocks. While the policy is for German certificates not to be awarded to fuels produced from areas designated for protection, it remains to see how effectively this can be enforced.

The State of California has begun developing a policy to reduce the carbon intensity of transport fuels, which could provide strong linkage between the support for biofuels used in the State and performance in terms of greenhouse gas emissions (Brandt *et al.*, 2007; Arons *et al.*, 2007). The policy will require the net greenhouse gas emissions of transportation fuels (measured in grams of CO_2 equivalent per MJ) distributed in the State to decline over time. While other transportation energy sources may compete to meet this standard, including, for instance electricity, biofuels will be strongly affected, in part because Californian gasoline already contains about 6% ethanol by volume.

The European Commission has proposed a similar instrument to reduce the carbon intensity of transport fuels in a draft Directive under consideration by the European Council and the European Parliament. If adopted this might replace the existing volumetric biofuel targets. The Commission is developing a framework for the certification of fuels that would be required for implementation of a carbon intensity regulation.

International consensus building on greenhouse gas calculation methodologies and sustainability standards is important if certification is to be successful in influencing the way imported fuels are produced and at the same time avoid simply acting as a trade barrier. Moreover, given the relatively poor understanding of the impact of different farming techniques, sustainability criteria have to be developed with local experts and can not be simply transposed from practices in other regions. The transaction costs involved suggest that, without complementary measures, certification will make it harder for small farmers to supply the market.

It was noted that a potential shortcoming of certification systems is that once a producer qualifies for certification there is no further incentive to improve performance. Subsidies provided to certified fuels need therefore to be linked to a life-cycle assessment of greenhouse gas emissions, with the attendant monitoring costs.

In summary, the following issues need to be addressed in designing certification systems:

- Agreement is required on the boundaries to life-cycle analysis and on the approach to addressing land-use change;
- More research is required on soil carbon and N_2O emissions from farming to reduce scientific uncertainties in life-cycle analysis;
- The potential for certification to be used as a barrier to imports from lower income countries needs to be minimised.

The costs of certifying production processes and farming practices, of monitoring compliance and of achieving consensus between stakeholders that certification is both fair and effective are not trivial and need to be contained. There is nevertheless a compelling argument for developing the business case for a certification process that can reduce the risks of subsidies encouraging environmentally-destructive feedstock production and promote biofuels production in proportion to the greenhouse gas emissions savings actually achieved. This is particularly true for governments so long as markets for biofuels remain almost entirely dependent on public subsidies.

8. OUTLOOK FOR BIOFUELS PRODUCTION

Discussions at the Round Table suggested that projections that biofuels production will grow to contribute a large share of energy supply are unrealistic. For example, the projection by the University of Texas of solid and liquid fuels derived from biomass covering 25% of US energy supply by 2025 would require 50% of all ecosystem production in the US (natural ecosystems as well as food and fibre crops) to be replaced with biofuel crops.

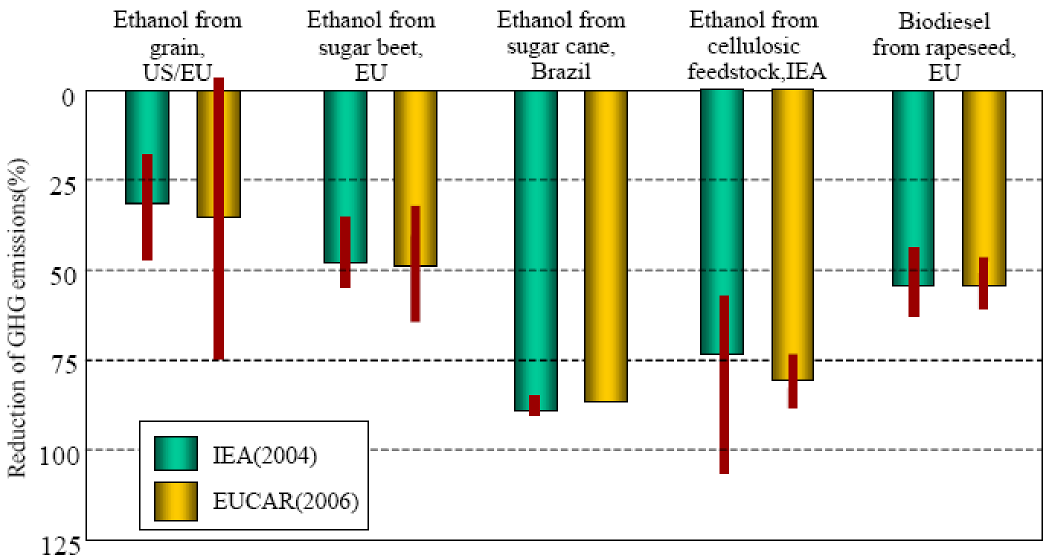
The 2007 Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report on climate change mitigation policies foresees a potential for biofuels from agricultural crops and wastes to replace 5-10% of road transport fuels by 2030, with an economic potential for net greenhouse gas reductions ranging from 0.6 to 1.5 Gt $CO_{2\text{-eq}}$ at carbon prices of up to USD 25/t $CO_{2\text{-eq}}$. It bases these projections on assessments of the life-cycle greenhouse gas emissions by the IEA, EUCAR-CONCAWE-JRC (Figure 6), GM-ANL and Toyota (see references).

The uncertainties surrounding estimates of the greenhouse gas emissions reduction potential identified at the Round Table suggest that the IPCC forecast needs to be viewed with circumspection. The forecast does assume significant advances in biofuel production but the figures for corn-ethanol production in the studies reviewed by Farrell *et al.* suggest more radical change would be required, with the abandonment of current land-intensive feedstocks such as corn and wheat.

Even if the IPCC's assumption that biofuels could be competitive with oil in 2030 proves to be the case, the discussion of the economics of biofuels at the Round Table suggests that hundreds of billions of dollars of subsidy will be spent on the production of biofuels in the interim, if proposed

EU and US targets to cover 10% of transport sector fuel consumption before 2020 are to be met. Only very small quantities of biofuels are currently produced without support and even the best performing biofuel industry, Brazilian sugar cane ethanol production, requires around USD 1 billion a year in support through excise tax and VAT exemptions.

Figure 6. **Reduction of well-to-wheels greenhouse gas emissions from biofuels compared to conventionally fuelled vehicles**



Source: IPCC, 2007.

NOTES

1. The European Council has endorsed the proposal subject to the development of sustainability standards, second generation biofuels becoming commercially available and amendment of the Fuel Quality Directive to allow for adequate levels of blending.

2. Very recently, some European ethanol producers have introduced semi-permeable membrane technology to replace distillation, with large energy savings.

3. Incorporating the full range of subsidies provided by federal and state administrations: import tariffs, volumetric excise tax credits, state excise tax exemptions, corporate tax credits, capital grants, etc.

4. Burning makes harvesting easier and empties the fields of snakes and other pests.

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INTRODUCTORY REPORTS

ENERGY AND GREENHOUSE IMPACTS OF BIOFUELS:

A FRAMEWORK FOR ANALYSIS

Daniel M. KAMMEN,
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SUMMARY

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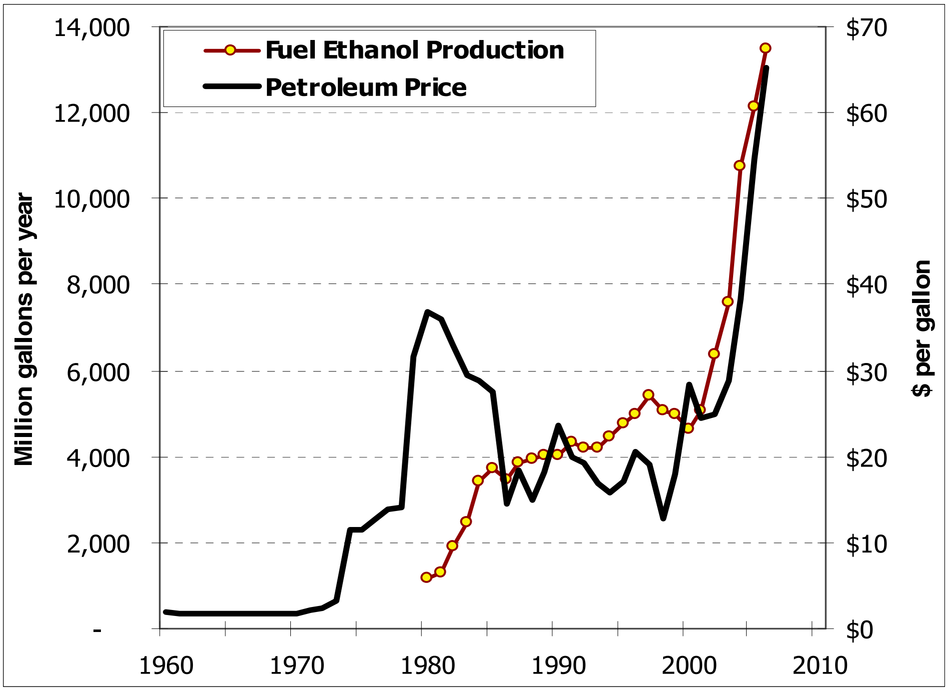
ABSTRACT

In this paper, we review some of the basic energy balance and climate change impact issues associated with biofuels. For both the basic energy and greenhouse gas balances of producing and using a range of fuels, and for the increasingly debated and important issues of non-greenhouse gas impacts, such as land, fertilizer and water use, we conclude that an improved framework for the analysis and evaluation of biofuels is needed. These new methodologies and data sets are needed on both the physical and socioeconomic aspects of the life-cycle of biofuels. We detail some of the components that could be used to build this methodology and highlight key areas for future research. We look at the history and potential impacts of building the resource base for biofuel research, as well as at some of the land-use and socioeconomic impacts of different feedstock-to-fuel pathways.

1. INTRODUCTION

The global industry producing biofuels – liquid transportation fuels from biomass that replace petroleum-based fuels – is growing rapidly. The rapid rise in biofuel production is driven by government mandates, regulation and subsidies, as well as high petroleum prices. Globally, biofuel production is dominated by ethanol, with Brazil and the United States each producing about one-third of the world total. Commercial production of Fatty Acid Methyl Ester (FAME, often identified simply as biodiesel) production began only after 1990 and is an order of magnitude smaller than ethanol production. Figure 1 illustrates the growth of the modern biofuel industry, highlighting the rapid evolution after the oil price shocks of 1973 and 1979 and the dramatic changes when oil prices have been above USD 25 per barrel.

Figure 1. **Worldwide fuel ethanol production and petroleum prices**



Sources: Petroleum prices from (BP, 2007) www.bp.com; Ethanol production is from the Renewable Fuels Association www.ethanolrfa.org where these data are cited as IEA.

Note: For ethanol production, the historical data series (1980-2004) does not match the data for more recent years, showing lower values for years that they overlap. The more recent values are shown here for 2004-2006.

Three common rationales exist for government policies to promote biofuels: 1) to support agriculture; 2) to reduce petroleum imports; and 3) to improve environmental quality (especially preventing global warming due to carbon dioxide emissions). In practice, however, current government biofuel policies tend to function most directly as agricultural support mechanisms, involving measures such as subsidies or mandates for the consumption of biofuels. By contrast, the environmental impacts of biofuels are often not measured, let alone used to determine the financial incentives or to guide government regulation. In addition, current biofuel feedstocks are fairly standard agricultural commodities (e.g. corn and soybeans) and current biofuel production processes are many years old. Yield maximisation for a number of agricultural staple crops often involves high levels of fossil-fuel inputs, further complicating the mix of rationales for biofuel support programmes. Ignoring the differential environmental effects of biofuels is thus unwise, for several reasons.

First, the biofuel industry is growing rapidly and is very profitable, in large part because of high world oil prices. Government policies to further subsidize, mandate, and otherwise promote biofuels are being implemented, and more are proposed. Given the large investments in research and capital that continue to flow into the biofuels sector, it is time to carefully assess the types and magnitudes of the incentives that could be employed to achieve high environmental performance. By engaging in this analysis, we can reward sustainable biofuel efforts, and avoid the very real possibility that the economy could be saddled with the legacy costs of shortsighted investments.

Second, biofuels are now being proposed, and often touted, as solutions to environmental problems, especially climate change. However biofuels can have a positive environmental impact relative to gasoline, or a negative one, depending on how the fuel is produced or grown, processed, and then used (Farrell *et al*., 2006). For instance, corn-based ethanol, if distilled in a coal-fired facility, can have a greenhouse gas signature worse than that of gasoline (unless the coal plant has nontrivial SO_X emissions, which have a significant cooling effect), while cellulosic ethanol, produced using the unfermentable lignin fraction for process heat, or better yet a solar or wind-powered distillery, can be dramatically superior to gasoline (unless the biomass feedstocks ultimately displace wetlands or tropical forests) (Turner, Plevin *et al*., 2007). To distinguish these cases, and the myriad of other feedstock-to-fuel pathways, clear standards, guidelines and models are needed.

Third, many new fuels, feedstocks and processing technologies are now emerging, with numerous others under consideration or active research [see, e.g., Lotero, Liu *et al*. (2005); Kalogo, Habibi *et al*. (2006); Kilman (2006); Lewandowski and Schmidt (2006); Mohan, Pittman *et al.* (2006); Tilman, Hill *et al.* (2006); Demirbas (2007); Gray (2007); Stephanopoulos (2007)]. These technologies are being developed as biofuel technologies *per se*; they are not simple adaptations of pre-existing agricultural production methods. If these developments can be managed to achieve high productivity while minimising negative environmental and social impacts, the next generation of biofuels could avoid the disadvantageous properties of a number of current biofuels (e.g. low energy density, corrosiveness, poor performance at low temperatures, and others). A transparent set of data on what we wish biofuels to provide, as well as clear and accessible analytic tools to assess different fuels and pathways, are both critical to efforts aimed at providing appropriate incentives for the commercialisation of cleaner fuels.

In this paper, we review some of the basic energy balance and climate change impact issues associated with biofuels. We conclude that an improved framework for the analysis and evaluation of biofuels is needed, and detail some of the components that could be used to build this methodology. An important consideration here is how the land-use impacts of biofuels can be measured and used in decision-making. We also summarise and examine the history and potential impacts of biofuel research.

2. BIOFUEL PRODUCTION

Biofuels are produced in two distinct stages: feedstock production (or collection) and processing (sometimes called conversion or bio-refining). Figure 2 shows biofuel production in the larger agricultural production system, and shows the major inputs and environmental concerns with each stage. It is helpful to think of biofuel "production pathways" that include feedstock production and processing of feedstock into fuel. Note that this figure does not include measures of sustainability of the production process.

On the left in Figure 2 is the feedstock phase, which includes crop production, agronomy and processing. The centre column covers processing, represented as a bio-refinery. On the right are some of the important markets into which biofuels and their co-products are sold. Biofuel production generally yields one or more co-products, or may be a co-product of some other, higher-valued process. As examples, animal feed is the key co-product of corn ethanol, while biodiesel (FAME) is often thought of as a co-product of the higher-valued soymeal. Ethanol production from sugar cane yields bagasse (residual plant fibre) that can be burned for heat or electricity production. Most of the markets into which biofuels and co-products are sold involve considerable international trade.

Figure 2. **General biofuel pathway with inputs and environmental impacts (simplified)**

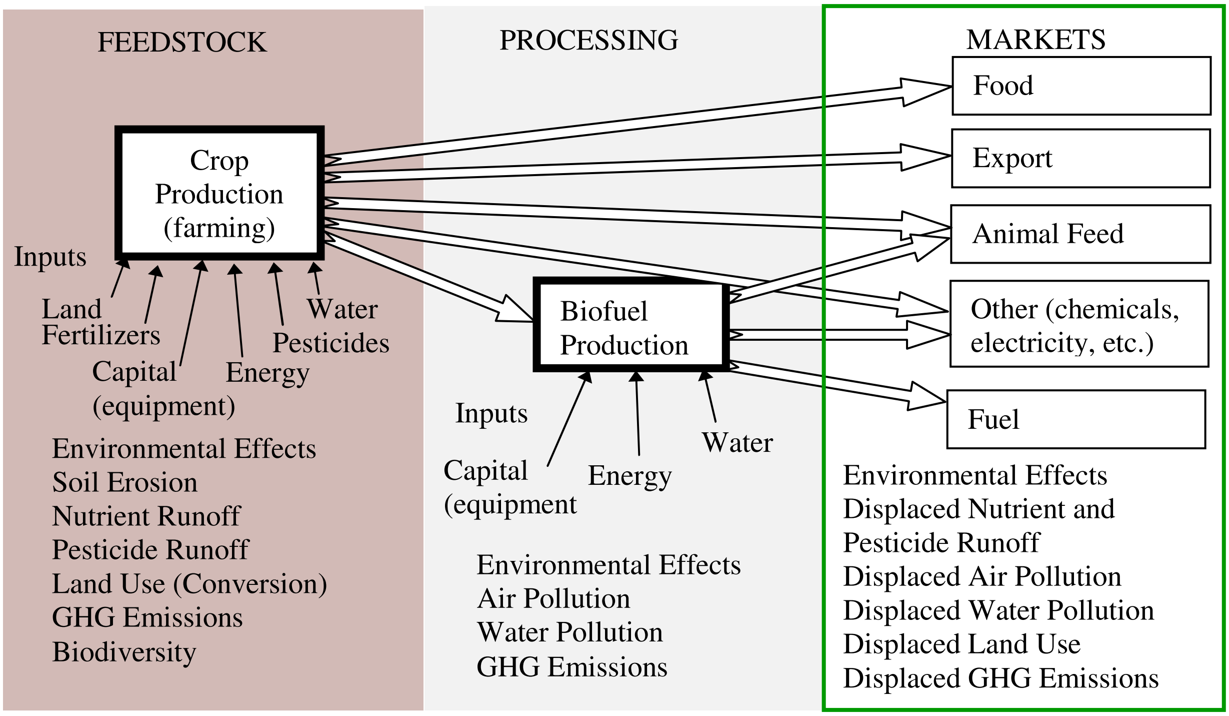


Figure 2 illustrates the crucial concept that biofuel production affects many different markets, including markets for inputs (e.g. land and water) as well as markets for agricultural products and biofuel co-products (e.g. food and animal feed). Note that some of these factors may be indirect, operating through market interactions rather than directly. It is vital to note – and to reflect in biofuel analyses – that the indirect impacts of biofuel production, and in particular the destruction of natural habitats to expand agricultural land (e.g. rainforests, savannah or, in some cases, the exploitation of "marginal" lands which are in active use, even at reduced productivity, by a range of communities, often poorer households and individuals), may have larger environmental impacts than the direct effects. The indirect GHG emissions of biofuels produced from productive land that could otherwise support food production may be larger than the emissions from an equal amount of fossil fuels [Delucchi (2006); Farrell, *et al.* (2006)]. Thus, indirect effects bring into question all current biofuel production pathways and many of those that are being developed. Attention to these issues is vital if biofuels are to become a significant component of sustainable energy and socioeconomic systems (Kammen, 2007).

In addition to causing environmental effects, such as soil erosion and GHG emissions, biofuel production and use also *displaces* some environmental effects because they substitute, in fuel and other markets, for products that have their own environmental effects. The extent to which the co-products of biofuel production displace other products and their environmental impacts (rather than stimulate additional consumption) depends on the elasticity of demand in the relevant markets (the more inelastic the demand, the greater the displacement), the way in which the co-products affect supply curves, and other market and non-market (i.e. political and regulatory) factors.

These market interactions vary greatly by fuel and pathway, so any attempt to illustrate a comprehensive set of biofuel pathways and related markets would quickly become overwhelming. This is especially true because different production pathways will often involve competition and substitution among inputs and co-products. Clarity in the assumed inputs and outputs of any such biofuel pathway is vital to developing a clear assessment of a particular fuel (Farrell *et al.*, 2006). The largest volume biofuel production pathways today are sugarcane ethanol, corn ethanol, soy biodiesel and palm biodiesel (the latter two are both FAME). In these production pathways, the key markets are for electricity and animal feed because these are where the co-products tend to be sold.

2.1 Life-cycle assessment

Lifecycle assessment (LCA) is one technique used to evaluate the energy and global warming impacts of biofuels. In fact, use of LCA techniques is both a method, and a policy framework to evaluate biofuels. It permits an "apples to apples" comparison of issues that include:

1) What is the net change in the world energy supply from increasing biofuel use by a given date?; and

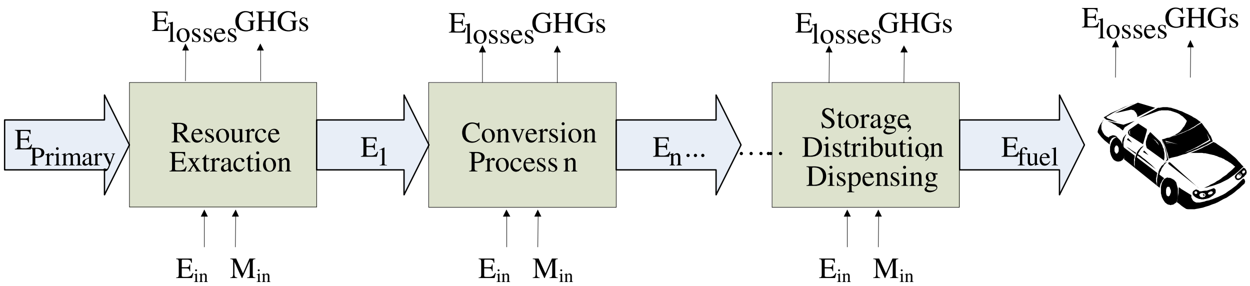
2) How much of the GHG emissions in the world should we attribute to a unit of biofuel produced?

Conceptually, a life cycle comprises all of the physical and economic processes involved directly or indirectly in the life of the product, from the recovery of raw materials used to make pieces of the product, to recycling of the product at the end of its life. In practice, however, the life cycle studied in most LCA tools includes the production of the fuel as well as its combustion, but typically ignore indirect effects or treat them poorly (Delucchi, 2004).

The basic building block in LCA is a set of energy and material inputs associated with a particular output of interest for a particular stage in a life cycle, with emission factors attached to some of the inputs (Hendrickson *et al.*, 2006). A life cycle is then a particular combination of building blocks linked together, where the output of one block (or stage) is one of the inputs to another stage, and the output of the last stage is the product or quantity of interest. An LCA aggregates the emissions attached to the inputs over all of the linked stages, to produce an estimate of total emissions per unit of final product output from the life cycle (Jones *et al.*, 2007).

Consider, for example, the simplified depiction of the fuel life cycle shown in Figure 3. The fuel lifecycle begins with resource extraction (e.g. crude oil production and shipment), proceeds next to conversion processes that transform the resource to fuel (e.g. petroleum refining), and then storage, distribution and dispensing. The final step is the use of the fuel in gasoline combustion. These steps are arranged linearly, like a process flow diagram.

Figure 3. **Traditional fuel life-cycle analyses that exclude indirect effects**



Each process in Figure 3 requires energy and material inputs (E_{in} and M_{in}), and each process has energy losses due to conversion efficiencies (E_{losses}), as well as greenhouse gas emissions (GHGs). Current LCA analyses roughly follow this approach, even though they can be quite complex. Some examples of this approach are the spreadsheet models, GREET, LEM, and GHGenius which is based on an early version of LEM. These models can be accessed or downloaded at:

GREET: http://www.transportation.anl.gov/software/GREET/
LEM: http://www.its.ucdavis.edu/people/faculty/delucchi/index.php#LifecycleEmissions
GHGenius: http://www.nrcan.gc.ca/es/etb/ctfca/PDFs/GHGenius/gh_genius_pamphlet0405_e.html

These early-generation LCA models calculate the GHG effects of fuels by summing of the CO_2-equivalent emissions from a sequence of steps, with the emissions for each step calculated by multiplying the rate of use of some input by a GHG emissions factor associated with that input.

2.2 Limitations of current LCA methods and tools

Current LCA methods have significant uncertainties and omissions [Delucchi (2004); Delucchi (2006); Pennington, Potting *et al.* (2004); Rebitzer, Ekvall *et al.* (2004); Arons *et al.* (2007)]. Several aspects of the areas of incompleteness and uncertainty are discussed below, including market-mediated effects, land-use change, climate impacts of emissions, and uncertain and highly variable data. Research into improved LCA methods is a key component of the effort to understand the energy and GHG implications of biofuels.

2.2.1 Market-mediated effects

Energy and environmental policies affect prices, which in turn affect consumption, and hence output, which then change emissions. Thus, GHG emissions are a function of market forces, and are notably at the intersection of global, not only national, food and energy markets.

Many fuel production pathways result in multiple products, such as food, feed or chemical co-products. Conceptually, the best way to handle this in an LCA of GHG emissions is to include all of the emissions from the entire joint production process, and then model what happens to production and hence emissions in the markets affected by the output of all of the "co-products" (all joint products other than the product of interest). This is the basis of what has been called the "displacement" or "system expansion" approach to estimating the emissions impacts of co-products[1]. However, most applications of this method assume that each unit of co-product manufactured along with the biofuel causes one unit to *not* be manufactured elsewhere, "displacing" that other production, whereas in reality the degree of displacement is the dynamic result of market interactions, and generally will be less than one-for-one. As a result, LCAs that simply assume one-for-one displacement will overestimate the so-called "displacement credit". Ideally, one would use an economic model to determine the effect of co-products on their markets and the extent to which co-products displace other production. No LCA has such an economic model built into it, although LEM does have a single parameter that is meant to account for these market-mediated impacts of co-products (Delucchi, 2003).

The same issue of joint production arises in petroleum refineries. A refinery turns crude oil into a broad slate of products, including numerous fuel products, petrochemicals and asphalt. A change in demand for one product, such as gasoline, can affect the production and price of other products. One needs a model of refinery production costs and demand for all refinery products to estimate the equilibrium changes in output and consumption, and finally emissions. No current generation LCA models incorporate this kind of analysis.

2.2.2 Land-use change

Among the most important market-mediated effects of expanded biofuel production is land-use change. An increase in the price of oil or a change in policy could result in expanded crop-based biofuel production, thereby displacing native ecosystems, existing agricultural production, or set-aside land. Changes in land use and vegetation can change physical parameters, such as albedo (reflectivity), evapo-transpiration, and fluxes of sensible and latent heat, that directly affect the absorption and disposition of energy at the surface of the earth, and thereby affect local and regional temperatures [Marland, Pielke *et al*. (2003); Feddema, Oleson *et al.* (2005)]. Some of these effects are more important regionally than globally, while global changes result in changes in carbon stocks (in the soil and biomass) as well as in N_2O and CH_4 emissions. The latter are not necessarily from land-use "change", but result from fertilizer use and other forms of human managed land management (use). In addition, the replacement of native vegetation with biofuel feedstocks and the subsequent cultivation of the biomass can also significantly change the amount of carbon stored in biomass and soils, and thereby significantly change the amount of CO_2 removed from or emitted to the atmosphere, compared with the assumed baseline.

By producing biofuels on a given plot of land, the demand for the product of the alternative land use is no longer met and over time new production would be required to meet at least some of that demand (prices will presumably increase, reducing consumption to some degree, although this effect is expected to be small because demand for food ultimately is very inelastic). This "displaced production" could lead to GHG emissions or other environmental impacts elsewhere, such as soil erosion or deforestation. Most current fuel life-cycle models ignore (or treat too simply) changes in land-use-related biomass grown to make biofuels. An exception is LEM, which does have a detailed treatment of the climate impact of changes in carbon sequestration due to changes in land use (Delucchi, 2003, 2006).

Although there is wide consensus that these effects may be important, there is no well-accepted method for calculating the magnitude of these effects. Delucchi (2003, 2006) has proposed a method which estimates the present value of carbon emissions from land-use change over the life of a biofuels programme, but neither this nor any other method has been adopted by others.

2.2.3 Climate impacts of emissions

A critical area for further refinement of the models, and development of new analytic approaches is that of the impacts of other pollutants, as well as the choice of not only the Global Warming Potentials used for specific gases, but also the analysis of non-constant carbon emission factors, based on the dynamics of biofuel production, refining and fuel end-use. Most fuel LCAs, for example, consider only three GHGs (CO_2, CH_4 and N_2O) and use the Global Warming Potentials (GWPs) developed by the IPCC to convert non-CO_2 GHGs into CO_2 equivalents. The IPCC GWPs equate gases on the basis of their radiative forcing over a 100-year period, assuming an exponential decay of the gases (with multiple decay functions in the case of CO_2).

However, all air emissions, including CO, VOCs, NOx, SOx, NH_3 and aerosols, affect climate. LEM (Delucchi, 2003, 2003a, 2006) includes a treatment of the climate impact of a significant range of air emissions.

Moreover, the black-carbon (BC) component of aerosols has a very strong global warming effect (Menon, Hansen *et al.*, 2002), and diesel engines are major sources of BC emissions. Very few LCAs include BC; with Delucchi (2003a, 2006) and Colella *et al.* (2005) being recent exceptions. Stringent, health-based emissions standards for black carbon are now being implemented in the United States and Europe, but such standards do not exist (or are not enforced) in many other countries. This suggests that while BC emissions may become less important in some places in the future, they may be very significant elsewhere.

Not all LCA models treat emissions the same, even when they are included. For instance, GREET does not include N_2O emissions from atmospheric nitrogen fixed by soybeans, while LEM does, contributing to an almost order-of-magnitude greater estimate of GWI for soybean biodiesel (Delucchi, 2006).

2.2.4 Uncertain and variable data

In practice, *all* of the values entering into a life-cycle GHG emissions calculation are uncertain. The emissions factors are generally more uncertain, as they usually represent a temporally- or spatially-varying natural process, or are the result of an earlier LCA. Unfortunately, in many cases there are so few real emissions data that we may only know emissions to within a factor of two. For example, nitrous oxide emissions from vehicles might contribute as little as 3% or as much as 10% of simple, first-order fuel-cycle emissions. Field-monitoring studies are needed to validate not only current and future LCA models, but in the long-run, the GHG labels associated with fuels, such as will be needed in California and other locations that adopt Low Carbon Fuel Standards [Arons *et al.* (2007); Brandt *et al.* (2007)].

Usage rates for process inputs can also be highly uncertain, particularly in assessments of average impacts, such as the average GWI of ethanol produced in the US, which averages across a heterogeneous mix of facilities that use a variety of fuels at differing efficiencies. In many cases, input usage rates are based on unaudited, self-reported values from a self-selected subset of companies engaged in a given practice. Statistically meaningful probability distributions cannot be derived from these data (especially if our goal is to predict *future* fuel use, a point we will take up later). In other cases, input usage rates are inferred from related statistics. For example, on-farm energy use is not tracked in USDA statistical surveys of crop production; rather, energy use is estimated from expenditures on fuels, based on assumptions about average fuel prices. Exactly how this process biases the resulting estimates is not clear.

An often poorly characterised source of emissions is the change in carbon sequestration in biomass and soils as a result of changes in land use related to the establishment of biomass used as a feedstock for biofuels. Generic data on the carbon contents of soils and plants are available, but there can be much variation about these generic means from site to site. The uncertainty inherent in carbon-storage factors related to land use can change life-cycle CO_2-equivalent emissions by several percentage points.

If the probability distributions for each of the usage rates and emissions factors and the correlations among them were well-defined, we could use standard statistical methods or Monte Carlo simulation to propagate uncertainty through the life-cycle assessment model to understand the overall uncertainty of the result. However, in practice, many of the probability distributions are not known. Moreover, even if we had a complete and accurate sampling of current practice, say, with regard to fuel use at ethanol facilities, we could not readily use this information to predict future practice (i.e. fuel use at future ethanol facilities). In order to meaningfully apply probability distributions to the question of what will happen in the future, we have to build a model that has parameters (such as fuel costs) that themselves can be meaningfully characterised by objective probability distributions, and this does not now seem possible. What might be feasible, however, would be an investigation into the sensitivity of the LCA methods to uncertainty in various parameters, in order to better understand the climate impacts of various transportation fuels. However, standard Monte Carlo techniques (and similar analyses) are unlikely to be useful at the current time.

2.3 Analytic approaches to modelling land-use change

Land-use change has both local and global impacts. Further complicating the situation is that some land-use changes associated with bioenergy crop production are direct and others are indirect. For example, conversion from soybean to corn ethanol production in the US (direct change) will increase pressure to grow soybeans for food in the Amazon (indirect change) by an unknown amount. However, there is little data about indirect land-use conversion effects, nor an agreed-upon approach to deal with them [Delucchi (2004, 2006); Tilman, Hill *et al*. (2006); Mathews (2007)].

Land-use conversion effects associated with biofuel production are potentially significant, for both direct conversion for biofuel production and indirect effects mediated through commodity and land markets. Accurately including all of the indirect land-use changes associated with biofuel production would be very difficult. Between enormous data gaps, model uncertainty, deep uncertainties about future policies and prices, etc., the value of this exercise *as a prediction of a GWI that is meaningful in a regulatory context* may be questionable.

Furthermore, excluding global land-use conversion effectively assigns a zero value to this effect, which we know to be a poor estimate. Instead, a policy-motivated LCFS could include a rough estimate of the portion of emissions from global land-use conversion that is potentially attributable to crop-derived biofuels. While rough, such an estimate would send the correct signal about biofuels pathways that involve land-use conversion.

As illustrated by the analysis in the LEM model, changes in carbon stocks related to deforestation and soil degradation are probably the most important factor associated with land-use conversion affecting the global climate (Delucchi, 2006). Estimates of the carbon emissions associated with global land-use conversion exist in the literature on terrestrial carbon balances [Houghton (1999); Potter (1999); Schimel, House *et al.* (2001); Houghton (2003)]. Globally, the terrestrial ecosystem is a net sink for carbon (Schimel, House *et al.*, 2001). However, land-use conversion is estimated to have contributed between 0.6 and 2.5 gigatons of carbon annually (Gt C / yr) during the 1980s and between 0.8 and 2.4 gigatons of carbon annually (Gt C / yr) during the 1990s (Schimel, House *et al.*, 2001). Because such estimates often rely on bottom-up aggregations of data on specific land-use conversions, the particular contribution of crop-related land-use conversions can be estimated. One such study attributes about 1.3 gigatons of carbon annually to crop-related land-use conversion during the 1980s (Houghton, 1999). Table 1 provides illustrative estimates that allow us to calculate emissions from land use.

Table 1. **Illustrative land-use change calculations for various feedstocks**

	Ethanol		
Feedstock (g CO_2e/kg)	**Corn**	**Grass**	**Wood**
Soil	96	48	45
Biomass	4	5	-31
Total	100	54	14
Fuel yield (L/Mg)	83	70	67
Energy content (MJ/L, HHV)	24	24	24
Emissions (g CO_2e/MJ)	51	32	9
Where we use 60 lbs/bushel for soy, 56 for corn, and 948.452 BTU/MJ			

The simple approach presented above yields values that push the GWI of most domestic crop-based biofuels above the GWI of gasoline. Although any attempt to calculate such values will be uncertain and open to debate, assigning zero emissions for global land-use change clearly underestimates the effect. Hence, we believe a precautionary stance of assigning a non-zero value is appropriate because of the importance of providing signals and incentives to steer innovation and investment.

While inclusion of a simple land-use conversion factor in biofuel GHG calculations used to label or regulate biofuels will yield more appropriate weightings between crop-based biofuels and other fuels, such regulation may not be the most appropriate mechanism to influence climatic change associated with land-use conversion. Biofuel production is only a small portion of global land use (<5%), but as this percentage will increase it will have an increasing influence on the entire land-use system. Many of these changes will be indirect. A comprehensive regulatory scheme on land-use change and climate change, operating independently of fuel-centred regulation, would minimise the negative climate effects associated with land use. However, no such regulation exists, and significant barriers may prevent implementing such regulations on a global scale.

If global efforts to curb deforestation and control climatic forcings associated with land-use conversion are successful, the land-use conversion charge outlined above will diminish. If, on the other hand, crop-based biofuels and a growing demand to feed a larger and more affluent global population increases pressure on forest and soil resources, then the land-use conversion charge would increase. This charge should be updated periodically to reflect current conditions, though in practice, updates may be limited by data availability. The need to update these values as markets evolve creates some degree of unavoidable regulatory uncertainty, though the magnitude of the change for each update should stabilise after agreement has been reached on an appropriate methodology.

3. IMPACTS OF LAND CONVERSION: AN INITIAL FRAMEWORK

What happens to carbon emissions from soil and biomass due to land-use changes related to actions involving a particular biofuel or biofuel feedstock (e.g. corn ethanol)? A useful quantity that provides an answer to this question is grammes of CO_2-equivalent emissions from land-use change per BTU of biofuel produced. This quantity can be estimated as follows:

$$FLUCE_F = FEA_F \cdot \sum_L LUCE_{L \to L^*} \cdot LUC_{F:L \to L^*}$$

where:

$FLUCE_F$ =	Land-use change emissions due to production of biofuel *F* (grammes CO_2-equivalent emissions per BTU of fuel *F* produced);
FEA_F =	Areal energy production rate of biofuel *F* (BTUs of *F* produced per acre of land upon which the biomass feedstock for *F* is grown);
$LUCE_{L \to L^*}$ =	Emissions per acre of land changed from type *L* to type *L** (grammes CO_2-equivalent emissions per acre of land so changed);
$LUC_{F:L \to L^*}$ =	fraction of an acre of land changed from type *L* to type *L** per acre of land upon which the biomass feedstock for *F* is grown;
subscript L =	land-use categories (e.g. tropical forest, temperate grassland).

The areal energy production rate, FEA, is reasonably well known. Data are available to estimate C emissions from soil and biomass due to land-use change for different types of land use (parameter LUCE), although there is a great deal of variability in the data pertaining to generic land-use types, on account of variability in climate, topography, soil characteristics, management techniques, and other factors that determine C sequestration and emissions. However, there is considerable difficulty in estimating how land uses change (parameter LUC), and it is on this parameter that we will focus.

Because it is likely that the set of values for LUC_F depend not only on the particular fuel *F* but also on the particular policy or action by which *F* is brought into production, it would be ideal to estimate LUC_F using a sophisticated model that includes detailed representations of agricultural economics, land uses, policies, trade and other aspects. Models of this sort exist, and recently have been applied to precisely this question (see www.biofuelassessment.dtu.dk/). However, one reasonably may doubt that these models are yet sophisticated enough to provide reliable estimates of land-use changes related to biofuel production, given the complexity of global policies and markets for agriculture, energy and land. If this is the case, one may propose simpler methods for estimating the relevant parameters in the equation given above, so long as the methods account for all of the relevant effects and emissions and are meant to represent reality, even if in a simplified way.

Thus, rather than attempt to actually model how specific land uses will change as a result of crop-specific policies, one may claim that because of the global interconnectedness of land and agricultural markets, it is likely that future crop-specific values do not deviate much from historical all-crop global averages. One can then use historical data to estimate global average values for LUCE and perhaps

LUC, for all biomass (crops) and land-use types. For example, Houghton and Hackler (2001) provide estimates of emissions from land-use change by type of change, and of historical changes in land use by land-use type. With these data, one can calculate a global, all-land-uses average per-acre emission rate from land-use change (parameter LUCE).

However, the calculation of a global all-crop, all-land-uses average value for LUC (acres of land changed per acre of land brought into production) is not necessarily straightforward. In the following, we use an example to illustrate the interpretation and possible range of this parameter.

A farmer owns 11 acres of land. In the "no-biofuels" base case, one acre is uncultivated grassland and 10 acres are planted with corn at 100 bushels per acre, thus providing 1 000 bushels to the market. In the biofuels scenario, the new demand for corn from a new biofuels plant causes the price of corn to rise, and the farmer contracts to provide an additional 100 bushels of corn per year to the new ethanol facility, while still supplying 1 000 bushels to the non-biofuels market. Ignoring for now the effect of higher prices on corn demand, the farmer's range of choices in this biofuels scenario is defined by two bounds. First, he can simply grow the additional 100 bushels on what would have been his uncultivated acre of grassland (his 11^{th} acre). In this case, the acre and 100 bushels of corn produced for the biofuels market has caused one acre of land-use change – the cultivation of the grassland – and LUC (acres of land use changed per acre of land brought into production to supply the biofuels market) therefore is 1.0.

However, at the other bound, the farmer can leave the grassland alone, and – specifically because of the *increase* in corn price – decide it is now worthwhile to spend the extra money needed to increase yield to 110 bushels per acre on the 10 acres (by applying more fertilizer or water, for instance) rather than cultivate the 11^{th} acre (grassland) at 100 bushels/acre. In this scenario, he nominally uses 0.91 acres for the 100 bushels grown for the biofuels market, and the remaining 9.1 acres to supply the other 1 000 bushels to the market. In this case then, the 0.91 acres and 100 bushels of corn produced for biofuels have not resulted in *any* land-use change (apart from the impacts of intensification *per se*), and LUC therefore is zero. Of course, the farmer may choose to do something in between.

Two points are important here. First, the yield increase in the second example must be due specifically to the increased demand for and price of corn, and not part of an ongoing increase in yields in the base case due to ongoing research and development and competitive pressure to increase outputs.

Second, our example so far does not account for the effect of price changes on demand. It may be, for example, that because of the higher price of corn, the farmer can sell only 990 bushels to the non-biofuels market, versus 1 000 bushels in the no-biofuels base case. In this case, the farmer can use the now idled 0.1 of the 10 acres to produce 10 bushels of corn for the biofuels market, and then cultivate 0.9 of the 11^{th} acre of grassland to produce the other 90 bushels of corn for the biofuels market. In this case, one acre of corn for ethanol brings into cultivation 0.9 acres of grassland, and LUC on account of this factor is 0.9/1.0 = 0.9.

As mentioned above, the inelasticity of demand for food suggests that the price-effect element of LUC (whereby higher prices due to biofuel demand suppress consumption in non-biofuels markets) is not likely to be significant. However, the yield intensification effect, whereby higher prices spur additional (beyond-baseline) increases in yield, is unknown. [For more discussion of the yield intensification effect, see Kløverpris *et al*. (2007).]

It is not clear if there is a simple way to estimate an all-crop, historical average value for LUC. The basic difficulty is that LUC depends ultimately on supply and demand functions, whereas what we observe are changes in consumption and production and changes in price. However, it may be possible to make serviceable estimates of LUC, based on inferences from observed consumption and price changes, without having to do general equilibrium modelling. More work in this area is needed.

Finally, we note two closely related, important methodological issues buried in the estimation of the parameter LUCE in the equation above. First, the period over which fuel production from an acre of land occurs is not the same as the period over which emissions from land-use change occur. Second, whereas the annual fuel production from an acre can reasonably be assumed to be constant, annual emissions from land-use change are not. One must make some transformations of one or the other stream in order to properly divide the emissions stream by the fuel production stream. Delucchi (2003) uses an annualization/present-value method to do this, but other methods may be possible.

4. A COMPARISON OF RECENT BIOFUEL ANALYSES

The literature on biofuel LCAs contains conflicting studies; in addition, published studies often employ differing units and system boundaries, making comparisons across studies difficult. As an example, we present in this section a comparison of six papers that evaluate the same biofuel production pathway, US corn ethanol (Farrell *et al*., 2006). These studies all use current-generation LCA methods, and so ignore or treat poorly many important issues. Nonetheless, it is still useful to compare them to illustrate how such different results can come about.

The ERG Biofuel Analysis Meta-Model (EBAMM, available online at http://rael.berkeley.edu/ebamm) is a relatively simple, transparent tool for the comparison of biofuel production processes. EBAMM is available for free download and use. We used EBAMM to compare six published articles that illustrate the range of assumptions and data found for one biofuel, corn-based ethanol [Wang (2001); Graboski (2002); Patzek (2004); Shapouri, Duffield *et al.* (2004); Dias de Oliveira, Vaughan *et al.* (2005); Pimentel and Patzek (2005)]. Although the six articles have rather divergent results, the fundamental structure of their analyses is virtually identical. However, EBAMM is designed only to evaluate these six studies and thus ignores or treats poorly issues that these studies have ignored or treated poorly, in particular, land-use change and end-use technologies.

In addition, each study sheet calculates the coal, natural gas and petroleum energy consumed at each stage of production. This permits us to estimate the total primary energy required to produce ethanol. Similar calculations are performed in the study worksheets for net GHG emissions. These results are summarised in worksheets labelled “Petroleum” and “GHGs”, respectively.

The *Cellulosic* case presented here is a preliminary estimate of a rapidly evolving technology designed to highlight the dramatic reductions in GHG emissions anticipated; it should not be taken as a definitive representation of the potential of this technology. In addition, other biofuel technologies are in active development which are not addressed at all.

While the six studies compared here are very similar, each uses slightly different system boundaries. To make the results commensurate, we adjusted all the studies so that they conformed to a consistent system boundary. Two parameters – caloric intake of farm workers and farm worker transportation – were deemed outside the system boundaries and were thus set to zero in the adjusted versions. (These factors are very small and the qualitative results would not change if they were included.) Six parameters were added if not reported: embodied energy in farm machinery, inputs packaging, embodied energy in capital equipment, process water, effluent restoration, and co-product credit. Typical co-products include dried distillers’ grains with solubles, corn gluten feed and corn oil, which add value to ethanol production equivalent to USD 0.10-USD 0.40 per litre of corn ethanol.

Two of the six studies stand out from the others because they report negative net energy values, and imply relatively high GHG emissions and petroleum inputs [Patzek (2004); Pimentel and Patzek (2005)]. The close evaluation required to replicate the net energy results showed that these two studies also stand apart from the others, by assuming that ethanol co-products (materials inevitably generated when ethanol is made, such as dried distillers’ grains with solubles, corn gluten feed and corn oil) should not be credited with any of the input energy as a rough approximation of the impacts of soil erosion, and by including some input data that is old and unrepresentative of current processes, or so poorly documented that its quality cannot be evaluated [see Tables S2 and S3 in the Supplemental Online Material for Farrell *et al.* (2006), found at http://rael.berkeley.edu/ebamm].

Sensitivity analyses with EBAMM and elsewhere show that net energy calculations are most sensitive to assumptions about co-product allocation (Kim and Dale, 2002). Co-products of ethanol have positive economic value and displace competing products that require energy to make. Therefore, increases in corn ethanol production to meet the requirements of EPACT 2005 will lead to more co-products that displace whole corn and soybean meal in animal feed, and the energy thereby saved partly offsets the energy required for ethanol production [Delucchi (2004); Food and Agricultural Policy Research Institute (2005)].

Producing one MJ of ethanol – for all pathways considered – requires far less petroleum than is required to produce one MJ of gasoline (Figure 4). However, the GHG metric illustrates that the environmental performance of ethanol varies greatly depending on production processes. However, single-factor metrics may be poor guides for policy. Using the petroleum intensity metric, the *Ethanol Today* case would be slightly preferred over the *Cellulosic* case (a petroleum input ratio of 0.06 compared to 0.08); however, the *Ethanol Today* case results in greater GHG emissions than does *Cellulosic* (77 compared to 11), though both pathways have lower GHG emissions than gasoline. Indirect land-use conversion tends to increase this disparity because it is more likely to apply to corn-based ethanol than to cellulosic ethanol (especially if wastes or residues are used as the cellulosic feedstock).

Figure 4a) **Net energy and net greenhouse gases for gasoline - six studies and three cases**

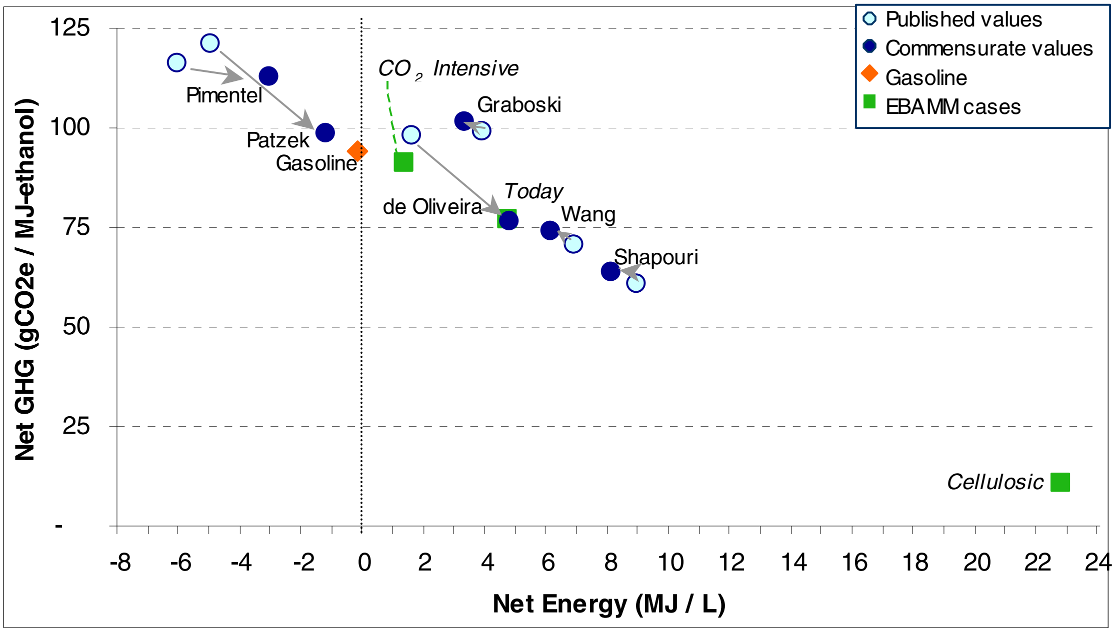
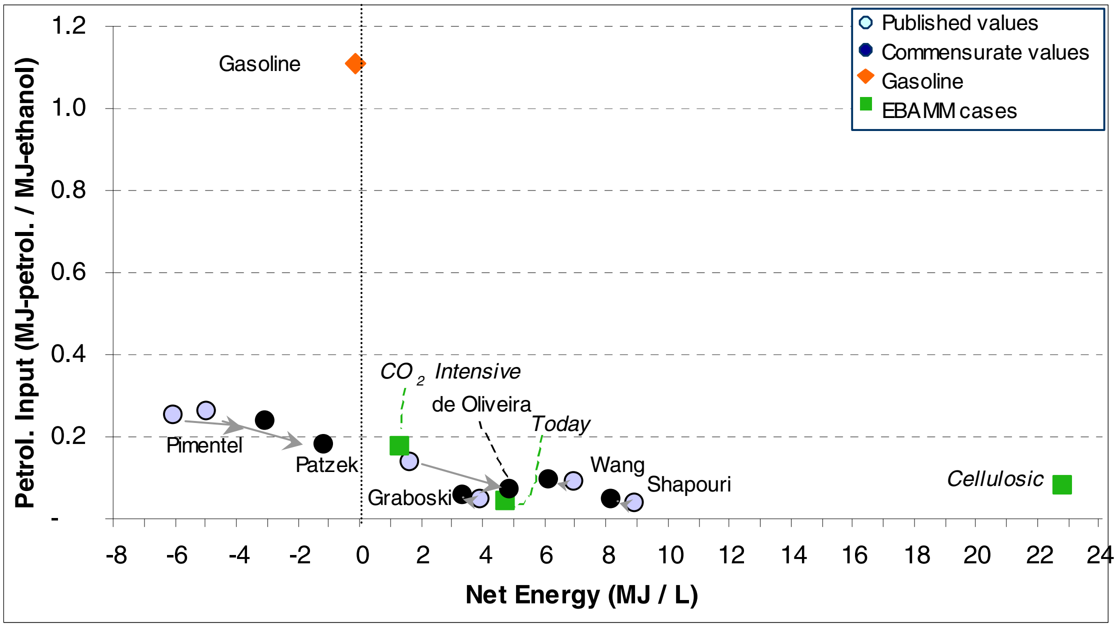


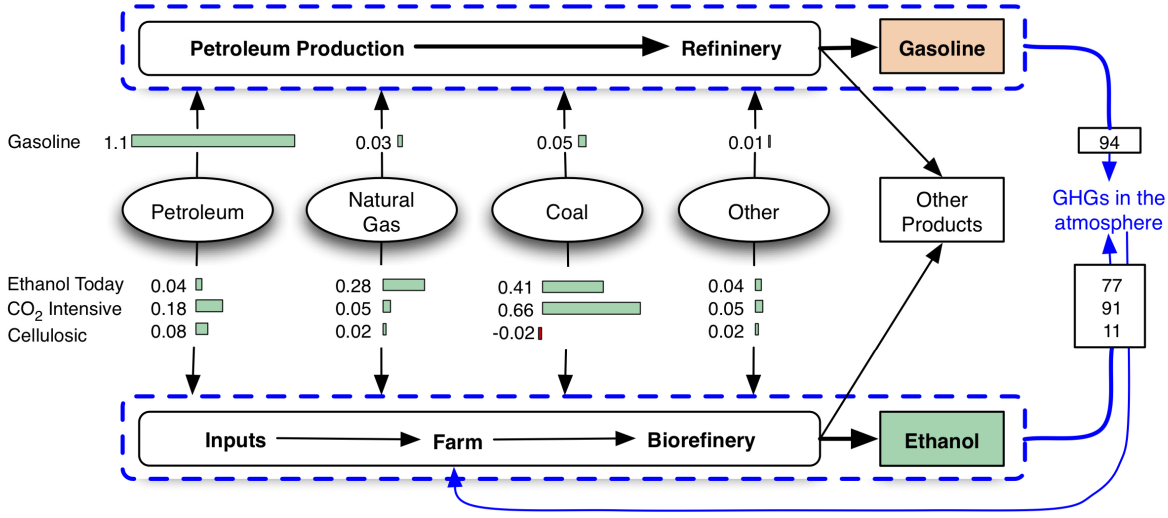
Figure 4b) **Net energy and petroleum inputs for the same**



Note: In these figures, hollow triangles are reported data that include incommensurate assumptions, while solid triangles are adjusted values that use identical system boundaries. Conventional Gasoline is shown as orange circles and *EBAMM Scenarios* are shown as green squares. Indirect GHG emissions due to land-use change are not included in these calculations, and could increase corn-based ethanol emissions significantly.

Source: Farrell *et al*. (2006).

Figure 5. **Alternative metrics for evaluating ethanol based on the intensity of primary energy inputs (MJ) per MJ of fuel and of net greenhouse gas emissions (kgCO_2-equivalent) per MJ of fuel**



Note: For gasoline both petroleum feedstock and petroleum energy inputs are included. "Other" includes nuclear and hydro electricity generation. Relative to gasoline, ethanol produced today is much less petroleum intensive, but much more natural gas and coal intensive. Production of ethanol from lignite-fired biorefineries located far from where the corn is grown results in ethanol with a high coal intensity and a moderate petroleum intensity. Cellulosic ethanol is expected to have an extremely low intensity for all fossil fuels and a slightly negative coal intensity due to electricity sales that would displace coal. Indirect GHG emissions due to land-use change are not included in these calculations, and could increase corn-based ethanol emissions significantly.

Source: Farrell *et al.* (2006).

GHG emissions due to indirect land-use change are assigned to those biofuels produced from feedstocks grown on arable land that competes for food production. These preliminary and primarily illustrative values are shown in Table 1 above. By considering indirect land use in this way, ethanol produced from corn in a coal-fired dry mill has *higher* GHG emissions than gasoline. The "Low Input Biofuel" under consideration is E85, containing ethanol produced from a mixed prairie grass system, described by Tilman *et al.* (2006). The large negative GHG emissions in this case are based on the assumption that grasses requiring very little input (e.g. fertilizer) are grown on degraded lands that are unsuitable for food production.

In this case, carbon is stored by the grasses in their roots and in the soil. This carbon can be sequestered in this way for long periods of time, but is vulnerable to release should that land ever be turned over to conventional agriculture. This technology is not yet proven and is somewhat controversial. It also has relatively low yield per unit area, because the inputs are so low; however, the amount of degraded land available for such cultivation may be large. It should be noted though that the benefits of this scenario derive from the presumption that the degraded land would otherwise have remained degraded. This is not necessarily a reasonable assumption, because it is always possible to actively restore degraded land to some other "natural" state that stores even more carbon than does a managed, mixed prairie grass system[2]. In any event, studies into the technical and commercial feasibility of this approach, and its potential application in ways that would not place additional pressure for the conversion of natural ecosystems to biofuel crops, form a very important area of research.

Note that carbon storage in roots and soil may also be feasible for other biomass production systems, including possibly switchgrass (*Panicum virgatum*) and miscanthus (*Miscanthus x giganteus*). These species may be more productive than collections of prairie grasses, and therefore may be more profitable than the system proposed by Tilman *et al.* (2006), while still having very good GHG profiles. There are currently significant biotechnology research and development efforts underway to improve such species, potentially setting up a competition between semi-natural biofuel production and production through the large-scale cultivation of genetically modified monocrops. Understanding how to evaluate the relative costs and benefits of such systems is also an important research task.

Note also that the only differences between the two corn-based ethanol cases depicted are in biomass processing; all the other stages are identical in the two cases. A better understanding of the range of potential GHG emissions associated with feedstock production, and perhaps reductions in these emissions, might show even greater variation.

5. BIOFUEL MARKET DEVELOPMENT

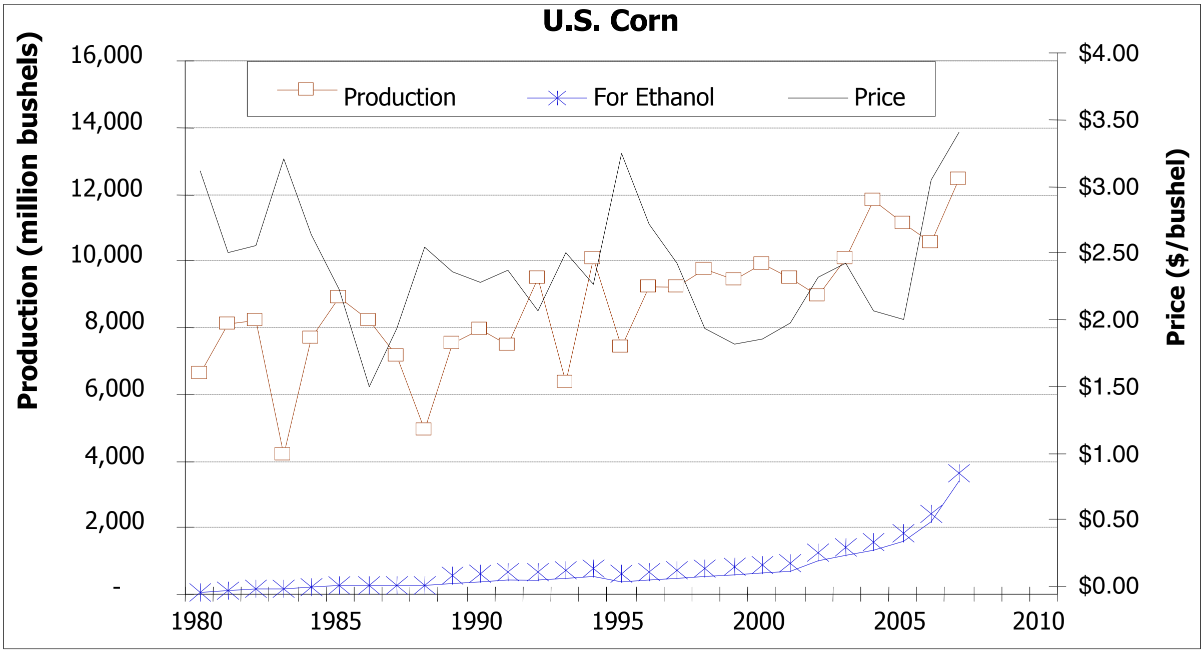
Growth of global demand for biofuels (Figure 1) has so far resulted in large increases in the scale of production of ethanol and FAME biodiesel. One indicator of the magnitude of this increase in demand for biofuels is its impact on prices in large, established agricultural commodity markets. Consider as an example, changes in US corn markets during the development of the ethanol industry (Figure 6). Since 1980, average corn prices in the United States have exceeded three dollars per bushel only five times, including 2006 and the forecast for this year. Note that in the three prior cases—in 1980, 1983 and 1995—high prices for corn accompanied substantial declines in production. In contrast, in 2006 and 2007 (forecast) high production is expected to accompany high prices. Indeed, both average corn prices and total corn production for 2007 are forecasted to set new records. The additional demand for corn by ethanol producers is raising corn prices because the incremental corn production involves higher production costs due to increased competition with other uses for land, expansion to less productive land, and the need to employ more expensive production methods. Because corn is a globally traded commodity and the corn market affects other agricultural commodities, such as sugar and animal feed, high prices for corn will tend to increase the prices for other crops. Over the last several years, the increased demand for corn by ethanol producers has risen faster than total US corn production, contributing to a decline in corn exports and an increase in the cost of animal feed.

Demand for ethanol feedstock has greatly exceeded expectations. The United States Department of Agriculture's Economic Research Service reports that corn acreage for 2007 increased by 11% to 87 million acres. Only two years ago the *high* forecast for 2008 acreage was less than this total. Many recent forecasts for US ethanol include a *doubling* of production over the next 4 to 6 years. The US Department of Agriculture's central case forecast is typical:

> Corn used to produce ethanol in the United States continues strong expansion through 2009-10, with slower growth in subsequent years. By the end of the projections, ethanol production exceeds 12 billion gallons per year, using more than 4.3 billion bushels of corn. The projected large increase in ethanol production reflects the Energy Policy Act of 2005, the elimination of use of MTBE as a gasoline additive, ongoing ethanol plant construction, and economic incentives provided by continued high oil prices (US Department of Agriculture, 2007).

These forecasts run significantly in excess of the mandated levels of 7.5 billion gallons by 2012, as required by the Renewable Fuel Program of the US Energy Policy Act of 2005. This anticipated overshooting of the target indicates that some combination of expectations about future oil prices and the fuel additive requirements is the primary driver of growth.

Figure 6. **US corn production (left scale) and prices (right scale)**



Source: US Department of Agriculture, http://www.ers.usda.gov/data/feedgrains/FeedGrainsQueriable.aspx

This rapid growth in output using current ethanol production technologies is unlikely to continue over the longer term, due to the rapid development of biofuels with superior properties, and very significant concerns about the cost and environmental implications of current biofuel feedstock production (Biofuelwatch, 2007). It is not clear how biofuel markets will develop after 2010, but a framework for assessing the potential biofuel output, greenhouse gas impacts, land-use changes and socioeconomic impacts, will be required to assess the costs and benefits of the wide range of biofuel strategies that will be proposed and considered in the coming years.

In the last few years, a range of funding mechanisms has emerged to advance science and develop technologies that would significantly impact the biofuel feedstocks and pathways that are available to the market. These new investments are notable on several dimensions. First, they involve substantial funds – hundreds of millions of dollars – that dwarf earlier programmes. Second, each investor has committed to a long-term programme: time horizons for funding are in the 5 to 10-year range. Third, both the private and public sectors are committing these funds. Furthermore, and crucially in terms of who is performing the research, the parties involved in each initiative have established linkages among multiple universities and government laboratories, as well as both mature and entrepreneurial firms at the outset. The involvement of this diverse set of actors is promising because it addresses obstacles to the transfer of technical knowledge in the innovation process, from early-stage research to commercial products.

6. THE RETURNS ON RESEARCH AND DEVELOPMENT: EXAMPLES OF PAST EFFORTS

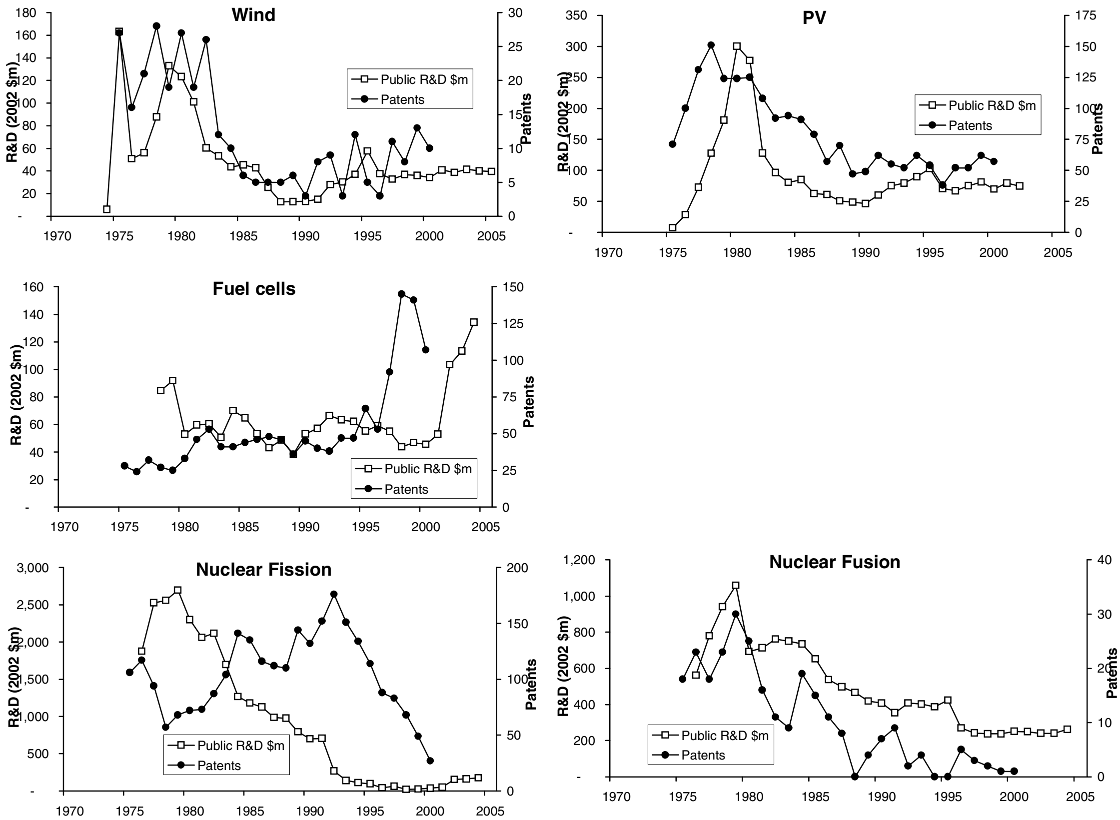
The potential for initiatives like these – and the others that are springing up, and will spring up globally – to make important, promising, and probably also challenging innovations in the entire pathway from laboratory-based crop design, to biofuel agronomy, to feedstock handling, to fuel production and infrastructure design, is significant. Figure 7 documents the research and development spending history, and the patenting levels, in five energy areas over the past forty years (Kammen and Nemet, 2005). In four of the five areas, funding and patenting are highly correlated, and in the fifth, nuclear fission, a correlation exists but the effective moratorium on reactor construction in the United States has likely led to some distortions in the technological evolution of the field.

The recent dramatic increase in interest in the biofuel sector – including dramatic increases in production of ethanol (Farrell, *et al.,* 2006) – as well as significant private sector interest in a diverse range of biofuels, provides a call for analysis similar to Figure 7 in the biofuel area. Previous studies (e.g. Evenson and Waggoner, 1979) have shown a strong relationship between effort – both funding and market opportunity, and innovation in the biofuel sector. Unlike our previous work in energy, where few public sector funding avenues exist (e.g. primarily the US Department of Energy), multiple funding sources may exist for biofuel/bioproducts research, and we consider this note to be a first pass, not suitable yet for policy use, as has been made of our prior work (Margolis and Kammen, 1999; Kammen and Nemet, 2005). Our goal is to begin the assessment here, and to examine next possible other funding sources, patenting/implementation uses of the sources of support in order to draw a clearer picture of what we might expect from dramatic increases in biofuel development and deployment.

As an example of a private-sector funded initiative, the University of California Berkeley, along with partners, the Lawrence Berkeley National Laboratory and the University of Illinois at Urbana Champaign, have formed the Energy Biosciences Institute (http://www.ebiweb.org/). EBI is supported by a 10-year, USD 500 million commitment from BP, and is envisioned to focus on a wide range of biofuel analysis and production pathways, with the fast-growing C4 plant, *Miscanthus Giganticus* (elephant grass) seen as a promising initial crop for investigation.

In the public sector, the US Department of Energy has committed USD 375m over five years to establish three “Bioenergy Research Centres”. Based at the Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory and the University of Wisconsin, the centres will engage in research on cellulosic ethanol and other biofuels as part of the federal goal to reduce US gasoline consumption by 20% within 10 years.

Figure 7. **Patenting provides a measure of the outcomes of the innovation process**



Note: We use records of successful U.S. patent applications as a proxy for the intensity of innovative activity and find strong correlations between public R&D and patenting across a variety of energy technologies. Since the early 1980s, all three indicators—public sector R&D, private sector R&D, and patenting—exhibit consistently negative trends. The data include only U.S. patents issued to U.S. inventors. Patents are dated by their year of application to remove the effects of the lag between application and approval.

Source: Margolis and Kammen, 1999; Kammen and Nemet, 2005; Nemet and Kammen, 2007.

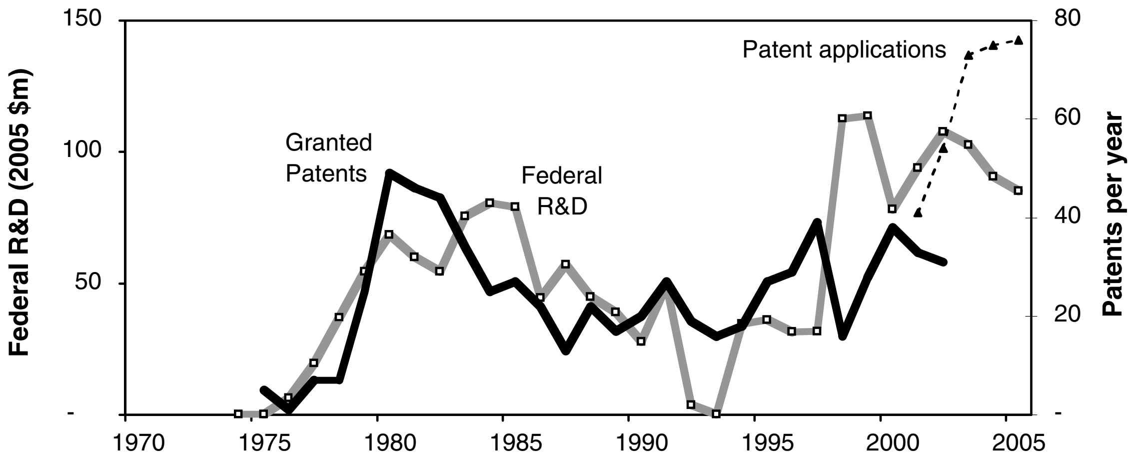
Among this group, the Joint Bioenergy Institute (JBEI) at Lawrence Berkeley Lab (http://jbei.lbl.gov) will focus its scientific effort in three key areas: feedstock production, deconstruction and fuels synthesis. JBEI will employ an opportunistic "start-up company" approach, partnering with industry, to develop new science and technologies that address the most challenging steps in industrial bioenergy processing. Crosscutting technologies in computational tools, systems and synthetic biology tools, and advanced imaging will be applied in a multi-pronged approach for biomass-to-biofuel solutions, in addition to discovery-driven benefits for biohydrogen research, solar-to-fuel initiatives and broader DOE programmes.

The venture capital industry, which typically expects a financial return after three to seven years, has recently begun to invest heavily in entrepreneurial biofuels firms. In aggregate, the industry invested over USD 800m in biofuels companies in 2006, after investing only USD 20m in 2005, and less than a million dollars in 2004 (Makower and Pernick, *et al*., 2007).

Investments like these have great potential to generate important innovations in the entire pathway from laboratory-based crop design, to biofuel agronomy, to feedstock handling, to fuel production and infrastructure design.

While these large, long-term and collaborative investments are encouraging, they still only represent an input to the innovation process. Ultimately, the benefits of improved biofuels to the agricultural sector, environmental quality, and petroleum import reduction will depend on the effectiveness of the outputs of these efforts. Previous studies (e.g. Evenson and Waggoner, 1979) have shown a strong relationship between effort – both funding and market opportunity – and innovation outputs in the biofuels sector. Similarly, other work has found a strong link between R&D investment and innovation, as measured by patenting activity (Margolis and Kammen, 1999; Kammen and Nemet, 2005). With the diverse variety of new funding sources that has emerged in only the past 12 months and the array of devices and processes involved in the production of biofuels that is described above, measurement is less straightforward. Still, at a first glance, the relationship between investment and output in biofuels appears well correlated over the past three decades. We compared patenting activity in the field of bio-energy[3] to federal R&D investment (Figure 8). While there is year-to-year volatility in patenting activity, the general trend in patenting activity appears to be well correlated with that of federal R&D spending. This analysis represents a preliminary assessment. Subsequently, we will examine the wider spectrum of funding sources which has only emerged recently, as well as the characteristics of how these sources are used and how the outcomes are patented to draw a clearer picture of what we might expect from dramatic increases in biofuel development and deployment.

Figure 8. **A preliminary assessment of US bio-energy patents and federal R&D**



Note: The black solid line shows the number of patents that were ultimately granted by the year they were applied for (right axis). The dashed black line shows applications for patents in recent years (right axis). The grey line shows federal R&D funding (left axis).

While the number of patent search categories is significantly larger in the agricultural sector than in energy, we focused the patent searches on combinations of feedstock and fuel search strings. Using the US Patent and Trademark Office Bibliographic database as our data source (www.uspto.gov), we searched the abstracts of granted patents to capture the keywords: "biofuels", "biodiesel", "biomass gasification", "biomass energy", "ethanol for energy production", and "cellulosic ethanol" (Nemet, 2007; Nemet and Kammen, 2007; Nemet and Kammen, 2007a).

Already a number of new crops, including switchgrass, palm oil, cedar, willow and other fast-growing tree species, as well as municipal solid waste and algae, are being touted and explored as potential biofuel feedstocks. In addition, a wide range of output fuels are envisioned, in addition to the commonly cited examples of biodiesel and ethanol gasoline blends. In this rapidly evolving biofuel research and deployment field, a set of evaluation tools for both the potential return on research investment, as well as means to assess the energy benefits and greenhouse gas impacts of emerging fuels are critically needed.

7. CONCLUSIONS

The first, most obvious and most critical aspect of the biofuel economy today is that it is in dramatic flux and evolution. The existence and character of the global biofuel industry is strongly the result of policy interventions, motivated and justified largely as a means of agricultural support, but with increasing concern about environmental effects. These forces are not necessarily in alignment. If this situation persists, we are likely to see increasing tensions between policies, and problems developing in the valuation of biofuels versus other forms of energy sources, as well as over biofuels as they relate to land use, land spared for nature and the lives of the poor.

To address this clash of policies, views, economic valuations and environmental goals, a clear set of evaluation methodologies and high-quality, open access to data will be required. A vital first step is the design, public access and dialogue over the models and tools used to assess the impacts, costs and benefits of biofuels. Methodologically, several approaches now exist to examine the energy content and the greenhouse gas impact of biofuels. These approaches are already becoming policy tools through low-carbon fuel standards, and renewable fuel obligations (quotas). A vital next step is to evolve the models to not only reflect carbon, but also ecological and cultural sustainability for rich and poor countries and communities alike.

NOTES

1. In the context of biofuel LCAs, the displacement method was first clearly articulated and applied in Delucchi(1991, 1993), and has been applied most comprehensively in Graboski (2002) and Kim and Dale (2002).

2. In this vein, Marland and Schlamadinger (1995) have pointed out that "biofuels systems require a large resource commitment (land) and a greenhouse-gas assessment should consider the opportunity for using the land in other ways to minimize net greenhouse-gas emissions" (p. 1136).

3. Our definition of "bio-energy" includes the use of biological material to produce electricity and transportation fuels. The search terms used in the patents search reflect this definition.

ACKNOWLEDGEMENTS

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SUBSIDIES: THE DISTORTED ECONOMICS OF BIOFUELS

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ABBREVIATIONS AND ACRONYMS

2006$	US dollars at their year-2006 value
AoA	Agreement on Agriculture
ASCM	Agreement on Subsidies and Countervailing Measures
B20	A blend of 20% biodiesel and 80% petroleum diesel, by volume
B100	Pure biodiesel
CHF	Swiss franc
E5	A blend of 5% bio-ethanol and 95% gasoline (petrol), by volume
E10	A blend of 10% bio-ethanol and 90% gasoline (petrol), by volume
E85	A blend of 85% bio-ethanol and 15% gasoline (petrol), by volume
ETBE	Ethyl tertiary butyl ether
EU	European Union
GSI	Global Subsidies Initiative
HS	Harmonized Commodity Description and Coding System
IISD	International Institute for Sustainable Development
MTBE	Methyl tertiary butyl ether
OECD	Organisation for Economic Co-operation and Development
SVO	Straight vegetable oil
WCO	World Customs Organization
WTO	World Trade Organization

SUMMARY

Paris, May 2007

ABSTRACT

Governments have influenced the development of bio-energy, particularly liquid biofuels (ethanol, biodiesel and pure plant oil used as a fuel), for several decades. This paper discusses the economics of biofuels and provides an overview of current policy measures to support their production and consumption. It discusses also how the different policies supportive of biofuels interact with broader agricultural, energy, environmental and transport policies, and the relative effectiveness of biofuels in achieving objectives in these areas. The paper concludes with several observations and recommendations.

Keywords: *biofuels, ethanol, biodiesel, costs, subsidies, trade barriers.*

1. INTRODUCTION

As proponents of liquid biofuels frequently remind us, both ethanol and straight vegetable oil (SVO) were used as motor fuels at the dawn of the internal combustion engine, only to be supplanted within a few years by cheaper petroleum-derived gasoline and diesel (Dimitri and Effland, 2007). Biofuels have only started to emerge as serious rivals to those petroleum fuels within the last couple of decades, and particularly since 2003, when prices for a barrel of crude oil started rising above USD 30.

Currently, ethanol is being produced at a rate of around 60 billion litres a year worldwide, and the trajectory is sharply upward. Until recently, Brazil was the world's leading producer. In 2005, however, the United States and Brazil produced roughly equal amounts and in 2006 and 2007 the United States is expected to have moved into first position. India and several EU Member States are also important producers. The biodiesel industry emerged only in the 1990s, and the amounts produced, at around 5 billion litres a year in 2006, are still far below those of ethanol. But annual output through 2007 was growing at double-digit rates, with new countries joining the ranks of major producers every year.

These are not industries that have emerged simply in response to market forces, however. The production and demand for biofuels has been, and continues to be, shaped profoundly by government policies, both regulatory and directly financial.

Currently, the bulk of support to biofuels is linked to production, mainly through exemptions or rebates of fuel taxes that apply to gasoline and diesel, or (mainly in the United States), volumetric tax credits. Already the level of support enjoyed by the industry in OECD countries is of the order of US$10 billion a year in excise tax exemptions and income tax credits, for a pair of fuels that account for less than 3% of overall liquid transport fuel demand. Bringing that share to 30% – a level frequently suggested by proponents – without making radical changes to the current support system, and without substantially reducing demand, would imply annual subsidies of $100 billion a year or more, pushing them ever closer to the order of magnitude of support currently provided to the entire agricultural sector by OECD countries.

In order to assist policymakers in gaining a better understanding of the magnitude, direction and coherence of government policies supporting liquid biofuels, the Global Subsidies Initiative (GSI) – a new programme under the International Institute for Sustainable Development – embarked in 2006 on a series of studies on support policies in five OECD member countries, plus Brazil. The US study was released in October 2006, and the remainder are expected to be released in 2007 and 2008.

This paper highlights the main support elements documented in these studies, stressing the high number of policies that vary in proportion to output, or to sales. It then discusses some of the interlinkages between these policies and objectives in other policy domains affected by government support for biofuels.

2. OVERVIEW OF THE LIQUID BIOFUELS INDUSTRY

To understand the political economy of government support to biofuels, it is helpful to review the industry's ownership and cost structure. As background, this section begins with an overview of production by country.

2.1. Global overview

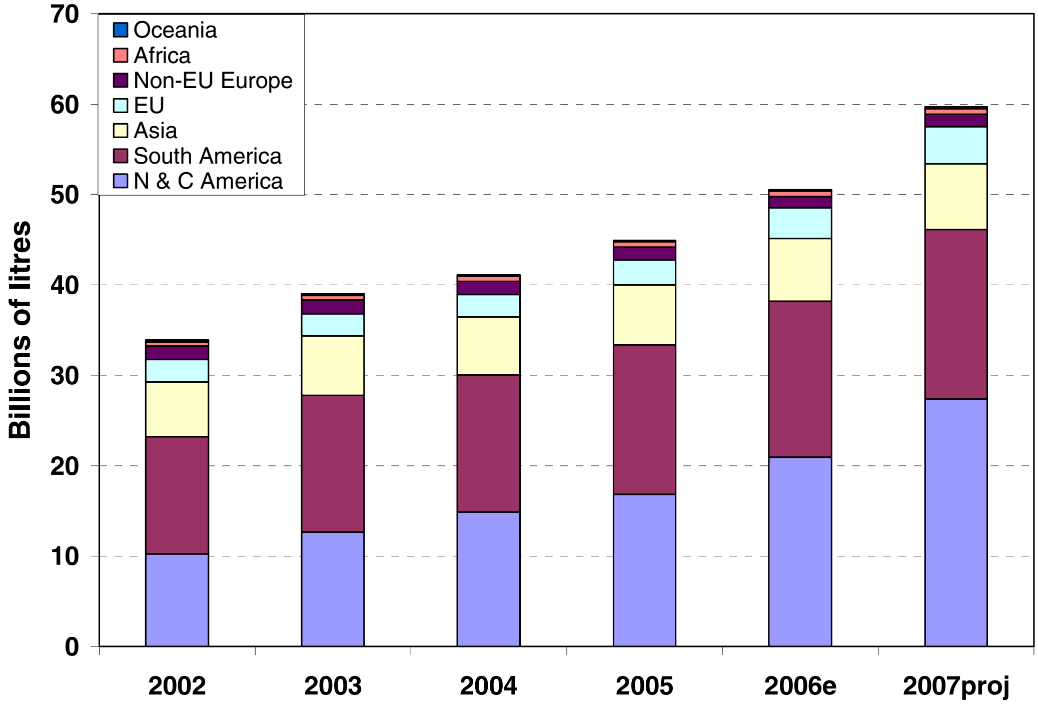
2.1.1 Bio-ethanol

Currently, ethanol is being produced at a rate of around 60 billion litres a year (Figure 1). Until recently, Brazil was the world's leading producer. In 2005, however, the United States and Brazil produced roughly equal amounts and in 2006 and 2007 the United States is expected to have moved into first position. China holds a distant but important third place in world rankings, followed by India, Germany, Spain and France.

Generally, countries lying within the tropics produce ethanol from sucrose, mainly from cane sugar or molasses. Much smaller quantities of ethanol are produced from sweet sorghum or cassava. Production in temperate-zone countries is largely based on starchy grains, particularly maize (corn) in the United States, and wheat, barley and sorghum elsewhere. The exception is Europe, where some ethanol is produced from beet sugar.

Production of fuel ethanol commenced later in Switzerland than in other countries (in 2005), in large part because of the high prices of its sugar and starch yielding crops, but also because of a law that remained in effect until 1997, effectively banning the domestic production of ethanol from crops. In contrast with other countries, its production (just under 1 million litres in 2005) is based entirely on wood cellulose. Japan imports small amounts of EBTE (ethyl tertiary butyl ether), an octane enhancer and oxygenate derived from ethanol, from France, but produces very little fuel-grade ethanol of its own. However, its government has established a target to use 6 billion litres of biofuels, or roughly 10% of transport fuel consumption, by 2030, and is investigating options to supply a substantial portion of that from domestic sources (Siu, 2007).

Figure 1. **Ethanol production by world region, 2002-2007**



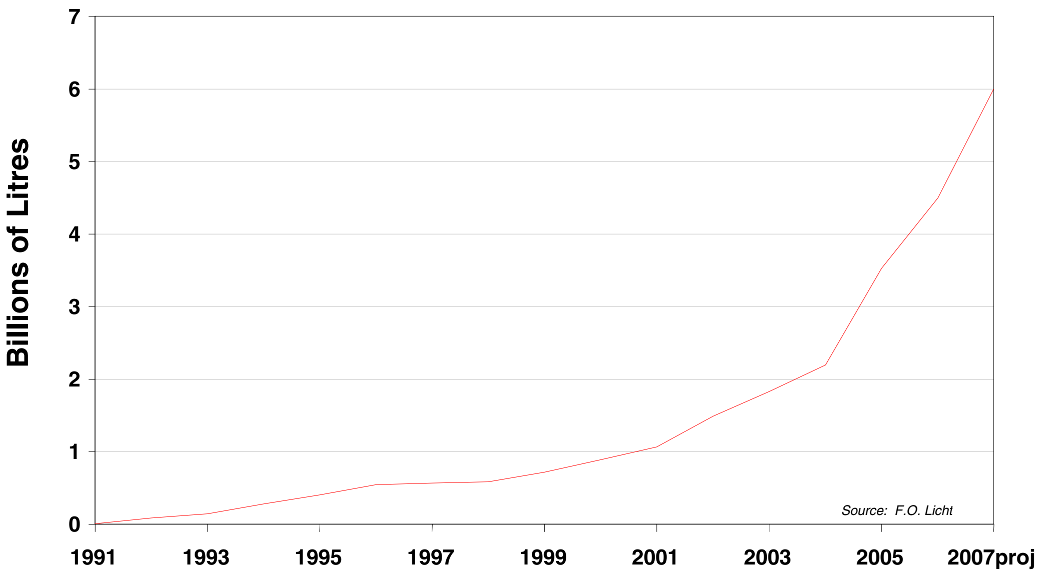
Source: Data from F.O. Licht.

2.1.2 Biodiesel

Biodiesel started to be produced on a commercial scale in the EU during the beginning of the 1990s, and in Switzerland a few years later, based mainly on virgin vegetable oils – generally rapeseed or sunflower-seed oil. Small (<5 million litres per year) plants turning waste cooking oils ("yellow grease") started to be built in other OECD countries by the end of the 1990s, but the industry outside Europe remained insignificant until around 2004. Since then, governments around the world have instituted various policies to encourage development of the industry, and new capacity in North America, South-East Asia and Brazil has begun to come on stream at a brisk rate (Figure 2).

Although plants using recovered waste oil continue to be built, as well as some large-scale plants using tallow or even fish oil as feedstocks, most of the new capacity is designed to use virgin vegetable oils. In Argentina, Brazil and the United States, soybean oil has so far been the feedstock of choice. In Canada, the EU, Switzerland, Russia and Eastern Europe, oilseed rape (canola) remains dominant. Companies in Malaysia and Indonesia are building their plants based on palm oil. Elsewhere, governments and entrepreneurs are experimenting with producing biodiesel from nitrogen-fixing and drought-tolerant plants, such as *Jatropha* or *Jajoba*, which produce non-edible oils[1].

Figure 2. World biodiesel production, 1991-2007



Source: Data from F.O. Licht.

2.2. Ownership structure of production and capacity

Because of the fast pace of developments in the biofuel industry, and the relatively small percentage of final product that enters international trade, its market structure is still fragmented, and not as vertically integrated as the petroleum industry with which it is often compared.

2.2.1 Production of feedstock crops

The production of the crops used as feedstock in biofuel manufacturing is carried out by hundreds of thousands of farmers across the world. Although no figures are available on the size distribution of the farms involved in that production, there is no reason to suppose that it is any different than that for the crops themselves.

The size of farms producing sugarcane tends to be larger than farms producing sugar beets, starch-based crops, such as maize and wheat, and oilseeds; and all of these farms tend to be larger on average than farms growing horticultural crops. Sugar cane is generally grown as a monocrop, but maize (for ethanol) and soybeans (for biodiesel) are often grown in rotation on the same parcel of land, as are wheat, sugar beets and oilseeds.

The other providers of feedstock are companies that collect yellow grease and other waste oils and fats. These companies tend to be small and local.

2.2.2 Biofuel manufacturing

Several companies stand out from among the crowd as major players, most notably Archer Daniels Midland (ADM), Bunge, Cargill and Louis Dreyfus. ADM is not only the leading manufacturer of bio-ethanol in the United States, but it is also the second-largest manufacturer of biodiesel in the EU. It has also invested in plants in Brazil.

Few other companies have the same scale of international presence as the agri-business giants, though the number of companies operating in more than one country is increasing rapidly. Examples include Malaysia's Golden Hope (in The Netherlands), Spain's Abengoa (in the United States), and France's Tereos (in Brazil).

Ethanol manufacturing

Because bio-ethanol has emerged by and large as a by-product or alternative product of processing sugar and starch crops, ownership of production plants has so far been dominated by companies that were already major players in the agri-food business.

In *Brazil*, the country that until recently was the largest bio-ethanol producer in the world, production is dominated by companies with integrated mills that can switch production streams within their plants between sugar and ethanol in response to market prices. Most of these producers have gone on to develop technology and logistics for ethanol production and distribution.

The structure of the industry in the *United States* has gone through several stages of expansion and consolidation, at all times dominated by ADM and a handful of other companies, mostly agri-food giants. However, because of policies intended to encourage farmer-owned value-adding activities, the number of plants owned by agricultural co-operatives remains significant. Ethanol is produced in the *EU* from a variety of sources, including sugar beets, grains (wheat and maize), potatoes and wine. The companies involved are typically part of the agricultural industry. *Canada* until recently had only a handful of ethanol producers, and total output was small. Although agri-food companies have become engaged in the business, some energy companies – most notably Husky Oil – have entered the business as well. Ethanol is produced in *Australia* from molasses and downgraded grains. The leading producers are sugar refiners.

Biodiesel manufacturing

The structure of the biodiesel industry can be described as bi-polar, with a few large companies involved in producing biodiesel on an industrial scale, and at the other end a large number of very small, often locally or farmer-owned companies.

In the *EU*, the European Biodiesel Board (www.ebb-eu.org/members.php) lists more than 20 separate producing members (and another 20 "associate members"), representing multinational agri-food giants [e.g. ADM, Bunge (Novaol) and Cargill], chemical companies (Dow), and specialist biodiesel producers (e.g. D1 Oils). The *United States*' National Biodiesel Board lists a similarly diverse membership, including numerous small companies producing biodiesel from yellow grease. Much of the newest and largest capacity, however – plants with an annual capacity of 40 million gallons (150 million litres) or greater – is being built by agri-business companies such as ADM or Louis Dreyfus, or joint ventures involving agri-business companies (e.g. Bunge).

Brazil has only recently begun producing biodiesel on a commercial scale. The first, and currently the leading producer of biodiesel in the country (accounting for 58% of the biodiesel sold at auction until August 2006) is Brasil Ecodiesel, a company set up to co-ordinate production from mainly family-run farms growing castor oil plants, sunflower or *Jatropha curcas*. Numerous other companies have built or are building biodiesel plants designed to process soybeans, including several Brazilian and multinational agri-food companies (of which ADM), as well as Petrobras, Brazil's state-controlled oil company.

2.2.3 Distribution and retail sales

The wholesale distribution (including blending) and retail segments of the biofuels industry is carried out by small and medium-sized companies in some countries and by large, sometimes state-owned oil companies in others.

Brazil decided early on to market its ethanol through the state oil company, Petrobras. At the retail level, however, ethanol is available at virtually all the filling stations in the eastern part of the country. In *Australia, Canada,* the *United States* and the *EU*, both ethanol and biodiesel are distributed through the existing networks of gasoline and diesel fuel distributors. At least one company in the United States, Earth Biofuels, was created expressly to distribute and sell biofuels, and is now trying to build up a network of filling stations, dispensing blends of ethanol and biodiesel. In *Switzerland*, Alcosuisse, the commercial arm of the State Alcohol Board, manages the storage, blending and wholesale distribution of ethanol throughout the country, but fuel retailers sell the blended fuel to final customers.

2.2.4 End users

The majority of end users of biofuels are individual owners of private automobiles. In some countries, however, government agencies, including military forces, account for a significant share of purchases. In many countries, municipal governments have taken the lead in converting their fleets of vehicles to run on E85 or biodiesel-diesel blends. A number of cities around the world, from Auckland to Helsinki, now run at least some of their public buses on biodiesel blends.

Many state-owned enterprises have also decided to buy biofuels for their fleets. Switzerland's fuel-ethanol industry, for example, was kick-started by a decision by Swisscom, the state telecoms company, to cut back its fuel consumption, by reducing the size of its fleet and using E5 in some of its vehicles in the Bern region.[2]

Perhaps the biggest single consumer of biodiesel is the US military, through its Defense Energy Support Center (DESC), which co-ordinates the US Federal Government's fuel purchases. The DESC is the largest single purchaser of biodiesel in the United States and has been procuring B20 for its administrative vehicles since 2000.

2.3. Current and future production costs

The costs of producing biofuels varies significantly according to feedstock, process and location. Location determines access to particular feedstocks and energy supplies, the prices of which to a large degree are driven by market developments at the global scale – including, increasingly, the demand for crops to supply biofuel production itself. The basic processes currently used for producing ethanol and biodiesel do not vary so greatly, though the scale of actual plants does. Moreover, rapid developments in the design of ethanol plants in order to make more-efficient use of energy, or to improve the profitability of by-products, are having a profound effect on the economics of new plants. For these reasons, the brief discussion that follow should be regarded as only roughly indicative of the relative costs of biofuel production in different countries, and for the potential for changes in those costs.

2.3.1 Ethanol

Production costs for ethanol vary widely from one country to another, depending on the feedstock and process used, and the costs of energy and labour.

Currently there are three "conventional" processes in use for producing ethanol from biomass, all relatively mature: (i) distillation of alcohol from wine; (ii) fermentation and distillation of alcohol from sugars or mollases; and (iii) conversion, fermentation and distillation of alcohol from starch derived from crops. The first process is straight-forward. Because its production exists largely as a result of structural surpluses in the European wine market, it is expected to account for a diminishing share of the world's supply in future years.

Most of the fuel ethanol produced in the tropics and subtropics is derived from sugar-cane, either the cane juice itself or its molasses. The cost of the process depends primarily on the cost of the feedstock as well as the scale of the operation and the ability to switch between the ethanol and the sugar markets. Most modern ethanol-manufacturing plants based on sugar-cane have been able to avoid high costs for process heat by burning bagasse (cane residue). Many also co-generate electricity and sell surplus electric power to the grid.

Some fuel-ethanol is produced in northern climates, chiefly the EU, from sugar beet. The process of fermenting and distilling the sucrose sugar is similar to that used for cane-derived sucrose, but the plants do not have access to bagasse – the leftover cane stalk after the sucrose is pressed out – hence they must purchase commercial fuels for their process heat. Labour costs are considerably higher than in developing countries, which also works to their disadvantage.

Two grains account for the bulk of ethanol produced from starch. Maize is the most significant of the starchy crops used for ethanol production (in eastern Canada, China, southern and central Europe, and the United States), followed by wheat (in western Canada and northern Europe). Smaller amounts of fuel ethanol are produced from cassava, potatoes and sorghum.

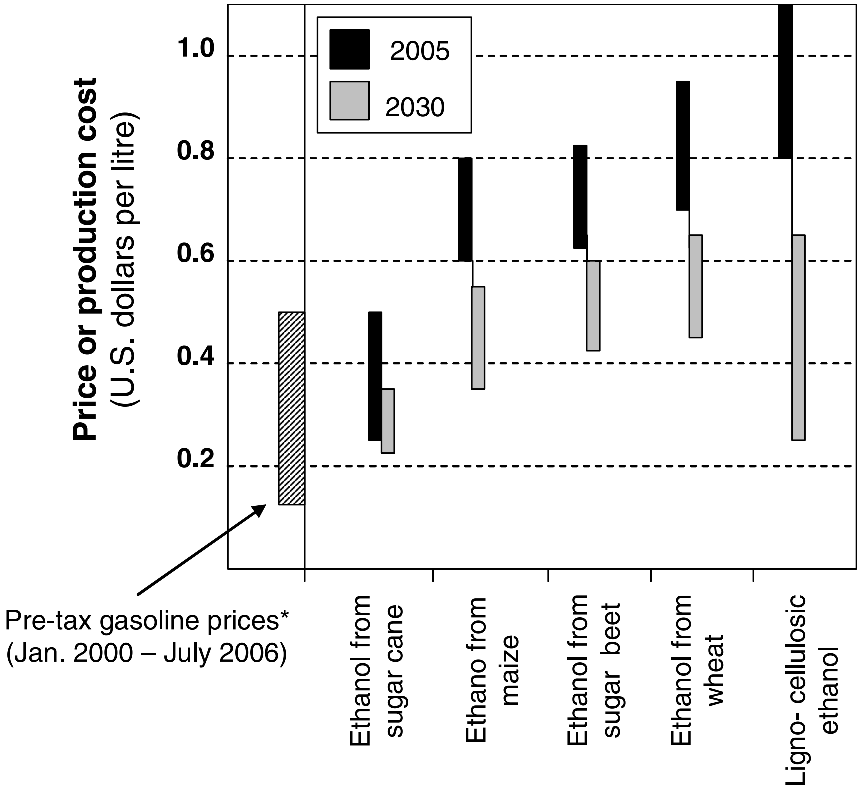
A great variety of plant configurations are being used to manufacture ethanol from starchy grains. One basic distinction is whether the plant uses a dry-milling or a wet-milling process. In *dry milling*, the entire maize kernel (or other starchy grain) is ground into a flour and processed without first separating out the various component parts of the grain. Water is then added to form a "mash", to which enzymes are added in order to convert the starch to dextrose. The mash is then processed at a high-temperature, cooled and fermented, yielding a "beer" containing ethanol, carbon dioxide (CO_2), water and solids ("stillage"). Further processing concentrates the ethanol and dehydrates the stillage, ending up with a by-product called dried distillers grains with solubles (DDGS), a high-protein livestock feed. The CO_2 released during fermentation is also captured, and typically sold for use in carbonating beverages and the manufacture of dry ice. In *wet milling*, maize is steeped in water and dilute sulphuric acid to facilitate the separation of the grain into its many component parts. Additional processing eventually yields corn germ (from which corn oil is extracted), fibre, gluten and starch. The gluten component is filtered and dried to produce a corn-gluten meal, which is sold as livestock feed, and the starch is fermented and distilled much as in the dry-milling process.[3]

Additional differences arise from the fuel used for process heat. Traditionally in the United States and eastern Canada, ethanol plants have relied primarily on natural gas, and electricity purchased from the grid. With the recent steep rises in the price of natural gas, some operators are turning to cheaper coal. A few plants are being built adjacent to power plants, so as to use their waste heat. And at least one is being built to run off of methane generated from manure produced by cattle in an associated feedlot.

Figure 3 compares the current and projected future costs of producing ethanol from different feedstocks, as calculated by the IEA. Brazil's costs, at USD 0.20 per litre (USD 0.30 per litre of gasoline equivalent) for ethanol produced in new plants, are the lowest in the world. Even before the recent rise in maize prices in the United States, grain-based ethanol cost some 50% more to produce in the United States than in cane-based ethanol Brazil, and 100% more in the EU than in the United States. These costs do not include the costs of transporting, splash blending and distributing ethanol, however, which can easily add another USD 0.20 per litre at the pump.

According to the IEA (2006), "further incremental cost reductions can be expected, particularly through large-scale processing plants, but no breakthroughs in technology that would bring costs down dramatically are likely." They foresee such technological improvements helping to reduce costs by one-third between 2005 and 2030, in part driven by reductions in the costs of feedstocks. Whereas they project feedstock costs declining by around one-quarter in the EU, and one-third in Brazil, they assume that net feedstock costs will shrink by more than half in the United States. In all cases, the IEA[4] assumed current rates of subsidies to crops and ethanol production remain in place.

Figure 3. **Current and projected future ethanol production costs, compared with recent (pre-tax) gasoline prices**



*Based on monthly average import prices for crude oil into the IEA region.
Note: Cost estimates exclude from consideration subsidies to crops or to the biofuel itself.
Source: Adapted from IEA (2006), Figure 14.7.

Expecting feed-stock costs in the EU to fall over the next 25 years is not an unreasonable assumption, given that changes in policies (notably the elimination of export subsidies for sugar) and improvements in plant genetics alone could put downward pressure on costs. Yet with pressure on commodities to feed a growing world population, uncertain changes in yields caused by global climate change, as well as demand for biomass for fuels, relative prices for feedstocks could well rise significantly. Already, between 2005 and 2007, prices for maize and wheat — key ethanol feedstocks in OECD countries — had risen by more than 50% in nominal terms (Table 1). If one compares average prices in 2005 with prices for maize and wheat at the end of 2007, they have doubled. Meanwhile, the price for sugar is back to its level in 2005. Spot prices can be expected to remain volatile, nonetheless. At its peak in February 2006, for example, the reference price for sugar was more than twice its lowest value only nine months earlier.

Table 1. **Reference international commodity prices for sugar, maize and wheat, 2005-2007**

Commodity	**Average price in 2005 (USD/tonne)**	**Peak price since May 2005 (USD/tonne and week ending)**	**Average price, in 2007 (USD/tonne)**	**Percentage change, nominal terms, 2005 to 2007**
Sugar[1]	$218	$406 (*03.02.06*)	$221	1%
Maize[2]	$109	$211 (*18.01.08*)	$164	50%
Wheat[3]	$150	$353 (*21.12.07*)	$235	57%

1. Based on weekly averages of International Sugar Organization (ISO) daily price, expressed in US cents per pound.
2. US No.2, Yellow, price at US Gulf ports (Friday quotations), expressed in USD per short ton.
3. US No.2, Soft Red Winter Wheat , price at US Gulf ports (Tuesday quotations).
Source: Data from Food and Agricultural Organization of the United Nations, "International Commodity Prices" website (www.fao.org/es/esc/prices), accessed on 24 January 2008.

It bears stressing that while the costs of producing sugar in Brazil, maize in the United States or wheat in Argentina or Canada will be lower than the international prices shown in Table 1, what matters to the economics of biofuels is the *opportunity cost* of diverting these feedstocks to ethanol production, as opposed to selling them to other buyers. Studies of the costs of producing biofuels must make assumptions about the price of the feedstock biomass as well as the price that the fuel will fetch in the market. As Kojima *et al.* (2007) point out, while the accounting cost of producing a biofuel may be less than the price of its nearest petroleum alternative, it still may not be economical to produce if the market price for the feedstock is high.

2.3.2 Biodiesel

Over 50 species of plants produce oils that can be extracted from their seeds, nuts or kernels. All, technically, can be used as fuel (or transformed into biodiesel). Most of these oils are prohibitively expensive to produce on a large scale for a comparatively low-value use such as fuel, however. Currently, the main oils used for fuel in one way or another are derived from one of a handful of seeds or nuts: soybeans, oil-palm fruit or kernels, coconut, rapeseed (canola), sunflower seed, and physic nut (*Jatropha curcas*).

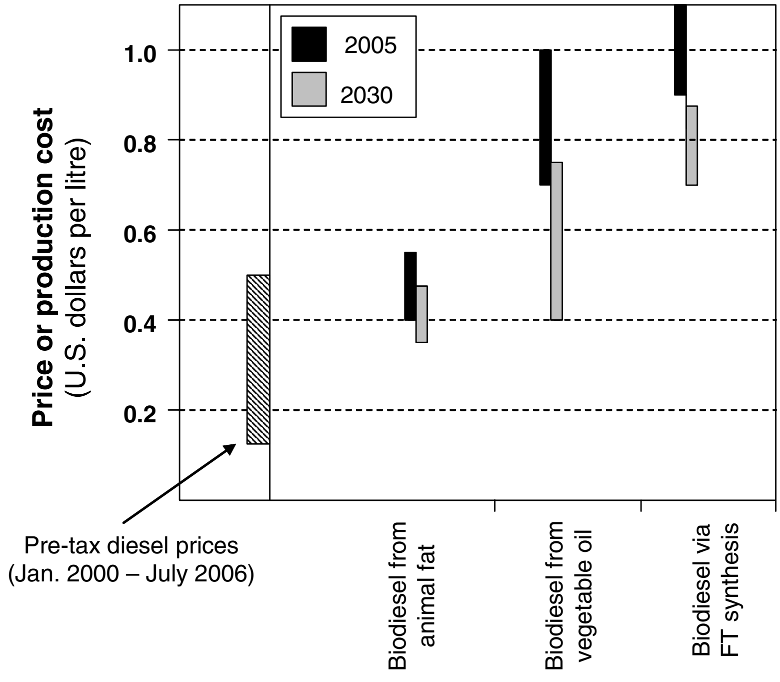
Oil yields (in kilogrammes or litres per hectare) vary widely among the leading sources. Typical yields are 400-600 litres per hectare for soybeans, 1200-1700 litres per hectare for oilseed rape, and 4 000-7 000 litres per hectare for oil palm. Yield is not the only determinant of supply, however. Soybeans and rape have a value to farmers as crops that can be grown in rotation with other crops; and soybeans, because they fix nitrogen in the soil, reduce the need for nitrogenous fertilizers – both for the crop itself and for the follow-on crop. *Jatropha* is also nitrogen-fixing, but is planted as a perennial, often as a vegetative border, support (as for vanilla vines in Madagascar) or wind break.

All oil-bearing plants yield a residue after pressing, and that residue (cake or meal) has a value as well. The most valuable meal is soybean meal, because of its high protein content. Indeed, traditionally, soybean meal has been the main market for which soybeans have been produced, and soybean oil has been regarded as a by-product. The rapid growth in biodiesel produced from soybean oil may turn that market on its head, however, reversing the relative profitability of the two product streams. The meal left over from pressing rapeseed is also valuable, but normally commands a lower price than soy meal. The meal from Jatropha, because it is toxic to animals, is mainly ploughed back into the soil an organic fertilizer.

In OECD countries, the first plants using the transesterfication process to produce biodiesel have typically used low-value oils, such as used cooking oil (also known as "yellow grease"), fish oil or tallow. Because of the limited nature of the supply of yellow grease, these plants rarely exceed annual capacities of 30 million litres, and most have capacities of 5 million litres per year or less.

As low-cost supplies of these fats are exhausted, additional capacity has then had to be based on virgin oils. Over the long run, it is the cost of procuring virgin vegetable oils that largely determines the cost of producing biodiesel. As discussed in the previous section, the costs of producing biodiesel from virgin plant oils are heavily influenced by yields, the value of the oils in other uses, and the value of co-products. Generally, therefore, biodiesel made from palm oil will cost less to produce than from soybean oil or rapeseed oil, defining respectively the two ends of the range of costs shown in Figure 4.

Figure 4. **Current and projected future biodiesel production costs, compared with recent (pre-tax) gasoline prices**



*Based on monthly average import prices for crude oil into the IEA region.
Source: Adapted from IEA (2006), Figure 14.7.

The IEA (2006, p. 408) is less bullish on further incremental cost reductions , noting that "(t)here remains some scope for reducing the unit cost of conventional biodiesel production by building bigger plants. But technological breakthroughs on the standard transesterfication process, leading to substantial cost reductions in the future, are unlikely." They foresee production costs falling to by 37% between 2005 and 2030 in the United States (to around USD 0.33 per litre of diesel equivalent), and by 32% in the EU. Again, these projections assume net costs of feedstocks falling by around one-third in real terms over the projection period.

As with feedstocks for ethanol production, the prices of feedstocks for biodiesel production have been heading in the opposite direction since the IEA's cost estimates were produced. Between 2005 and February 2007, international reference prices for rapeseed oil, soybean oil, and crude palm oil rose, respectively, by 19%, 29% and 43% in nominal terms (Table 2). The price rises have been more monotonic, exhibiting less volatility than the prices for sugars and grains over the same period. What is interesting is that the prices for lower-value oils have been rising at a faster rate than for the traditionally higher-value oils, suggesting that palm oil is being substituted for the other, more-expensive oils.

Table 2. **Reference international commodity prices for rapeseed oil, soybean oil and crude palm oil, 2005-2007**

Commodity	**Average price in 2005 (USD/tonne)**	**Peak price since May 2005 (USD/tonne and month)**	**Average price in 2007 (USD/tonne)**	**Percentage change, nominal terms, 2005 to 2007**
Rapeseed oil[1]	$669	$1386 (*Dec 07*)	$969	45%
Soybean oil[2]	$545	$1164 (*Dec 07*)	$881	62%
Crude palm oil[3]	$422	$952 (*Nov 07*)	$780	85%

1. Monthly averages of ex-mill price (f.o.b.), Netherlands.
2. Monthly averages of ex-mill price (f.o.b.), Netherlands.
3. Monthly averages of import price (c.i.f.), north-west Europe.

Source: Data from Food and Agricultural Organization of the United Nations, "International Commodity Prices" website (www.fao.org/es/esc/prices), accessed on 24 January 2008.

The economics of biodiesel also depends on the price of crude glycerine, a by-product of transesterfication process that is used in a wide range of foods, cosmetics and other products. In the early years of the biodiesel industry, production of glycerine was small enough that it did not substantially affect market prices for the by-product. But as the amount of biodiesel and thus glycerine produced in the world has increased, the value of crude glycerine has declined. In September 2006, *Biodiesel Magazine* (Nilles, 2006) reported that crude glycerine, having once fetched USD 0.20-0.25 per pound, was heading towards 5 cents per pound (USD 110 per tonne) and perhaps lower. In response, some of the major biodiesel producers are considering building the capacity to refine crude glycerine to pharmaceutical grades, and are investigating new uses for the chemical. But for the near and medium-term future, the glut of crude glycerine is expected to reduce the profitability of biodiesel production.

2.3.3 Emerging processes

An explicit assumption behind government plans for large-scale displacement of petroleum fuels by biofuels is that the expansion of biofuels derived from starch, sugars or plant oils alone will hit a limit within the next decade or so, and that any increase in supplies beyond that will have to come from so-called second-generation technologies and feedstocks. For ethanol, that means technologies that are able to extract fermentable sugar from ligno-cellulosic and hemi-cellulosic materials ("cellulosic" for short). Potential sources of cellulosic materials include the non-starchy parts of the maize plant, perennial grasses, wheat straw, pulp from fast-growing trees, and even waste paper. Some cellulosic feedstocks could be grown on land that is not suitable for food crop production. Ligno-cellulosic biomass can also be gasified and then converted to a form of diesel via Fischer-Tropsch (FT) synthesis.

Demonstration plants have already been built to produce ethanol from ligno-cellulosic materials, but production costs are high, generally around USD 1.00 per litre on a gasoline-equivalent basis (IEA, 2006). Hundreds of millions of dollars have already been spent by both government and private industry researching ways to bring down those costs. Most of these efforts are focussing on the front-end of the process, the breaking down (through enzymes or microbes) of lignin, cellulose or hemi-cellulose into a form that can then be fermented, and increasing the ethanol contented in the fermented broth, so as to reduce the energy needed in the distillation stage.

Because of the rapid pace of technological developments, and uncertainty over the long-run costs of feedstock, projections of the probable future costs of producing ethanol from lingo-cellulosic materials vary widely. The IEA, in its *World Energy Outlook 2006*, notes that they could fall eventually to USD 0.40 per litre of gasoline equivalent. This goal may be achievable sooner than previously forecast, at least in integrated sugar-and-ethanol plants. In May 2007, Dedini SA, Brazil's leading manufacturer of sugar and biofuel equipment, announced that it had developed a way to produce cellulosic ethanol on an industrial scale from bagasse (Biopact team, 2007) at a cost of below USD 0.27 per litre, or USD 0.41 per litre on a gasoline-equivalent basis.[5] Dedini began producing small quantities of cellulose bioethanol from bagasse at the São Luiz Mill in São Paulo state in 2002. Its main innovation involves pretreatment of the biomass with organic solvents, followed by hydrolysis with diluted acids.

As with cellulosic ethanol, a considerable amount of research is being devoted also to reduce the costs of producing diesel from biomass, using the Fischer-Tropsch process, breaking down biomass into gas with heat or chemicals. A completely different approach to producing biodiesel would extract lipids from specially bred species of algae, which would then be transformed using the standard transesterfication process. However, recent evaluations of the potential for algal biodiesel are pessimistic about prospects for commercializing that technology (Dimitrov, 2007).

In addition to favourable technological breakthroughs, bringing down the costs of biofuel production may also require exploiting significant scale economies in the manufacturing plants. However, large manufacturing plants imply procuring biomass from over a wide area – a not insignificant logistical challenge. For production of biomass on marginal land this is a particularly significant cost, as with lower fertility or harsher climates yields are lower and the area over which biomass has to be sourced correspondingly larger. Moreover, most analyses of the procurement cost of the biomass feedstock undertaken to date focus on actual production costs, either without taking into account the rental value of the land or assuming a low value for it.

A notable exception is the study by the Center for Agricultural and Rural Development (CARD) at Iowa State University (Tokgoz *et al.*, 2007). The CARD analysis observes that farmers will not be willing to plant crops dedicated to cellulosic crops like switchgrass unless the crops offer a net return comparable to that of maize. Citing a study by Babcock *et al.* (2007), which calculated the price at which farmers would consider changing to switchgrass as USD 121 per tonne of switchgrass from land with a yield of 9 tonnes per hectacre, and USD 90 per tonne for land with a yield of 13.5 tonnes per hectare, the authors estimate that the maximum that ethanol plants can bid for these same tonnes is about USD 41 per tonne in years when ethanol is selling for USD 1.75 per gallon (USD 0.46 per litre). "Under these conditions", they note "switchgrass simply cannot offer farmers a market incentive that offsets the advantages of growing corn". Continuing:

> A key and possibly counterintuitive insight is that there is no ethanol price that makes it worthwhile to grow switchgrass because any ethanol price that allows ethanol plants to pay more for switchgrass also allows them to pay more for corn. So long as farms are responding to net returns in a rational manner and so long as ethanol plants are paying their breakeven price for raw material, farmers will plant corn as an energy crop. Switchgrass in the Corn Belt will make economic sense only if it receives an additional subsidy that is not provided for corn-based ethanol.

Not surprisingly, there are now several bills before the US Congress proposing new, additional incentives to encourage farmers to produce feedstock crops other than corn.

2.4. Price relationships between biofuels, petroleum products and crops

Ethanol and biodiesel are both complements and substitutes for gasoline and petroleum diesel, so one would expect their prices to track the prices of these fuels fairly closely, after adjusting for product subsidies or tax differentials. Yet, owing to government policies, and because biofuels in most countries are imperfect substitutes for their corresponding petroleum-derived fuels, price behaviour is a bit more complex than this.

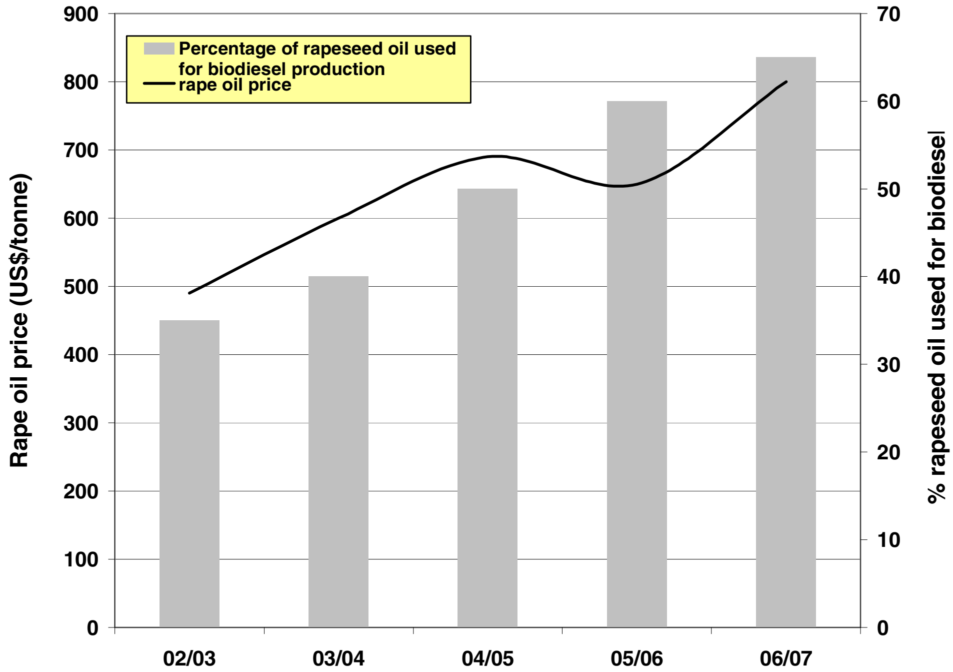
Ethanol contains less energy than gasoline but has a higher octane rating and is therefore used as an octane enhancer (necessary for modern engines using lead-free fuels). As a pure fuel, it has an octane rating of 113, compared with 87 for gasoline. In blends of up to around 5% with gasoline, therefore, ethanol should command a premium over gasoline. Tyler (2007) places this premium at around USD 0.25 per gallon (USD 0.066 per litre); Stoft (2007) argues it should be worth only a few percentage points, because ethanol also has some negative attributes – namely, it has an affinity for water, and raises the vapour pressure of ethanol-gasoline blends. The unusually high spread between the ethanol and the gasoline price in the United States in May through July 2006 has been attributed to the regulatory changes that prompted gasoline producers to turn to ethanol after abandoning MTBE (methyl tertiary-butyl ether) when the US Environmental Protection Agency ruled MTBE could no longer be used as an octane enhancer (or oxygenate).

As the share of ethanol in a gasoline blend rises, the incremental value of the octane declines, and what matters more is the ethanol's energy content, which is about 67% that of gasoline. Running on blends containing 85% ethanol and 15% gasoline (E85), so-called flex-fuel vehicles (FFVs) designed to operate on that fuel typically travel 25% fewer kilometres than on an equal volume of pure gasoline. Hence, the market-clearing price for ethanol used in E85 should be not much more than 75% of the price of gasoline.

In the absence of blending mandates and differential tax treatment, the relationship between biodiesel prices and diesel prices should depend largely on the quality of the biodiesel and diesels being compared (particularly in terms of sulphur content), and their relative energy contents. These qualities depend on the type of engine in which the biodiesel is burned, the ratio of the blend, air-quality considerations, and so forth.

The demand for crops for producing biofuels has been an important factor – though not the only factor – in firming up prices for not only crops used directly in the production of ethanol and biodiesel (Figure 5), but also for substitutes for those crops, especially in the markets for feedgrains. While these price rises have been regarded as boons for producers of those crops, they have adversely affected livestock farmers, especially those that depend on purchased feed for the bulk of their livestock-feeding requirements.

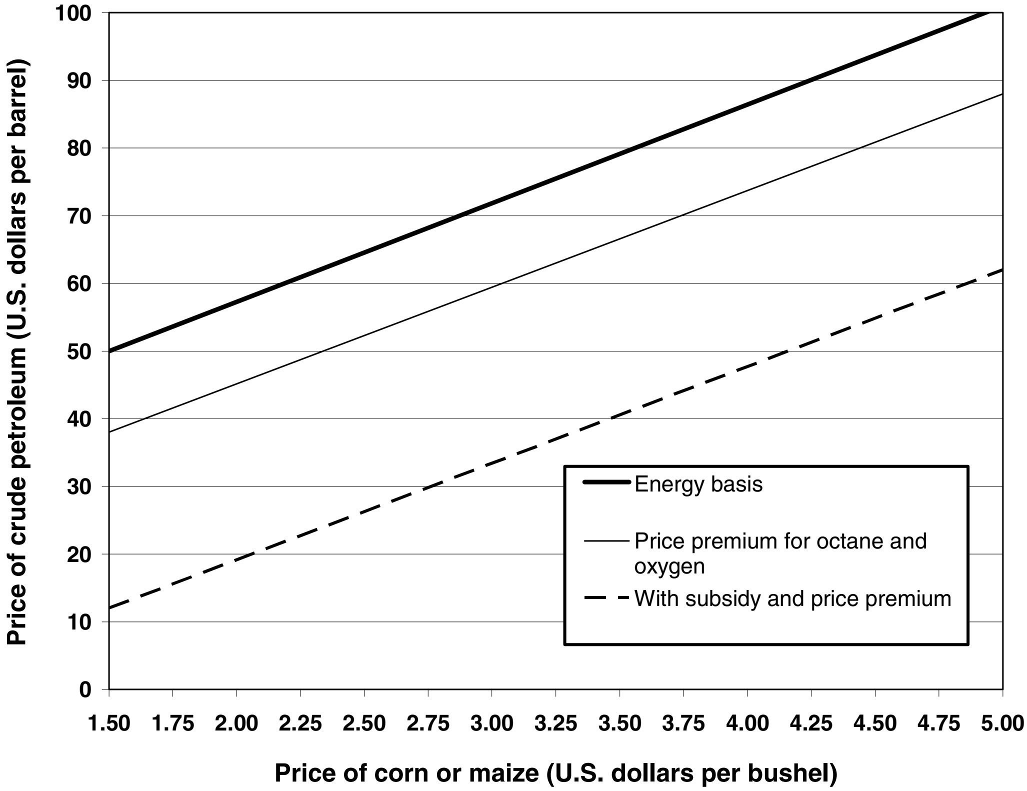
Figure 5. **Growth in EU biodiesel production and rape oil prices, 2002-03 through 2006-07**



Source: Jank *et al.* (2007).

Rising prices for grains and oilseeds also raise production costs for biofuel producers. At some point, as feedstock prices rise, biofuel producers get caught in a price squeeze. Where that occurs depends on the prices of competing petroleum-based fuels, and of course levels of subsidies. Figure 6 shows, using the example of the United States, that the price that ethanol manufacturers can pay for maize and still cover their costs is substantially increased by the existence of the USD 0.51 per gallon (USD 0.135 per litre) federal volumetric ethanol excise tax credit (VEETC). At a crude-oil price of USD 60 per barrel, the break-even price is USD 4.75 per bushel, or more than USD 1.75 per bushel higher than without the subsidy, even allowing a generous premium for the value of ethanol as an octane-enhancer.

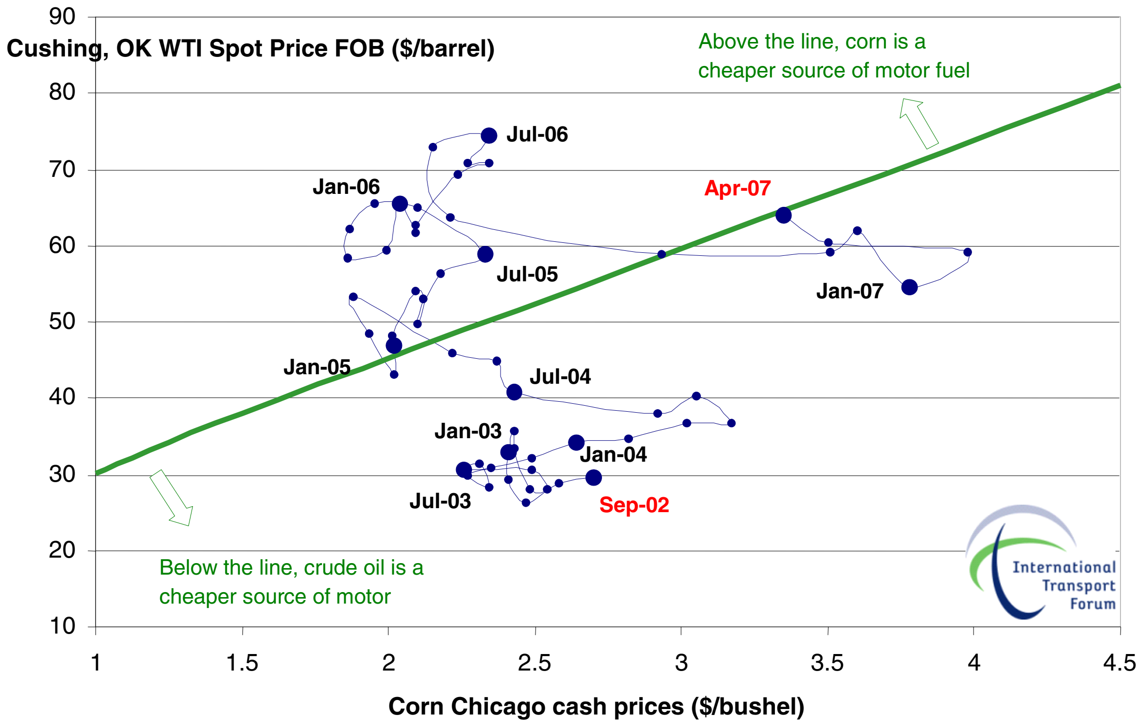
Figure 6. **Prices for maize and crude oil at which ethanol production breaks even in the United States**



Source: based on Hurt *et al.* (2006) and Tyner (2007).

Figure 7 plots the actual co-evolution of prices of maize and crude oil in the United States over the last five years. It shows that during 2005 and 2006, at the height of investment interest in the ethanol industry, corn prices were relatively low and petroleum prices relatively high. Before that period, petroleum prices were too low, and since the end of 2006 to date the maize price has been too high, for corn-based ethanol to compete with petroleum without subsidies.

Figure 7. **Prices of crude-oil and maize in the United States, September 2002-January 2007**



Source: Joint Transport Research Centre of the OECD and the International Transport Forum; data from the Energy Information administration (http://tonto.eia.doe.gov/dnav/pet/hist/rwtcM.htm) and USDA.

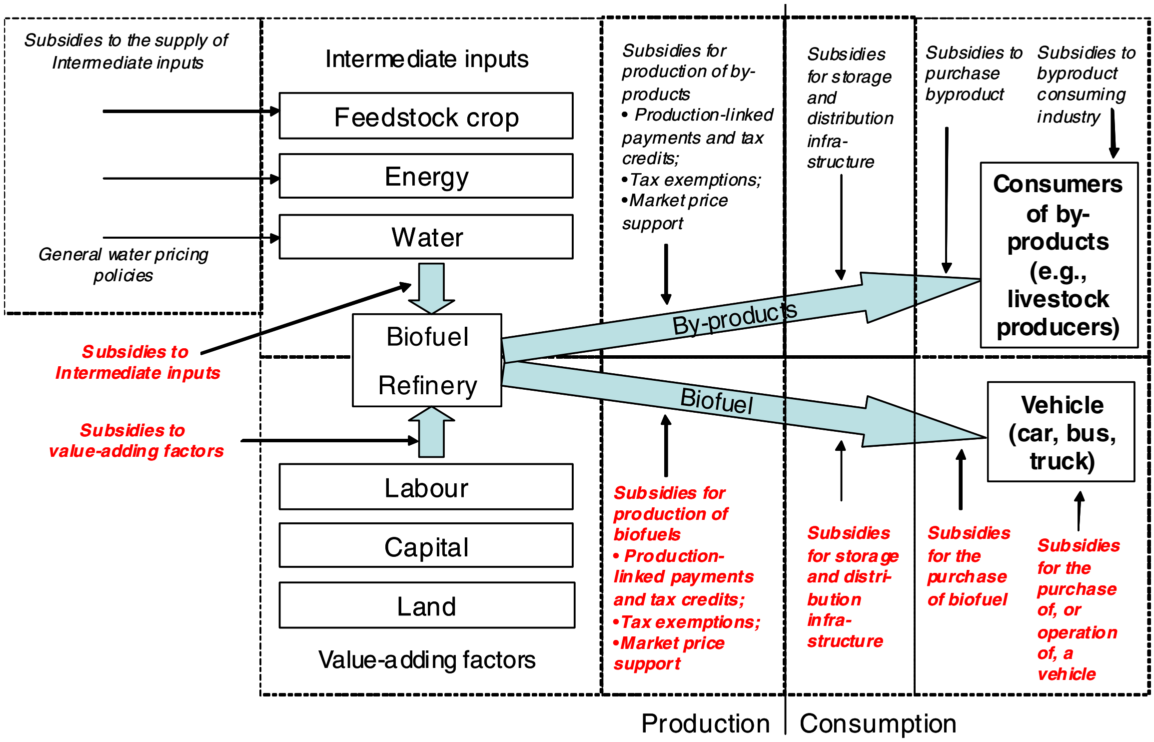
Blending mandates can also change the price relationship between the mandated and the non-mandated fuel. Whether they do depends on the cost of producing the mandated product relative to the market price of the non-mandated product. In the most simple situation, involving a 5% minimum blending mandate for biodiesel, if the price of petroleum diesel is below the marginal costs of producing biodiesel, the price of the biodiesel (adjusted for energy-content and quality differences) will keep rising until the mandated level is reached. If the price of petroleum diesel is higher than the short-run marginal cost of supplying biodiesel, the price of biodiesel should approach the price of the former as long as the share of biodiesel in the market is below whatever limits may be in place on the maximum percentage that can be sold commercially.

3. GOVERNMENT SUPPORT FOR LIQUID BIOFUELS

3.1. A framework for understanding industry support

Figure 8 illustrates the framework used in the GSI's country studies to discuss subsidies provided at different points in the supply chain for biofuels, from production of feedstock crops to final consumers. Defining a baseline requires deciding how many attributes to look at, and determining what programs are too broadly cast to consider in an analysis of one particular industrial sector. In our analyses, we focused on subsidies that affect production attributes that are significant to the cost structure of biofuels, including subsidies to producers of intermediate inputs to production, namely crop farmers. More remote subsidies, such as to particular modes of transport used to ship biofuels or their feedstocks, were beyond the boundaries of the analysis.

Figure 8. **Subsidies provided at different points in the biofuel supply chain.**



Source: Global Subsidies Initiative.

At the beginning of the supply chain are subsidies to what economists call "intermediate inputs" – goods and services that are consumed in the production process. The largest of these are subsidies to producers of feedstock crops used to make biofuels. For ethanol, the main feedstocks are sugarcane, maize (corn), sugar beet and wheat, and for biodiesel the main feedstocks are oilseed rape and soybeans. In some countries, the crop subsidies are small enough that they are only wealth transfers, and do not materially affect supply or prices. In others, border protection raises the domestic prices of the crops above international prices, thereby effectively taxing consumers of those crops, including biofuel producers. Some countries compensate for these “taxes” on the input feedstocks by providing countervailing subsidies to biofuel producers. However, to the extent that production of the feedstock crops creates a demand for subsidies, the proportional share of the total subsidies to those crops used in the production of biofuels can be considered one element of the gross costs to government of promoting biofuels. (The net cost would take into account any increased taxes paid by farmers as a result of increasing their taxable incomes.)

Subsidies to intermediate inputs are often complemented by subsidies to value-adding factors – capital goods; labour employed directly in the production process; and land. These may take the form of grants, or reduced-cost credit, for the building of ethanol refineries and biodiesel manufacturing plants. Some localities are providing land for biofuel plants for free or at below market prices as well. These types of subsidies lower both the fixed costs and the investor risks of new plants, improving the return on investment.

Further down the chain are subsidies directly linked to output. Output-linked support includes import tariffs on ethanol and biodiesel; exemptions from fuel-excise taxes; and grants or tax credits related to the volume produced, sold or blended. Although in a few cases, tax exemptions and subsidies have been used to actually depress biofuel (mainly ethanol) prices below the energy-equivalent cost of competing petroleum fuels, mainly they have enabled biofuels to be sold at retail prices that are roughly at parity with their (taxed) fossil-fuel counterparts.

Support to the downstream side of the biofuel market has generally been provided in one of five ways: credit to help reduce the cost of storing biofuels in-between the production seasons; grants, tax credits and loans to build dedicated infrastructure for the wholesale distribution and retailing of biofuels; grants to demonstrate the feasibility of using biofuels in particular vehicle fleets (e.g. biodiesel in municipal buses); measures to reduce the cost of purchasing biofuel-capable fleets; and government procurement programs that give preference to the purchase of biofuels.

A diagram such as Figure 8 is helpful for visualizing the different points at which governments intervene in the market for biofuels. When discussing support policies, however, it is standard to structure the discussion in an order reflecting the degree of influence on market outcomes. Generally, policies that directly bear on the level of production are considered to have the greatest level of distortion on production decisions, followed by subsidies to intermediate inputs, and subsidies to value-adding factors. Government support for research and development (R&D), as long as it is not production support in disguise, is normally the least distorting.

Following this structure, this section of the paper provides a brief survey of the types of support measures identified in the course of the GSI’s studies of support for ethanol and biodiesel in Australia, Brazil, Canada, the EU and its Member States, Switzerland, and the United States.

3.2. Current support for ethanol and biodiesel

3.2.1 Output-linked support

Domestic production of biofuels is directly supported by governments through two main instruments: border protection (mainly import tariffs) and volumetric production subsidies. Regulations mandating usage or blending percentages, and fuel-tax preferences, stimulate production directly as well. But whether that production occurs within a country’s borders or elsewhere depends in part on the level of border protection.

Most countries producing bio-ethanol apply a most-favoured nation (MFN) tariff that adds at least 20%, or €0.10 per litre, to the cost of imported ethanol (Table 3). The World Customs Organization (WCO), of which all OECD countries and Brazil are members, specifies two tariff lines for ethyl alcohol (ethanol) under its Harmonized Commodity Description and Coding System (HS): HS 2207.10 (undenatured ethyl alcohol of an alcoholic strength of at least 80% by volume) and HS 2207.20 (denatured ethyl alcohol of an alcoholic strength of at least 80% by volume). Most fuel-grade ethanol is traded in undenatured form – i.e. containing only pure ethyl alcohol and a small percentage of water. The United States further distinguishes between ethanol intended for use as a fuel from ethanol destined for beverages and other end uses, and charges an additional, "secondary" tariff on the former. The import duty on ethyl alcohol applied by Australia is set at the same level as the federal fuel excise tax on ethanol (and is among the highest in the OECD); however, domestically produced ethanol can qualify for a rebate of that tax.

Various exemptions from the MFN tariff and tariff-rate quotas apply. Biofuels are often charged at zero or reduced duty when imported from countries with which the importing country has signed a free-trade agreement, or which are covered by their General System of Preferences (GSP). The country coverage of these GSPs differ. Switzerland includes Brazil in its GSP, the EU does not. The United States maintains a low tariff-rate quota for ethanol imported from certain Caribbean countries under its Caribbean Basin Initiative.

Biodiesel, which is classified as a chemical under HS 3420.90, along with a wide number of other chemicals, is subject to much lower import tariffs than ethanol; these tariffs range from 0% in the Switzerland to 6.5% in the EU. Australia applies an excise duty of AUD 38.143 per litre on imported biodiesel, but as this duty is refunded, the effective duty is zero.

Table 3. **Applied tariffs on undenatured ethyl alcohol (HS 2207.10) during 2007 in several representative countries**

Country	**Applied MFN tariff (local currency or ad valorem rate)**	**At pre-tariff unit value of € 0.50/litre**		**Exceptions (in addition to other WTO member economies with which country has a free-trade agreement) or notes**
		Ad valorem equivalent (%)	**Specific-rate equiv. (€/litre)[1]**	
Australia	5% + AUD 38.143/litre	52%	€ 0.258	USA, New Zealand
Brazil	0%	0%	€ 0.000	Lowered from 20% in March 2006
Canada	CAD 0.0492/litre	%	€ 0.034	FTA partners
European Union	€ 19.2/hectolitre	38%	€ 0.192	EFTA countries, developing countries in GSP
Switzerland	CHF 35 per 100 kg	34%	€ 0.168	EU, developing countries in GSP
United States	2.5% + $0.51/gallon	22%	€ 0.110	FTA partners; CBI partners

1. At average exchange rates for the year.

Sources: GSI country reports and DG Trade, European Commission, "Market Access Database", http://mkaccdb.eu.int/mkaccdb2/indexPubli.htm

In addition to providing border protection, several countries and sub-national governments provide direct, production-related subsidies. The leading country in the use of these subsidies is the United States, which grants a USD 0.51 per gallon (€ 0.09 per litre) tax credit to blenders according to the amount of pure ethanol they bend with gasoline (petrol). The US federal government also grants a similar tax credit to companies that blend biodiesel with petroleum diesel. The credit is USD 1.00 per gallon (€ 0.18 per litre) for biodiesel derived from virgin agricultural fats and oils, and USD 0.50 per gallon (€ 0.09 per litre) for biodiesel derived from waste oils. An additional "federal small producer tax credit" of USD 0.10 per gallon (€ 0.02 per litre) is granted on the first 15 million gallons (56 million litres) of ethanol or biodiesel produced by plants with an annual capacity of less than 60 million gallons (225 million litres). Several US states provide their own volumetric subsidies to support in-state production of ethanol or biodiesel at rates equivalent to USD 0.20 per pure biofuel gallon (€ 0.04 per litre) or more. And in a few cases, these subsidies are contingent on the use of feedstock produced in the same state.

In March 2007 Canada announced that it would allocate CAD 1.5 billion over seven years towards an operating incentive to producers of renewable alternatives to gasoline, such as ethanol, and renewable alternatives to diesel, such as biodiesel, "under conditions where industry requires support to remain profitable" (Department of Finance Canada, 2007).[6] Payments rates from 2007 through 2009 will be up to CAD 0.10 (€ 0.07) per litre for renewable alternatives to gasoline and up to CAD 0.20 (€ 0.14) per litre for renewable alternatives to diesel, then decline thereafter. Uniquely, no government support will be provided when rates of return earned by producers exceed 20% on an annual basis. Support under the program to individual companies will also be capped. Concurrent with the implementation of the operating incentive programme, the Government has proposed that the *Excise Tax Act* be amended to eliminate the current exemptions for ethanol and biodiesel as from 1 April 2008.

Most other countries (and some US states) support biofuel use (and therefore production, where border protection is effective) through tax preferences tied to fuel-excise taxes or sales taxes (Table 4). These most commonly take the form of reductions in, or exemptions from, per-litre excise taxes normally charged on transport fuels. Brazil was one of the first countries to grant reductions in taxes applied to biofuels. Its national exemption for ethanol, worth about € 0.11 per litre, is topped up by even higher exemptions in some states. Thus ethanol sold in the State of São Paulo, benefits from a R$0.50 (€ 0.181) lower fuel tax than that applied by the state on petrol. Brazil's tax exemptions for biodiesel depend on the location and type of producer from which the vegetative feedstock was procured. It is highest for biodiesel made from castor or palm oil harvested from subsistence farms in the north and northeast.

The European Union has no Community-wide excise tax on transport fuels. Rather, it has authorized its Member States to grant tax preferences to biofuels, within limits. Expressed on a pure biofuel-equivalent basis, these range from 0 to € 0.60 per litre, with many in the neighbourhood of € 0.30 per litre. The Netherlands had offered a temporary fuel-tax exemption for biofuels in 2006, but stopped offering it when it introduced a blending mandate. Germany has followed a similar policy, but still offers a fuel-tax exemption for biodiesel and SVO when intended for use in unblended forms.

Canada began exempting the ethanol portion of blended fuels from the federal excise tax on petrol (now CAD 0.10 per litre) in the 1990s. It now grants an exemption to biodiesel as well. Most of Canada's Provinces have since created their own exemptions for ethanol, and British Columbia, Manitoba, and Ontario exempt the biodiesel proportion of fuel blends from their fuel excise taxes.

Switzerland, through 2007, besides exempting biodiesel, SVO and ethanol produced in approved "pilot and demonstration plants" from its fuel excise taxes, alsed exempts these fuels from the CHF 0.015 per litre of diesel levy collected by the Climate Cent Foundation to fund projects for CO_2 reduction.

Table 4. **Value of excise tax reductions or rebates for liquid biofuels as of 1 August 2007**[1]

Country	**Ethanol or ETBE**		**Biodiesel or pure plant oil**	
Province or state	**Local currency***	**US$ per litre of pure ethanol equivalent**	**Local currency***	**US$ per litre of pure biodiesel equivalent**
Australia[2]	AUD 0.38143/litre	0.314	AUD 0.38143/litre	0.314
Brazil				
Federal	R$ 0.30/litre	0.16	R$ 0–0.218/litre	0–0.12
São Paulo State	R$ 0.50/litre	0.27	—	—
Canada				
Federal[3]	CAD 0.010/l of E10	0.094	CAD 0.002/l of B5	0.038
Alberta	CAD 0.009/l of E10	0.085	—	—
B. Columbia	CAD 0.014/l of E10	0.132	CAD 0.007/l of B5	0.132
Manitoba	CAD 0.025/l of E10	0.237	—	—
Ontario	CAD 0.015/l of E10	0.142	CAD 0.007/l of B5	0.132
Quebec	—	—	CAD 0.152/l of B100	0.144
Saskatchewan[4]	CAD 0.015/l of E10	0.142	—	—

Country	Ethanol or ETBE		Biodiesel or pure plant oil	
Province or state	**Local currency***	**US$ per litre of pure ethanol equivalent**	**Local currency***	**US$ per litre of pure biodiesel equivalent**
EU				
Austria	€ 445 per 1000 litres (Unleaded) € 517 per 1000 litres (Leaded)	0.607 (Unleaded) 0.706 (Leaded)	€ 325 per 1000 litres	0.444
Belgium	€ 353 per 1000 litres (on 37,884 litres[5])	0.482	€ 163.1 per 1000 litres (on 250,760 litres[6])	0.223
Czech Rep.	Under consideration	—	€ 331.1 per 1000 litres	0.452
Denmark	€ 30 per 1000 litres	0.041	€ 354.9 per 1000 litres	0.484
Estonia	Complete exemption but fossil fuel rate unknown	—	Complete exemption but fossil fuel rate unknown	—
Finland	No exemption	—	€ 319 per 1000 litres	0.435
France	€ 330 per 1000 litres (ETBE: 224 648) (Ethanol: 337,147)	0.450	€ 250 per 1000 litres (1,342,503)	0.341
Germany	Quantities to reach mandatory blending: no exemption	—	Used as additive: no exemption any more but a quota obligation	—
	E85: ethanol exempted from excise tax of € 0.6545 per litre	0.893	Used as pure fuels: tax rebates for the amounts of biofuels exceeding the quota	—

Country	Ethanol or ETBE		Biodiesel or pure plant oil	
Province or state	**Local currency***	**US$ per litre of pure ethanol equivalent**	**Local currency***	**US$ per litre of pure biodiesel equivalent**
EU (continued)				
Greece	No exemption	—	€ 260 per 1000 litres	0.355
Hungary	ETBE: € 414 per 1000 litres	0.565	€ 340 per 1000 litres	0.464
Ireland	€ 442.7 per 1000 litres (67,087)	0.604	€ 368 per 1000 litres (52,816)	0.502
Italy	No tax exemption	—	€ 382 per 1000 litres (200,000)	0.521
Latvia	€ 270 per 1000 litres	0.369	€ 230 per 1000 litres	0.314
Lithuania	€ 278.8 per 1000 litres	0.381	€ 243.7 per 1000 litres	0.333
Luxembourg	No exemption	—	Pure biofuels only	—
Malta	An exemption exists but rate unknown	—	An exemption exists but rate unknown	—
Netherlands	€ 505 per 1000 litres	0.689	€ 305 per 1000 litres	0.416
Poland	€ 390 per 1000 litres	0.532	€ 260 per 1000 liters	0.355
Portugal	An exemption exist but data not available	—	An exemption exist but data not available	—
Slovakia	€ 372 per 1000 litres	0.508	€ 384 per 1000 liters	0.524

Country	Ethanol or ETBE		Biodiesel or pure plant oil	
Province or state	**Local currency***	**US$ per litre of pure ethanol equivalent**	**Local currency***	**US$ per litre of pure biodiesel equivalent**
Slovenia	Proportionate to the percentage of biofuels added but may not exceed 25% of the excise duty paid	Depends on market price	Proportionate to the percentage of biofuels added but may not exceed 25% of the excise duty paid	Depends on market price
Spain	€ 371.7 per 1000 litres	0.507	€ 269.8 per 1000 litres	0.368
Sweden	€ 530 per 1000 liters	0.723	€ 390 per 1000 litres	0.532
UK	€ 289 per 1000 litres	0.394	€ 289 per 1000 litres	0.394
Switzerland	CHF 0.7312 per litre	0.0.608	CHF 0.7587 per litre	0.631
USA				
Arkansas	$0.098/gal of E85	0.115	—	—
California	$0.090/gal of E85	0.106	—	—
Delaware	$0.010/gal of E85	0.012	—	—
Florida	$0.200/gal of E85	0.235	—	—
Hawaii	4% on E10 or E85	Depends on market price	4% on $\geq$B2	Depends on market price
Idaho	$0.025/gal of E85	0.029	$0.025/gal of B2	1.25
Illinois	$6.25% on >E70	Depends on market price	6.25% on >B10	Depends on market price
Indiana	$0.020/gal of E85	0.024	$0.010/gal of B2	0.50
Iowa	$0.020/gal of E10	0.200	—	—
Maine	$0.020/gal of E10	0.200	—	—

Country	Ethanol or ETBE		Biodiesel or pure plant oil	
Province or state	**Local currency***	**US$ per litre of pure ethanol equivalent**	**Local currency***	**US$ per litre of pure biodiesel equivalent**
Minnesota	$0.058/gal of E85	0.068	—	—
Missouri	$0.270/gal of E85	0.318	—	—
Montana	$0.041/gal of E10	0.410	—	—
New York	$0.420/gal of E85	0.494	$0.420/gal of B100	0.420
N. Carolina	$0.202/gal of E85	0.238	$0.202/gal of B20	1.01
N. Dakota	$0.220/gal of E85	0.256		
Oklahoma	$0.002/gal of E10	0.020	—	—
Pennsylvania	$0.041/gal of E10	0.410	—	—
S. Dakota	$0.020/gal of E10	0.200	—	—

* Where quotas exist, they are marked in parentheses and denominated in tonnes.

1. Rates refer to ethanol, biodiesel or pure vegetable oil content of fuels, unless otherwise indicated.
2. Excise tax is rebated in full for ethanol produced within Australia, and for all biodiesel.
3. Proposed for elimination effective 1 April 2008.
4. Refers to producer payment, which exactly offsets excise tax for ethanol produced in Saskatchewan.
5. On 48 million litres from 1 December 2007 through 31 December 2007.
6. From 1 January 2006 until 30 September 2007.

Sources: Updated from Steenblik (2007), based on GSI country reports (www.globalsubsidies.org).

Complementing many of the aforementioned production-related support measures are various targets and mandated requirements for the amount or share of designated "renewable fuels" consumed as components of ethanol-petrol or biodiesel-diesel blends. Some of these targets and mandates (confusingly called a "standard", which implies voluntary compliance, in the United States), do not discriminate by biofuel (Table 5a). Many others are specific to either ethanol or biodiesel (Table 5b). Some jurisdictions in the United States have linked implementation of the mandates with the development of in-state biofuel manufacturing capacity. Generally, where specific blending targets or requirements are set, they are higher for ethanol are than for biodiesel. Switzerland has so far avoided establishing even target future levels of biofuel use.

Table 5a. **Use and blending share targets (T) and mandates (M) for liquid biofuels that can be met by either ethanol or biodiesel**

Country	Type	Quantity or blending share	Comment
Australia	T	350 million litres by 2010	Indicative target
Victoria	T	5% by 2010	Voluntary but could become mandatory
EU[1]	T I M	5.75% by 2010 I 10% by 2020	2020 target refers to renewable fuels
Austria	M	2.5% by 2006, rising to 5.75% by 2009	
France	M	7% by 2010; 10% by 2015	
Japan	T	6 billion litres by 2020	
USA (federal)	M	2.78% by volume of gasoline consumption in 2006 (4 billion gallons , or 15 GL); 7.5 billion gallons (28 GL) by 2012	Of which 0.25 billion gallons (0.95 GL) must be cellulosic ethanol in 2013. Credit rate varies by feedstock.
Iowa	T	10% by 2009; 25% by 2020	

1. Member States' targets or mandates are listed only if they are more ambitious than the EU targets and mandated levels.

Source: Steenblik (2007, p. 28), based on GSI country reports (www.globalsubsidies.org)..

Table 5b. **Use and blending share targets and mandates specifically for ethanol or biodiesel**

Country	Ethanol			Biodiesel		
Province or state	**Type**	**Quantity or blending share**	**Year**	**Type**	**Quantity or blending share**	**Year**
Australia						
New South Wales	M	2% I 10%	2007 I 2011	–	None	–
Queensland	M	10%	2010	–	None	–
Brazil (federal)	M	25%	1966	M	2%	2008
	M	20-25%	1992	M	5%	2013
Canada						
Federal	M	5%	2010	–	2%	2012
British Columbia	M	5% (proposed)	2010	M	5% (proposed)	2010
Saskatchewan	M	1% I 7.5%	2005 I 2007	M	2.5% I 5%	2008 I 2010
Manitoba	M	8.5% (proposed)	expected early 2008	–	None	–
Ontario	M I T	5% I 10%	2007 I	–	None	–

Country Province or state	Ethanol Type	Ethanol Quantity or blending share	Ethanol Year	Biodiesel Type	Biodiesel Quantity or blending share	Biodiesel Year
			2010			
Quebec	M	5% (proposed)	2012	–	None	–
EU						
Germany	M	3.6%	2010		4.4%	2007
USA						
Hawaii	M	85% of gasoline must contain >10% ethanol	2006	–	None	–
Louisiana	M	2%	([1])	M	2%	([2])
Minnesota	M	20%	2013	M	2%	2005
Missouri	M	10%	2008	–	None	–
Montana	M	10%	([3])	–	None	
New Mexico	–	None	–	M	5%	2012
Oregon	M	10%	2007	M	2% ǀ 5%	2007 (2010)
Oregon (Portland)	M	10%	2007	M	2% (10%)	2007 (2010)
Washington(4)	M	2%	2008	M	2%	2008

1. Requirement starts to apply within six months after monthly production of denatured ethanol, produced in the state, equals or exceeds an annual production volume of at least 50 million gallons. To qualify, the ethanol must be produced from domestically grown feedstock.
2. Requirement starts to apply within six months after monthly production of biodiesel produced in the state equals or exceeds an annual production volume of 10 million gallons. To qualify, the biodiesel must be produced from domestically grown feedstock.
3. Requirement starts to apply within one year after the Montana Department of Transportation has certified that the state has produced 40 million gallons of ethanol and has maintained that level of production on an annualized basis for at least 3 months.
4. Requirement could apply earlier if a positive determination is made by the Director of the State Department of Ecology that feedstock grown in Washington State can satisfy a 2% fuel blend requirement. The biodiesel requirement would increase to 5% once in-state feedstocks and oil-seed crushing capacity can meet a 3% requirement.

Data sources: Steenblik (2007), based on GSI country reports (www.globalsubsidies.org).

3.2.2 Support to production factors and intermediate inputs

The main intermediate inputs used in the production of ethanol are the biomass feedstock, which in Brazil and Australia is mainly cane sugar or molasses; in Canada, wheat; in the EU grains, sugar beets and wine; in Switzerland wood-cellulose; and in the United States maize. Water, and fuels for providing process heat in the fermentation and distillation processes, are also important inputs to ethanol manufacturing, and methanol and sodium hydroxide to biodiesel manufacturing, but identifying subsidies to these inputs was beyond the scope of these studies.

One indicator of the degree to which the price paid for a product by consumers is raised by market-intervention policies is the consumer nominal protection coefficient (consumer NPC), which measures the ratio of the average price paid by consumers and the price at the border (both normalized to the price at the farm gate). Table 6 shows that in 2005, in most of the countries studied, the consumer NPC was close to unity for major biofuel feedstock crops – i.e. biofuel producers were not being penalized by policies that kept domestic prices for these crops higher than the same crops available from foreign suppliers.

There were some exceptions. Some potential ethanol feedstocks in several countries are made prohibitively expensive by policies, mainly border tariffs, that raise their internal prices. Thus, were domestic firms in Switzerland to start producing bio-ethanol from domestically grown crops, using a standard fermentation and distillation process, their costs of the feedstock would be much higher than faced by bio-ethanol producers in other countries. The consumer NPC for crops imply that wheat was 46% more, maize 91% more, other grains 76% more expensive within Switzerland than available on international markets. Prices for sugar were 250% more expensive (i.e. almost 3½ times the world price).[7] Not surprisingly, Switzerland produced just under 1 million litres of ethanol in 2005, based entirely on wood cellulose.[8]

Table 6. **Nominal consumer protection coefficients for crops used, or could be potentially used, as biofuel feedstocks, 2005**

	Sugar (source)	Starchy grains	Oilseeds
Australia	Sugar cane: 1.00	Common wheat: 1.00	NA[1]
Brazil	Sugar cane: 1.00	NA	Soybeans: 1.00
Canada	NA	Wheat: 1.00 Maize: 1.00	Rape seed (canola): 1.00
EU	Beet sugar: 2.40	Common wheat: 1.08 Maize: 1.29 Potatoes: 1.10	Rape seed: 1.00 Sunflower seed: 1.00
Switzerland	Beet sugar: 3.51	Wheat: 1.46 Maize: 1.91	Oilseeds: 3.87
United States	Cane & beet sugar: 2.09	Maize: 1.00 Sorghum: 1.00	Soybeans: 1.00

1. Biodiesel in Australia is made principally from tallow and waste cooking oil.
Sources: • **Brazil:** OECD (2005); • **All other countries:** OECD, Producer and Consumer Support Estimates, OECD Database 1986-2005,
www.oecd.org/document/55/0,2340,en_2649_37401_36956855_1_1_1_37401,00.html

3.2.3 Support to production factors

One of the most difficult forms of support to track to any industry is support for factors used in production, particularly capital plant. By definition, general policies designed to spur capital investment generally are not considered specific subsidies and therefore not counted in sectoral subsidy accounting. Specific budgetary allocations for grants, government loans or government guaranteed loans for capital investment are often reported, but details of the actual allocations (and in the case of loans and loan guarantees, the financial details) are less often made publicly available.

That certainly seems to be the case for public assistance to investments in biofuel plants, which have benefited from a host of subsidies, many provided by sub-national governments.

Brazil's sugar and sugar-to-ethanol industry benefited from some very large loans in the 1970s and 1980s, many of which were forgiven, or paid back at interest rates far below the prevailing market rates. It has been several years since the Brazilian government offered such assistance.

Numerous more recent examples can be found elsewhere, though in total the values provided are probably much less than the value of production-related incentives. In 2003, for example, Australia introduced an AUD 37.6 million Biofuels Capital Grants Program in an attempt to stimulate the development of new biofuel plants. Much more significantly, Section 1512 of the United States' Energy Policy Act of 2005 authorizes grants for building cellulosic ethanol plants, starting at USD 100 million in 2006 and rising to USD 400 million in 2008.

In several countries, grants and government loans have been used to increase farmer participation in biofuel plants. The US state of Minnesota, for example, specifically targeted farmer-owned ethanol co-operatives in its Ethanol Production Facility Loan Program, which ended in 1999. Similarly, in Europe, Austria provides support for biofuel production facilities up to 55% of the total investment costs as long as at least 51% of the facility in question is owned by farmers. Canada's Province of Manitoba has provided CAD 1.2 million in subsidies to support small and medium-size biofuel plants.

Canada, for the most part, however, has avoided providing pure grants for biofuel production facilities, preferring to offer loans. The Federal Government of Canada, for example, recently announced that it would provide CAD 200 million in loans to renewable fuels projects, starting April 2007. This follows an earlier "Ethanol Expansion Programme" which provided deferred-repayment loans worth CAD 117.5 million to support the construction or expansion of 12 ethanol plants across Canada.

One phenomenon increasingly witnessed in federal systems is what the US study calls "subsidy stacking" – the ability of investors to tap into multiple sources of public financing assistance. It is not uncommon for biofuel plants to benefit from municipal-government support, often in the form of free land or utility connections; state-level support, such as tax credits for investment, or economic development grants or loans; and support from federal agencies under various regional development, agricultural or energy programmes. In one specific plant examined in the US state of Ohio, more than 60% of the plant's capital is expected to be provided by government-intermediated credit or grants (Koplow, 2006).

Subsidies to value-adding factors, particularly for capital investments in new plants, are much smaller on a subsidy-equivalent basis than output-related subsidies, and many are provided under general programs. But because these government-intermediated loans and loan guarantees often shift the risk of default to the government body providing the assistance, a large number of communities have thereby committed a significant amount of public money to the future of biofuels production. The amount of public capital used, the degree of risk being taken, and the implications in terms of future local government dependence on the continuation of national biofuels subsidies are all important issues that warrant examining in greater depth.

3.2.4 Support for research, development and innovation

Most biofuel-producing countries have established government-funded programmes to support research, development and innovation in respect of different stages in the supply chain. Because of the multitude of specializations involved, from agronomy to combustion, and the different government agencies with an interest in biofuels (agriculture, energy, transport, environment), identifying all the programmes directly supporting the industry is not an easy task.

What does seem clear from the pattern of current funding across countries is that an increasing proportion of R&D funds are being channelled in support of second-generation biofuels, particularly cellulosic ethanol. Notable examples include:

- Canada's CAD 145 million Agricultural Bioproducts Innovation Program, which, beginning in 2007, will provide support for cross-sector research networks conducting scientific research and development related to the advancement of a Canadian bio-based economy.

- The EU's Sixth Framework Programme for research, technological development and demonstration, which will provide at least €68 million to, among other aims, support research in the area of biomass to develop second-generation biofuels and integrated biomass use through biorefineries.

- The United States' Biofuels Initiative, launched in 2006, which aims to accelerate research so as to make cellulosic ethanol cost-competitive by 2012. This multi-agency programme focuses on the use of non-food based biomass, such as agricultural waste, trees, forest residues, and perennial grasses in the production of transportation fuels, electricity, and other products. One of its goals is to displace up to 30% of the nation's transport fuel use by biofuels by 2030. Funding is around USD 150 million a year.

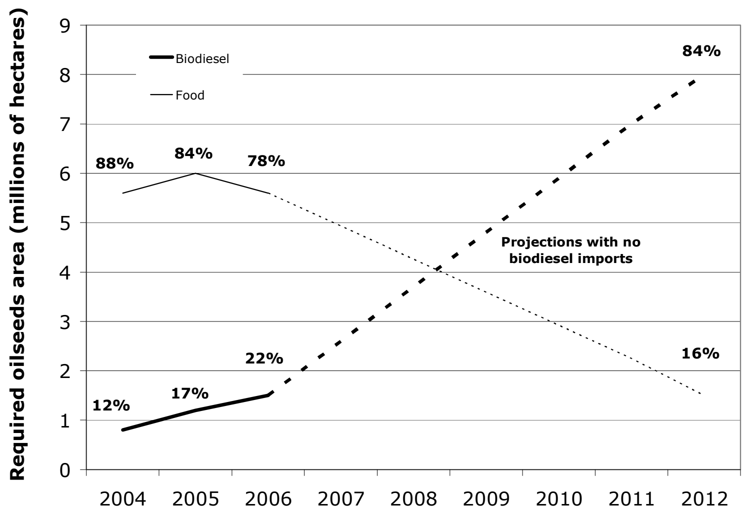
4. INTERNATIONAL MARKETS AND TRADE BARRIERS

Ethanol and vegetable oils have been travelling between countries for many decades. Ethanol was mainly imported for use in beverages or for industrial uses prior to the late 1970s. With the emergence of policies giving tax preferences to motor fuels blended with biofuels, particularly ethanol, however, a potential for an increase in traded volumes seemed likely. A major set-back occurred early on in the development of this trade, however, when the United States in 1980 imposed a so-called "secondary tariff" on imported fuel-ethanol.

With the return to high petroleum prices, and the creation of renewable-fuel targets in an increasing number of countries, trade in ethanol and vegetable oils is attracting attention once again. Because trade statistics do not distinguish fuel from other grades of ethanol, vegetable oils destined for use as feedstock from other uses, or biodiesel from other miscellaneous chemicals, it is not possible to determine precisely the volumes or the values being traded. However, a reasonable estimate is that in 2005 trade covered about 10% of the world's fuel ethanol consumption (Walter *et al.*, 2007). The percentage of vegetable oils used for biofuel feedstock (or as SVO) and biodiesel that was sourced abroad is unknown, but unlikely exceeded 10% of the market in 2005.

Trade is likely to grow in the future, if for no other reason than that limits to growth in production will be encountered in several of the main consuming countries of the OECD, particularly in Europe. Already, the area dedicated to growing oilseeds for energy use is taking up 22% of the land planted to oilseed crops in the EU. To meet its target volumes for 2012 would require dedicating 84% of its oilseed area – an unrealistic outcome (Figure 9). If, instead, the EU were to limit the oilseed area dedicated to biofuel feedstock to 50%, it would still need to import an additional 4.2 million tonnes of plant oils or biodiesel by 2012, compared with around 7.5 million tonnes (for both food and industrial uses) in 2006 (Jank *et al.*, 2007).

Figure 9. **Share of current and projected oilseed area that would be needed in order to meet EU targets for biofuels**



Source: Jank *et al.* (2007).

Nonetheless, a number of barriers to trade in biofuels and biofuel feedstocks remain. These are traditionally classified under two headings: tariff barriers and non-tariff barriers.

4.1. Tariff barriers

As discussed in Section 3.1, tariffs apply both to feedstock materials for making biofuels, and the biofuels themselves. The tariffs countries apply to ethanol and feedstocks for ethanol (especially sugar) are generally higher than for biodiesel or feedstocks for biodiesel (which can also be sold as SVO). For ethanol, the MFN tariffs range from roughly 6% to 50% on an ad-valorem equivalent basis in the OECD, and up to 186% in the case of India. Bound and applied tariffs on biodiesel in OECD economies are relatively low, varying between 0 and 7%. Tariffs applied by developing countries are generally between 14% and 50% (Steenblik, 2006).

Besides offering protection for domestic producers of these biofuels and feedstocks, enabling some production to take place that would not otherwise, the differential application of tariffs due to bilateral and regional trade arrangements and general systems of preferences, can be trade-diverting.[9] For example, prior to 1 July 2005, Pakistan benefited from Special Arrangements for Combating Drug Production and Trafficking under the EU's Generalized System of Preferences (GSP) anti-drug regime. Able to export its ethanol to the EU at zero tariff, it became the EU's second-leading foreign supplier of ethanol (Bendz, 2005). Once brought under the General Regime, Pakistan was still able to benefit from a 15% reduction in the import duty on ethanol for six months. But as of 1 January 2006, ethanol was withdrawn from the scope of the General Regime, which meant that Pakistan lost all preferences on its ethanol. Following the change in July 2005, Pakistan reported that the resulting loss of trade had led to the closing of two of its seven operating distilleries, and that another five new distilleries would probably abandon plans to begin operations due to uncertainties in the market situation (Bendz, 2005).

A similar fate could one day befall ethanol exporters in Caribbean Basin nations, which currently benefit from a special concession dating from 1983 that grants them tariff-free access to the US market on volumes up to 7% of US domestic consumption. Rather than produce ethanol themselves, most dehydrate ethanol imported from Brazil, a value-adding step that meets the US requirement that products qualifying under the tariff quota be "substantially transformed" if they do not originate from the countries themselves. In the past, Caribbean Basin nations have consistently been under-quota. But the prospect of exporting up to 9.3 billion litres of ethanol to the United States tariff-free (while still benefiting from the tax credit) – should President Bush's goal of using 35 billion gallons (132.5 billion litres) of alternative fuels by 2017 become mandated – is now attracting a flurry of new investments in dehydrating capacity (Etter and Millman, 2007). Almost all of this capacity would become redundant should the US Congress not renew the secondary tariff on ethanol when it expires at the end of 2008, or if it were to revoke the tariff-rate quota.

Another tariff-related issue concerns the classification of biofuels in the Harmonized System (HS). Because the tariff classifications do not correspond well with the how the biofuels are used, problems can arise with respect to consistency, certainty and non-discrimination in the application of tariffs (Howse *et al.,* 2006). Until the end of 2006, for example, Brazilian fuel ethanol entered Sweden not under the classification for denatured ethanol (HS 2297.20) but under the same HS sub-heading as used for biodiesel, HS 3824.90, which attracts a much lower rate of duty.[10]

4.2. Non-tariff barriers

In trade parlance, the term "non-tariff barriers" (NTBs) refers to a wide range of border and behind-the-border measures that may slow or inhibit trade. The UNCTAD Secretariat (UNCTAD, 2005) has produced a classification scheme for NTBs that defines the following categories:

- Government participation in trade and restrictive practices tolerated by governments;
- Customs and administrative entry procedures;
- Technical barriers to trade;
- Sanitary and phyto-sanitary measures;
- Specific limitations (such as quantitative restrictions);
- Charges on imports (other than tariffs, such as surcharges or port taxes).

Many non-tariff barriers, such as regulations relating to public health and safety, are recognized by the trade-policy community as essential. Other barriers, such as long delays in clearing customs because of over-bureaucratic customs and administrative-entry procedures, are regarded as generally worth streamlining. Here, only NTBs that are specific in their application to biofuels or their feedstocks are discussed. These are: government participation in trade and restrictive practices tolerated by governments, sanitary and phytosanitary measures, and technical barriers to trade.

4.2.1 Sanitary and phytosanitary standards

Biofuel feedstocks, final products and vehicles designed to run on biofuels often face sanitary and phytosanitary (SPS) measures or technical regulations applied at borders. SPS measures mainly affect feedstocks which, because of their biological origin, can carry pests or pathogens. One of the most common form of SPS measure is a limit on pesticide residues. Even though pesticide residues are regulated mainly to ensure the safety of food and beverages, and are much less of a problem in biofuels feedstocks that will undergo thermal or chemical processing, customs agents nonetheless may have no other choice than to apply the same regulations to vegetative biofuel feedstocks as to crops destined for human or animal consumption, especially if they have no way of determining the product's end use. Meeting pesticide residue limits is usually not difficult, but on occasion has led to the rejection of imported shipments of crop products, especially from developing countries (OECD, 2005).

4.2.2 Technical norms relating to product characteristics

In WTO parlance, technical regulations generally refer to mandatory requirements not covered by the SPS Agreement. In the area of biofuels, these concern the chemical and physical characteristics of the final product, as well as to regulations pertaining to how the biofuels or their feedstocks were produced and processed.

Regulations pertaining to the technical characteristics of liquid transport fuels, including biofuels, exist in all countries. These have been established in large part to ensure the safety of the fuels and to protect consumers from being sold fuels that could cause costly damage to their vehicles' engines.

Two types of technical regulations affect trade in biofuels: maximum levels of ethanol or biodiesel allowed in commercially sold blends with petroleum fuels, and regulations pertaining to the technical characteristics of the biofuels themselves.

Regulations pertaining to fuel characteristics are less of an issue for ethanol than for biodiesel. Ethyl alcohol is a simple chemical, and when sold as a fuel may contain water, trace amounts of impurities (such as methanol, chlorine and copper), and a denaturant, such as gasoline. Not all countries have created specific quality standards for fuel ethanol – in their absence, the standards that apply to neutral spirits suitable for making beverages, or to industrial-grade alcohol, are typically used – and thus some degree of variability in import requirements exists. (A listing of the applicable standards can be found at www.distill.com/specs/index.html.) Despite this variability in the levels of allowed denaturants and concentrations of impurities varying from one country to another, the regulations are generally not difficult to meet.

By contrast, many chemical and physical characteristics of biodiesel – such as density, viscosity, cetane value, flash point, iodine value and sulphur content – depend on the feedstock and how it has been processed, and can vary considerably. The definition of biodiesel applied by the World Customs Organization makes explicit reference to the ASTM (American Society for Testing and Materials) "Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels", or D 6751. However, under rules set out in the WTO's Agreement on Technical Barriers to Trade, Members are allowed to adopt their own regulations as long as they can justify them. Accordingly, the European Commission has issued its own norm (EN 14214), which in addition limits the iodine value of the biofuels to a maximum of 120 grams per 100 grams.[11] As Jank *et al.* (2007) point out, since soybean oil has a relatively high level of iodine, this regulation effectively limits the use of soy oil in biodiesel production to 20-25%. Biodiesel made from rapeseed oil, the principal biodiesel produced in Europe, has no trouble meeting the norm.

Biodiesel made from palm oil encounters problems meeting the standards of several countries. Because the temperature at which dissolved solids begin to form and separate from the oil (as measured by its "cloud point") is lower for palm oil than for most other nut or seed oils, biodiesel made from palm oil is less suitable for use in cold weather. This problem can be remedied through further processing, but it limits its use in climates like those of Northern Europe and Canada.

4.2.3 Sustainability standards and regulations

Increasingly more significant to biofuels trade are requirements imposed or considering being imposed on either feedstocks (such as palm oil) or final products that relate to non-product-related processes or production methods (PPMs). Discrimination in trade on the basis of PPMs is highly contentious, and has been the nub of several precedent-setting trade disputes at the WTO.

The different standards and regulations under consideration are discussed in more depth in a companion paper to this one, but may be summarized as falling into four broad categories:

I. *Private-sector standards,* which are promulgated by non-governmental bodies and are strictly speaking voluntary.

II. *Government voluntary standards,* which are often implemented in connection with positive labels, and are intended to reward (through the higher prices expected to be paid by concerned consumers) performance beyond the norm.

III. *Regulations linked to tax exemptions or subsidies,* which make eligibility to benefit from a government support measure or similar policy contingent on satisfying particular criteria.

IV. *Regulations linked to achievement of a domestic policy goal,* which make attainment of a domestic policy goal – e.g. meeting a sector-specific greenhouse-gas emission reduction target – dependent on certification of regulations or some stage in an imported product's production or processing.

The following paragraphs provide some examples of current and emerging standards and regulations.

Private-sector standards

Private-sector standards and certification schemes may be led by producers, consumers, and even by parties without a direct financial interest in the business, or any combination thereof. Numerous indicative standards are being developed at the national level, such as the US-based Institute for Agriculture and Trade Policy (IATP's) "Principles and Practices for Sustainable Biomass Production", which aims to improve the sustainability of biomass production in the upper Midwest (Kleinschmit, 2006a and 2006b). At the international level, stakeholders with interests in the oilseeds and sugarcane industries have formed, respectively, the Roundtable on Sustainable Palm Oil (www.rspo.org) and the Roundtable on Sustainable Soy[12], as well as the Better Sugarcane Initiative (www.bettersugarcane.org). These initiatives tend to be aimed at improving environmental and social standards of producers within the industry, often through creating voluntary codes of good practice.

At a more global, all-encompassing level, is the Roundtable on Sustainable Biofuels, formally launched in April 2007. The Roundtable, which is hosted by the Energy Center at the Ecole Polytechnique Fédérale de Lausanne, Switzerland, has assembled non-governmental organizations, companies, governments, inter-governmental organizations, experts, and other concerned parties "to draft principles and criteria to ensure that biofuels deliver on their promise of sustainability."[13] Four sets of criteria are being developed: greenhouse gas life-cycle efficiency; environmental impacts, such as impacts on biodiversity, soil and water resources; social impacts, ranging from labour rights to impacts on food security; and implementation (i.e. that the standards are easy to implement and measure). The Roundtable has set a target of early 2008 for its first draft standards. Its hope is that these standards will then "create a tool that consumers, policy-makers, companies, banks, and other actors can use to ensure that biofuels deliver on their promise of sustainability" (EPFL Energy Center, 2007).

Government voluntary standards

Government-endorsed sustainability standards that serve merely an indicative role are also emerging in many OECD countries, often initially as preludes to the adoption of standards or regulations linked to subsidies or environmental policies (van Dam *et al.*, 2006). At present, however, none are operating except as pilot schemes.

Standards linked to tax exemptions or subsidies

There is at least one operating and two proposed examples of type III standards in the world today. Brazil's Social Fuel Seal, which was created at the end of 2004 (Decrees 5297 and 5298) as part of a package of measures under the country's National Biodiesel Programme, strives to take into account regional social inequalities and the agro-ecological potential for biodiesel feedstock production of different regions. Certification enables biodiesel producers to benefit from reduced rates of taxation on biodiesel, compared with the rates normally applied to petroleum diesel. The rate of exemption is 100% for biodiesel certified with the Social Fuel Seal produced from castor oil or palm oil in the North and North-east regions, versus 67% for biodiesel produced from any source in other regions that do not qualify for the Social Fuel Seal. In the way that it operates, only Brazilian firms can qualify for the higher tax breaks.

In March 2007, the Swiss Government amended its Mineral Fuel Tax in a way that will in the future (probably starting in 2008) also tie tax benefits for biofuels to a system based on various environmental and social criteria (Box 4.1). Under the new rules, both domestic and imported biofuels that benefit from a reduced fuel excise tax require "proof of a positive total ecological assessment that ensures also that the conditions of production are socially acceptable". But, in addition, the government, "taking into account of the amount of domestically available renewable fuels, shall establish the quantity of renewable fuels that can be exempted from the tax at the time of the importation."

Even more recently, a group commissioned by the government of the Netherlands in 2006 submitted their proposals to the Dutch Minister of Housing, Spatial Planning and the Environment on how to create a market for sustainable bio-energy (Creative Energie, 2007).[14] The report proposes that access to any subsidies for biofuels be contingent on satisfying nine major criteria and numerous sub-criteria (Annex 1). According to Rembrant (2007):

> Many of these criteria still need to be worked out in further detail regarding how to monitor their compliance by bioenergy companies. A preliminary system with less stringent criteria will come into effect in the course of 2008 when the new subsidy scheme for sustainable energy of the Dutch Government will start to function. After that several years of development and testing will take place, [so] as to put the full system of criteria with the relevant indicators and monitoring systems in place in 2011. By then, the European Commission probably will have proposed a similar system for the entire European Union.

Box 4.1. The 23 March 2007 Amendments to Switzerland's Mineral Oil Tax Law pertaining to tax exemptions for biofuels

Article 12b — Tax exemption for fuels derived from renewable raw materials

1. Domestically produced fuels derived from renewable raw materials are exempted from the [mineral oil] tax in accordance with Paragraph 3.

2. The Federal Council, taking into account of the amount of domestically available renewable fuels, shall establish the quantity of renewable fuels that can be exempted from the tax at the time of the importation. This tax exemption can be granted only if the requirements of Paragraph 3 are also met.

3. The Federal Council shall establish for fuels derived from renewable raw materials:

a. The amount of the tax exemption, taking into account:

1. in particular, the domestic supply of renewable raw materials;

2. the contribution that these fuels will make to environmental protection and the objectives of [the country's] energy policy;

3. the competitiveness of these fuels compared with fuels of fossil origin;

b. the minimal requirements relating to the proof of a positive total ecological assessment that ensures also that the conditions of production are socially acceptable.

Taken together, the proposed criteria are extremely stringent, and would be a challenge to satisfy, even by many producers in OECD countries. Moreover, they are in several cases highly prescriptive. For example, Criterion 2.2 stipulates that the biomass production "will not take place in areas with a high risk of significant carbon losses from the soil, such as certain types of grasslands, peat lands, mangroves and wet areas." Would that bar, for example, ethanol produced from tapping mangrove palms in Malaysia – a practice that would seem to actually *encourage* the reservation of the carbon in these soils?

Regulations linked to achievement of a domestic policy goal

The leading example of this type of regulation is the UK's Renewable Transport Fuel Obligation (RTFO). Beginning 1 April 2008, the RTFO will oblige fuel suppliers to ensure that a certain percentage of their aggregate sales is made up of biofuels – 5% by 2010. Obligated companies will be required to submit reports on both the net greenhouse gas saving and sustainability of the biofuels they supply. This information, in turn, will be used to develop sustainability standards, which may be imposed if the RTFO is extended.

Although the reporting requirement does not (yet) discriminate among sources, failure to report makes a fuel supplier ineligible for any certificates proving that they have met their biofuel obligations. It remains to be seen whether the reporting obligation will bias the fuel suppliers towards biofuel producers whose records are comprehensive, and in English, and whose claims can be easily verified by inspection. Moreover, as described in the UK Department of Transport's web page on "Frequently Asked Questions"[15], the Administrator of the RTFO expects that these reports, once published, will constitute a "league table" of suppliers and biofuel producers, thus encouraging better performance.

Longer term, the scheme could evolve into one that specifically links RTFO certificates with GHG savings determined though a standardized GHG certification system. Already, a feasibility study, commissioned by the UK government (Bauen *et al.*, 2005), has recommended such a scheme.

On 18 January 2007 the Governor of California established a Low Carbon Fuel Standard (LCFS) by executive order. The LCFS requires that the carbon intensity of transportation fuels sold in California be reduced by at least 10% by 2020. Two weeks later, the European Commission announced a new pollution standard for motor fuels that is almost identical to California's. Both plans would rely on developing an agreed method for measuring the full fuel-cycle carbon output of alternative fuels and a system of certification of the life-cycle carbon emissions of fuels, including biofuels. However, the Commission plans also to allow only those biofuels whose cultivation complies with minimum sustainability standards to count towards the EU's renewable fuel targets. Collabouration between the EU and California aims at ensuring that their standards and rules converge and provide a more seamless market for fuel producers and distributors.

4.2.4 Possible effects on trade

It is too early to say whether any of the sustainability certification schemes in existence or proposed will on balance enhance or hinder trade. Today it is recognized that private-sector standards can have a small or a big effect on trade, depending on the share of the market they cover, the way they are implemented, their complexity, and so forth. At the moment, none of the private, voluntary standards appear to be influencing trade flows or volumes. But these are still early days.

In respect of to "sustainability requirements" imposed by governments, often compliance with the standards themselves is the least of an exporter's concerns. Rather, the proliferation of different standards may be problematic, or the process of accrediting local certifiers may be onerous, thus requiring inspection by experts from abroad, which can raise the costs of producing for foreign markets considerably (OECD, 2005). Fortunately, the fact that countries and non-governmental organizations seem to have acknowledged these types of potential problems early suggests that some of barriers created by national regulation of organic product standards (see OECD, 2005) may be avoided in the case of biofuels. Encouragingly, the EU, for one, has expressed its intention to apply its proposed system of certificates in a non-discriminatory way to domestically produced biofuels and imports (EC, 2005).

4.3. Future changes in trade policy

Until around 2003, to the extent anybody used the words "ethanol" and "trade policy" in the same sentence, it was most likely in the context of ensuring that tariffs protecting domestic producers remained in place. Nowadays "biofuels" and "trade round" are being linked at every turn, though those making the linkage have very different agendas, and thus are advocating different ideas.

One of the discussions into which liquid biofuels have been injected are the negotiations on liberalizing trade in environmental goods and services (paragraph 31(iii) of the Doha Development Agenda). These negotiations have been taking place mainly in the WTO's Committee on Trade and Environment, meeting in special session (CTE-SS), which has been set the task of identifying which goods (i.e. tariff lines) should qualify as "environmental" when the issue of modalities for implementing the mandate is taken up in the Negotiating Group on Non-Agricultural Market Access (NAMA). The CTE-SS discussions have been stymied by disagreement between OECD member economies and a large number (though not all) developing countries over whether normal liberalization of trade in environmental goods, as opposed to liberalization on a project-by-project basis, is in everybody's best interest. Nonetheless, that has not prevented some of the WTO members who have remained non-commital in this dispute from suggesting that if they *were* to support the liberalization of particular goods, their priority products would be ethanol and associated technologies.

Many WTO Members, including virtually all OECD countries, have pointed to the fact that ethanol is covered by the Agreement on Agriculture, which, they insist, disqualifies it for consideration as an environmental good. Biodiesel is not burdened by that classification problem, by contrast, and at one point was being proposed by several OECD member countries (e.g. Canada and New Zealand) for inclusion among a draft WTO list of environmental goods. This was a rather uncontroversial suggestion, as applied *ad valorem* tariffs on biodiesel, which is classified as a chemical rather than an agricultural product, are already 6.5% or less in OECD countries.

Alas, the negotiations on environmental goods and services came to a standstill in July 2006, along with the rest of the Doha Round multilateral trade talks, primarily over one issue: agriculture.

Enter biofuels to the rescue! Production of biofuels, it is assumed, by absorbing surplus production will allow developing countries either to sell more commodities to the industrial North, or transform more of their commodities, such as sugar and sweet sorghum, into biofuels, both for their own use and for export.

The notion that biofuels hold the key to unlocking the Doha Round trade negotiations already has some powerful supporters. The United Nations Foundation, the foundation endowed with a USD 1 billion grant from US media tycoon Ted Turner, has been in the vanguard. At the WTO's September 2006 Public Forum, Mr. Turner hailed biofuels as ushering in a brave new world in which low commodity prices will be a thing of the past, and agricultural export subsidies would disappear. Details on exactly what kind of deal he would like to see are sketchy, but it appears that it would involve a shift in subsidies from crop production to biofuel production: As Mr. Turner recommended at one point in his speech, "Developed countries should agree to phase out tariffs and reduce their subsidies for food and fiber crops and replace them with support for biofuels." (Turner, 2006)

Meanwhile, another group, calling itself Biopact (www.biopact.com), is working for "a green energy pact between Europe and Africa". It's "Biofuels Manifesto", written by John Mathews, a professor of Strategic Management at Macquarie University, Sydney, calls for, among other policy changes, the elimination of barriers to trade in biofuels: "Here the WTO has an enormously important role to play", writes Mathews, "in ensuring that the coming biofuels century is not wrecked at the outset by greedy and short-sighted protectionist measures enacted by the developed world to obstruct global trade in biofuels."

While there may be increasing agreement that biofuels hold the key to re-opening the WTO trade negotiations, there are major differences of opinion on the desired outcome. One scenario envisages a WTO deal on agriculture that legitimizes current and future subsidies to domestic production of ethanol and biodiesel; the other envisages reducing or bringing down barriers to trade in biofuels, including trade-distorting subsidies.

Of course, subsidies and tariffs benefiting crops used as inputs to biofuels (sugarbeets, maize, wheat and oilseeds) are not the only ones that are contentious at the WTO. Agreement needs to be reached on how to treat continuing high levels of support for cotton, rice and livestock products (particularly dairy products). Indeed, as feed prices are driven up by diversion of crops to biofuel production, livestock producers are finding themselves in a squeeze. We should not be surprised if they start demanding offsetting subsidies as well.

Meanwhile, in the absence of a renewed Agreement on Agriculture, trade policies affecting biofuels continue to be made. Recently, for example, the US Congress extended its USD 0.54 per gallon (USD 0.143 per litre) MFN tariff on ethanol imported for fuel uses. That tariff had been due to expire at the end of September 2007; it will now remain in place until at least 31 December 2008. “At least” is a judicious phrase: a bill was introduced in the US Congress early in January 2007 to make the tariff permanent.

5. POLICY IMPLICATIONS

The policy implications of government interventions in the market for biofuels – particularly use or blending mandates and production-linked subsidies and tax breaks – are manifold. The world is only just beginning to witness some of the effects of policies in this area, and not all are intended. This section provides only a brief overview of the implications that continued subsidization of biofuels has for agricultural markets, energy, environmental and transport policies.

5.1. Impacts on agricultural markets

The motivations for supporting biofuels have been surprisingly constant across countries. In all cases, the desire to stimulate new demand for crops in order to raise prices has been paramount. Although spokespersons for the Brazilian ethanol industry stress the emphasis given to find domestic substitutes for imported petroleum when the country embarked on its Proalcol programme in the 1970s, the depressed international price of sugar at the time was also an important factor. Similarly, policymakers in the United States and the EU have emphasized the opportunity growing crops for energy holds for its farmers. Frustrated by decades of propping up their farming sectors, they point to the “savings” in price-linked commodity payments that will result as prices for sugar, starch and oil crops rise.

Until recently, policies in OECD countries to promote biofuels provided an additional outlet for crops, helping at the margin to absorb surpluses, without substantially affecting end-user prices. Since 2005, however, prices for all crops used as inputs to biofuel production have risen dramatically (Tables 1 and 2).

In the United States, for one, the rises in the prices of corn and soybeans translate into smaller levels of certain crop-related government subsidies for 2006 and probably for 2007 (Annex Table 1). However, any savings to be squeezed out of the main price-triggered commodity support programmes – counter-cyclical payments and marketing loan benefits (loan deficiency payments, marketing loan gains, and certificate exchange gains) – have for the most part been realized. Meanwhile, the volumetric excise tax credits for ethanol and biodiesel – the main federal support mechanisms for biofuels in the United States – can be expected to continue to grow along with increased production. Thus while farm payments in 2007 are forecast to be at the same level as for 2002 (USD 12.4 billion), the total of farm payments *plus* the excise tax credits is forecast to be USD 16.4 billion. This is USD 2.9 billion more than the total of farm payments plus the excise tax exemptions in 2002. By 2010, losses to the US Treasury from domestic biofuel production (i.e. not counting tax credits paid on imported biofuels) could reach USD 6.8 billion a year. Note also that one effect of support for biofuels has been to raise the value of farm assets, particularly land. While this benefits existing land owners, it raises costs for those who lease land for farming, and also the cost of reserving land for conservation purposes.

Producers of the feedstock crops number among the winners of the biofuels boom, of course, at least in the short term. (Time will tell whether there will be a biofuel bust.) The effect on livestock producers has been more mixed, however. The cattle industry, or at least that part of it in the proximity of grain-ethanol plants, has experienced only moderate rises in the price of protein feeds – thanks to increased production of dried distillers' grains with solubles (DDGS). Producers of pigs and poultry, however, have had to contend with steep increases in the prices of energy grains, such as maize.

Rising prices are also affecting the bottom line of companies that purchase sugar, wheat, maize and oilseeds as inputs into foods and other consumer products. Much has been made of the so-called "tortilla crisis" in Mexico, which witnessed a 60% rise in the price of tortillas – a staple food of poor families – in December 2006 (Navarro, 2007)[16], but there have been other industries that have been adversely affected as well, including manufacturers of soap (who use tallow), pasta and beer.

5.2. Energy policies

The idea that producing biofuels at home will reduce a country's dependence on foreign sources of energy, particularly oil from the Middle East, has also helped increase the political popularity of biofuels. This rational, present at the time that Brazil's and the USA's first biofuel-support programmes were crafted, waned during the 1980s and 1990s, but has recently returned to centre stage.

Security of supply is perhaps the pre-eminent goal of "energy policy", often expressed in terms of minimizing risk of interruptions in supplies (such as imports of petroleum or natural gas, or electric-power outages), but more accurately stated in economic terms. Basically, all else equal, governments want to keep prices of energy low, minimize volatility and reduce the environmental impact of energy.

Most OECD countries have active departments in their Energy Ministries to promote renewable energy. Since the shock of the 1973-74 oil crisis, renewable energy has been widely viewed as an intrinsically "good thing" – produced at home, often "high tech", and not dependent on finite stock resources. Biofuels gained the coveted "renewable energy" label as soon as they started to be produced again in the 1970s. No matter that many of the inputs used to produce them are decidedly non-renewable – soils, agrichemicals, fossil fuels – the label has stuck. This labelling has benefited the industry politically to the extent that it has deflected criticism. Who can be against renewable energy?

Public subsidies to biofuels are often proposed as a way to wean a country from its dependence on fossil fuels in general, and petroleum in particular. How efficiently biofuels subsidies help to reduce reliance on petroleum, or on fossil fuels in general, depends on the amount of petroleum (or fossil energy in general) invested in creating and delivering the biofuel to the final user.

The production of ethanol, except in countries producing it from cane, relies heavily on fossil fuels, particularly natural gas. Unfortunately, natural gas markets are developing many of the same supply insecurities as exist with imported oil. Coal can also be used to fuel ethanol refineries, as is becoming commonplace in China, and to a lesser extent in the United States, but that then worsens the environmental profile of ethanol substantially.

The degree to which the use of biofuels displaces petroleum (and fossil) energy varies fairly widely across estimates by different researchers, even when system boundaries have been standardized. For the US study, Koplow (2007) side-stepped this controversy by simply using the highest and lowest normalized values from a range of life-cycle analyses. He found that both ethanol and biodiesel provide fairly good petroleum displacement, though at a high cost. To displace one GJ of liquid petroleum fuels with ethanol, for example, cost anywhere between USD 12 and USD 18 in subsidies. That is equivalent to about € 0.32 per litre of petrol displaced, and is in addition to what the consumer pays for the fuel at the pump. Similar poor cost-effectiveness was reported by Steenblik (2007) for other OECD countries.

Displacement factors for fossil fuels overall are considerably worse for biodiesel and starch-based ethanol than for cellulosic ethanol. This is due to a fossil-intensive fuel cycle, including feedstock production and high consumption of natural gas within the plants themselves. Nonetheless, even the cellulosic process (assuming similar subsidies per litre as for starch-based ethanol) would still require between USD 23 and USD 58 in subsidies per GJ of fossil energy displaced. It is not clear that this would be competitive with alternative strategies, especially those that took into consideration the potential for demand-side measures.

In the current rush to promote biofuels, the demand side of the equation has almost been forgotten. Even the most ardent proponents of biofuels concede that starch-based ethanol takes a considerable amount of energy to make, and that the net yield is modest. That is not surprising for any supply-side approach. By comparison, a litre of gasoline or diesel conserved because a person walks, rides a bicycle, carpools or tunes up his or her vehicle's engine more often is a full litre of gasoline or diesel saved, at a much lower cost to the economy.

Because most liquid biofuels will be consumed as blends with gasoline or petroleum diesel, biofuels will for some time to come be complements to petroleum-based transport fuels, not major competitors with them. This complementarity is illustrated in some of the unintended consequences of policies (regulatory or tax incentives) to encourage the production and purchase of automobiles capable of running on pure petrol (gasoline) or any ethanol-petrol blend up to E85 (a blend of 85% ethanol by volume and 15% petrol) or even pure ethanol. Brazil's first supported the sale and consumption of cars designed to run only on 100% hydrous ethanol. These were not flex-fuel vehicles (FFVs), as they could not use gasoline. The policy was a success, measured by share of the market, but ended in tragedy in the 1980s, when high sugar prices and low petrol prices resulted in shortages of hydrous ethanol, and long queues at filling stations. The market for alcohol-only vehicles dried up almost over night. More recently, automobile manufacturers have started selling true FFVs, and now the majority of new cars bought are flex-fuel. But the actual fuel they consume depends on the relative prices of ethanol and gasoline.

The United States took a regulatory approach to promoting FFVs. Rather than subsidize FFVs directly, the US Congress allowed makers of FFVs (and several other approved categories of alternative-fuel vehicles) to obtain credits against corporate average fuel-economy (CAFE) standards. The problem with what came to be known colloquially as the "dual-fuel" loophole was it depends only on "capability" to use E85, not actual use. The motivating hypothesis was that, as the number of FFVs on the road increased, pumps for dispensing E85 would follow. It did not happen that way.

As a result, the vast majority of owners of FFVs ran their vehicles exclusively on gasoline, and many were not even aware that their vehicle could run on E85. Moreover, because the fuel-economy credit for FFVs in the United States is greatest in respect of the least-efficient models, automobile manufacturers have concentrated on the larger, more-expensive end of the market –

sport utility vehicles (SUVs) and “light trucks”. Even in 2005 (the latest year for which figures are available), only 25% of the FFV models sold in the United States were sedans or minivans; the rest were SUVs, light trucks, or “medium-duty” vehicles. The consequence of avoiding having to comply with tighter fuel-economy standards means that the United States in 2005 actually imported 80,000 more barrels of oil a day than it would have in the absence of the dual-fuel loophole (MacKenzie *et al.*, 2005).

5.3. Environmental policies

Another motivation for supporting liquid biofuels has come from their emission profiles when used as motor fuels. Especially when compared with low-grade gasoline and diesel, liquid biofuels generate lower levels of particulate matter and sulphur oxides. Ethanol also boosts the octane level of gasoline, and is generally considered less harmful to human health than other octane boosters, such as lead- or methyl-tertiary butyl ether (MTBE). Such factors have been important in gaining support for biofuels in the cities of the United States, and to some extent Brazil and Europe.

In Europe, biofuels are supported because, by substituting for fossil fuels, they can (depending on the production process) reduce global emissions of carbon dioxide (CO_2), an atmospheric gas that helps to retard the escape of infra-red radiation from the earth and thus keep it warm. Since the oxidation of the carbon bonds in the biofuel are counterbalanced by the uptake of CO_2 by the feedstock plant material, the photosynthetic and combustion portions of the biofuel life cycle are carbon-neutral.

By contrast, the intermediate stages of the cycle – planting, fertilizing, harvesting, transporting and transforming the feedstock crops into biofuels and their byproducts – can require substantial energy inputs. Moreover, if growing the feedstock crops involves exposing carbon resident in the soil to air, or burning down forests, additional CO_2 may be released into the atmosphere. Whether the CO_2 emitted in the various stages of biofuel production (and how one counts those emissions) exceeds the CO_2 absorbed by the crops was already a topic of fierce debate in the 1980s, and remains so today. That the emission balance can vary widely depending on the type of crop, agricultural system, and the technology for transforming it into a biofuel, is, at least, widely acknowledged.

Once the intermediate stage is taken into account, the cost of obtaining a metric ton of CO_2-equivalent (tCO_2-eq) reduction through subsidies to biofuels can prove to be much higher than alternatives. In most OECD countries, existing incentives cost over USD 250 to offset one tCO_2-eq (Table 7). (If the heat source for processing is coal, the GHG gain is small or even negative.) Yet even under best-case scenario assumptions for GHG reductions from biodiesel or starch-based ethanol, one could have achieved far more reductions for the same amount of money by simply purchasing the reductions in the marketplace. In 2006, the highest prices at which futures contracts for carbon offsets were exchanging hands on the European Climate Exchange were € 35 (USD 44) per tCO_2-eq; on the Chicago Climate Exchange they sold for no more than per USD 5 per tCO_2-eq. Subsidizing ethanol made from cellulosic sources of biomass would improve the cost-effectiveness of current incentives, but the rate per tCO_2-eq would still be higher than for many other investments. Koplow (2007) calculated that current ethanol subsidies would still cost more than USD 100 per metric ton of CO_2 equivalent avoided even if the ethanol had the emission profile of cellulosic ethanol.

Table 7. **Order-of-magnitude subsidies to ethanol and biodiesel per metric ton of CO_2-equivalent avoided in selected OECD countries in 2006**

(USD per metric tonne of CO_2-equivalent, rounded to the closest USD 50)

OECD economy	Ethanol	Biodiesel
United States[1]	300 – (600)	250 – (850)
EU[2]	700 – 5000	250 – 1050
Australia[3]	400 – 800	150 – 300
Canada[4]	250 – 1900	250 – 450
Switzerland[5]	300 – 400	250 – 2000+

(1) Number in brackets indicates a negative value – i.e., that net GHG emissions are being subsidized. Some estimates suggest that GHG emissions are actually increased on a life-cycle basis under certain assumptions regarding input energy.

(2) The range for ethanol reflects differences in displacement rates between imported ethanol produced from sugarcane and ethanol produced from wheat using lignite as a process fuel; the range for biodiesel reflects differences between methyl ester produced from used cooking oil and rape methyl ester.

(3) The range for ethanol reflects differences in displacement rates between ethanol produced from waste wheat starch and the high end of estimates for ethanol produced from C-molasses; the range for biodiesel reflects differences between methyl ester produced from used cooking oil and rape methyl ester.

(4) Provisional estimates. The range for ethanol reflects differences in displacement rates between ethanol produced from wheat and ethanol produced from maize; the range for biodiesel reflects differences between methyl ester produced from used cooking oil and rape methyl ester.

(5) The range for ethanol reflects uncertainty as to the displacement factor for ethanol produced as a by-product of cellulose production; the range for biodiesel reflects differences between methyl ester produced from used cooking oil and rape methyl ester produced in the country from domestically grown oilseed rape.

Source: Updated from Steenblik (2007), based on GSI country studies.

Environmental policy concerns more than just emissions of air pollutants and greenhouse gases. In respect of soils and water, the expansion of crops for biofuels can actually have negative effects. Already, rapid growth in demand for biofuel feedstocks, particularly maize and soybeans, is changing cropping patterns in the US Midwest, leading to more frequent planting of corn in crop rotations, an increase in corn acreage at the expense of wheat, and the ploughing up of grasslands. Maize is also a crop that requires lots of water, and the current trend in the expansion of maize-based ethanol is westward, into areas that are more dependent on fossil water sources, like the Ogallala Aquifer, than is corn produced in the central Midwest. The ethanol plants themselves also require significant volumes of water, and reports in the press of local concerns over their effects on water supplies are appearing with increased regularity.

Proponents of cellulosic ethanol argue that a broader mix of indigenous feedstocks would address many of these problems. However, once cellulosic acreage is scaled to provide meaningful displacement of gasoline, many similar issues regarding crop diversification, land conversion, and the need for additional inputs like water and fertilizers could arise.

5.4. Transport and related tax policies

Even though many of the arguments used to support liquid biofuels are aimed at the very heart of industrialized countries' transport systems – vehicles propelled by internal combustion engines –

transport Ministries have generally been the policy takers rather than the policy makers with respect to biofuels. Transport planners and economists, as a rule, are sceptical of biofuels, and are often heard to argue that they are an expensive way to achieve public-policy objectives. Generally, this policy community has simply had to endure policies to support liquid biofuels that have been imposed on them by Parliaments.

Perhaps the largest intersection with transport policies has been the numerous exemptions from fuel excise taxes. In many countries, the revenues from these taxes flow straight into the treasury, and are not truly an element of "transport policy". In Canada, Switzerland and the United States, however, revenues from fuel-excise taxes are hypothecated to separate Trust Funds, from which investments in transport infrastructure are financed.

The United States was one of the first OECD countries to exempt ethanol-petrol blends from a fuel-excise tax, in 1979. The exemption was worth \$0.04 per gallon of "gasohol" (E10), or \$0.40 per gallon of pure ethanol. This had the unintended economic consequence of reducing appropriations from the Highway Trust Fund even to states that sold no gasohol. Rask (2004) estimates that between 1981 and 1996, US state governments lost between USD 3.2 billion and USD 7.6 billion in highway funds (compared with the counterfactual of no federal tax relief on gasohol), and that some of the biggest losers were states such as Florida, New York, and Pennsylvania, which during those years sold very little fuel containing ethanol.[17] The haemorrhaging of the Highway Trust Fund only came to an end with enactment of the 2004 JOBS Creation Act, which eliminated the federal tax exemption for E10 and replaced it with a \$0.51 per gallon (€0.11 per litre) credit against corporate income tax, called the Volumetric Ethanol Excise Tax Credit (VEETC). Meanwhile, at least one-third of US states continue to apply lower fuel taxes to E10, E85, or biodiesel blends.

Switzerland has taken a slightly different approach. Although legislation passed by its Parliament in October 2006 would in the future exempt all liquid biofuels from at least a portion of the normal fuel-excise taxes, not just liquid biofuels produced in recognized "pilot and demonstration plants", the new policy is intended to have a neutral effect on the total stream of revenues from fuel taxes. The government will maintain this revenue neutrality by raising taxes on petroleum-derived liquid transport fuels.

Many policies (beside the kinds described in the previous section on energy) have been used at a local level to favour flex-fuel vehicles, sometimes in creative ways. For example, in Sweden, company cars powered by ethanol have qualified for an 80% reduction of the (taxable) benefit attributed to users, compared with that which would have to be declared for a comparable "conventional" automobile. In addition, "clean cars" (for which FFVs qualify) enjoy free parking in several cities and are also exempted from the congestion charge recently introduced in Stockholm.

London, England's congestion charge – which is intended to reduce traffic in inner London, and all the externalities (unproductive time, air and noise pollution) that go along with it – has come under criticism from car manufacturers for not allowing an exemption or reduction in the charge for FFVs.

It is reasonable to ask, if congestion charges and similar policies are aimed at reducing traffic *per se*, why any vehicle that adds to the traffic should be exempt from a congestion charge. Even the reduced pollution argument for exempting FFVs is difficult to uphold, since it would be impractical to verify whether at any time an FFV is running on E85, pure gasoline, or some ethanol-gasoline blend in-between.

Across the Atlantic, municipalities in the United States have implemented all manner of exemptions from regulations and charges to favour FFVs. Some have allowed them to use special lanes set aside for HOVs (high-occupancy vehicles) – lanes on motorways normally reserved for vehicles carrying two or more people – even when the FFVs are being driven solo. Others have exempted FFVs from having to pay for parking. And several states have offered differential regulations, such as exempting FFVs from emissions testing (Koplow, 2006).

In the meantime, rapid changes in the pattern of freight transport are taking place in several countries as a result of increased movement of biofuels and their feedstocks. In Brazil, increasing export demand for its ethanol is encouraging major investments in dedicated long-distance ethanol pipelines and terminals.

Numerous states and municipalities in the United States are helping to finance the upgrading or construction of new rail spurs to biofuel, particularly ethanol, plants. Of course, the more money is invested in transport infrastructure to bring ethanol from the American heartland to the coastal megalopolises – where the majority of transport fuel is consumed – the harder it will be, politically, to eliminate the tariff that keeps cheaper, imported, ethanol from being delivered directly to these areas by ship.

6. CONCLUSIONS AND RECOMMENDATIONS

The settings of current production-linked support – the per-litre rates of subsidization – are highly arbitrary, and warrant re-examination. Overlapping programs may also carry a high cost for little benefit in terms of energy infrastructure. In a number of countries, production of biofuels is subsidized even though their consumption (through blending mandates or targets) is pre-determined. The maintenance of high tariffs on imported ethanol by Australia, the EU and the United States, in particular, sits at odds with the professed policy of their governments to encourage the substitution of gasoline by ethanol.

One indicator of the long-run cost-effectiveness of a public policy that is aims at reducing the use of a particular good, or the externalities associated with using that good, is how prescriptive it is about the alternatives. When the profile of the ideal desired alternative – e.g. a source of automotive power that is cheap, clean and flexible – requires unpredictable technological change, prudent policy would keep as many options open as possible.

Current biofuel support policies in OECD countries score low in terms of technological neutrality. Most are not linked to a specific process for producing ethanol or biodiesel, but they are specific to biofuels, or even to a particular biofuel, particularly on the consumption side. Mandates for biofuel use in transport fuels, while not yet at a level that risk crowding out other transport alternatives (e.g. hybrid cars that can run on biofuels), nonetheless send a strong signal by governments that they are committed to personal transport based on vehicles powered by internal-combustion engines.

The high proportion of production-related support also encourages investments in refineries that could require the maintenance of support policies over many years, if not decades, to remain viable. Many of these subsidies are defended as necessary to support the development of a market for biofuels, to prepare the ground for next-generation liquid biofuels in particular.

This logic has not been subjected to close scrutiny. In OECD countries, the potential markets for ethanol and biodiesel are quite large even without modifying the existing vehicle fleet at all. Petrol-powered vehicles can handle 10% ethanol on a volumetric basis, with no modifications. This level has been surpassed in Brazil but is not expected to be reached until sometime next decade in most other countries, except in regions such as the Midwestern United States where ethanol is most heavily supported.

If cellulosic ethanol were to become viable, there would be a phase-in period during which infrastructure would adjust without government subsidy at least up to the 10 per cent of domestic consumption threshold. If it were highly competitive, vehicle manufacturers would implement flexible fuel technology on their own.

Biofuels are but one of many technologies and policy shifts that can address issues such as GHG emissions, supply security, and petroleum displacement. Even cellulosic ethanol, despite being more efficient at meeting these goals than is starch-based ethanol, could still fail the market in competition with a wider range of fuels and demand-side approaches. Precluding this competition by instituting wide-ranging subsidies through the political process is not in the long-term interest of the public.

More research into the effects of continuing to subsidize and protect domestic production of liquid biofuels is sorely needed. But good research requires data, and that in turn necessitates that governments be much more transparent than they have been so far with information on subsidies to biofuels (and, indeed, to all forms of energy).

NOTES

1. One company in particular, UK-based D1 Oils Plc., has formed joint ventures with governments in countries surrounding the Indian Ocean, and in the Philippines, to establish plantations of Jatropha curcus, and small-scale units for producing biodiesel.

2. Etha+ project's website: <www.etha-plus.ch/page-e.asp?page=1000&language=e>

3. Condensed from Renewable Fuels Association, "How ethanol is made" (www.ethanolrfa.org/resource/made/).

4. In conjunction with the Energy Economics Group of the Vienna University of Technology.

5. Statements by Dedini released so far do not provide details on these cost estimates, however. In particular, it is not known whether they a positive cost to the bagasse, which currently is burned to cogenerate steam an electricity in many sugar-and-ethanol plants.

6. Prior to this decision, the Canadian province of Quebec was already offering a sliding-scale tax credit for ethanol that is based on the market price for West Texas Intermediate crude oil.

7. With the recent rise in world prices for grains and sugar, these price gaps may have narrowed.

8. Production of bio-ethanol for fuel commenced only very recently in Switzerland, in large part because of the high prices of its sugar and starch yielding crops, but also because of an anti-intoxication law that remained in effect until 1996, effectively banning the domestic production of ethyl alcohol from crops.

9. Walter et al. (2006) notes that 45% of the ethanol imported by the EU in 2005 came in under the normal MFN regime, 29% under reduced duty regimes and 26% of the imports had no duties.

10. Sweden's reasoning was apparently that the degree of denaturing was higher than would be normal for denatured ethanol (Howse et al., 2006).

11. http://www.biofueltesting.com/specifications.html

12. www.panda.org/about_wwf/what_we_do/forests/news/events_/index.cfm?uNewsID=17676

13. http://cgse.epfl.ch/page65660-en.html

14. The likelihood that these proposals will be considered very seriously seems high, as the woman who chaired the study group, Prof. Dr. Jacqueline Cramer, recently became the Dutch Minister of Housing, Spatial Planning and Environment, and thus submitted the report to herself.

15. http://www.dft.gov.uk/pgr/roads/environment/rtfo/faq

16. Although Mexican officials suspect uncompetitive behaviour on the part of the country's main tortilla producer, many are also pointing to the increased demand for corn for ethanol production.

17. These numbers do not count revenue losses from exemption of excise taxes levied by the states themselves on motor fuels.

18. Translation from the original Dutch (Creative Energie, 2007), as posted in English on The Oil Drum: Europe blog (http://europe.theoildrum.com/node/2521) by Rembrandt on 8 May 2007, "How a market for sustainable bio-energy is being developed".

Annex 1 –

Criteria for "Sustainable Biomass" proposed by The Netherlands' Project Group for Sustainable Biomass[18]

1. **The balance of greenhouse gas emissions in the production chain and application of biomass needs to be positive**

   Criterion 1.1: The reduction in emission of greenhouse gasses should be at least 50% to 70% for electricity production and at least 30% for biofuels, calculated by means of a mathematical framework (see Creative Energie, 2006). Furthermore, the Group sees it more than fitting to strive for a greenhouse gas emission reduction of 80% to 90% within ten years with respect to current fossil references.

2. **Biomass production should not come at the cost of important carbon reservoirs in the vegetation and the soil.**

   Criterion 2.1: The plantation of new biomass production units will not take place in areas in which the loss of above-ground carbon storage cannot be regained within a period of 10 years of the start of biomass production.

   Criterion 2.2: The plantation of new biomass production units will not take place in areas with a high risk of significant carbon losses from the soil, such as certain types of grasslands, peat lands, mangroves and wet areas.

3. **Biomass production for energy may not endanger the supply of food and local biomass applications (energy supply, medicines, building materials)**

   Criterion 3.1: A report can be issued when requested by the government regarding changes of land use in the region, including future developments.

   Criterion 3.2: A report can be issued when requested by the government regarding information on changes in the prices of land and food in the region, including future developments.

4. **Biomass production will not harm protected or vulnerable biodiversity and wherever possible will enhance biodiversity**

   Criterion 4.1: The relevant national and local rules will be upheld regarding land ownership and usage rights, forest and plantation management and exploitation, protected areas, hunting, spatial planning, management of the wild, national rules that originate from ratification of international conventions CBD (Convention on biological Diversity) and CITES (Convention on International Trade in Endangered Species).

   Criterion 4.2: Biomass production will not take place in recently developed areas that have by the government been marked as "gazetted protected areas", or in a zone extending 5 kilometers around these areas.

   Criterion 4.3: Biomass production will not take place in recently developed areas that by all involved parties have been classified as "High Conservation Value" (HCV) areas, or in a zone extending 5 kilometers around these areas.

   Criterion 4.4: When development of new biomass production areas is initiated, 10% of the area should be set aside to remain in the historical state to prevent the shaping of large monocultures. In addition, an indication should be given regarding in what land use zones the biomass production unit resides, how fragmentation is being prevented, whether the concept of ecological corridors is being applied and if there is any concern regarding the recovery of already degraded areas.

   Criterion 4.5: Good practices will be applied on and around the biomass production area to enhance and strengthen biodiversity, to take ecological corridors into account and to prevent fragmentation of biodiversity as much as possible.

5. **When producing and processing of biomass the quality of the soil will be maintained or enhanced**

   Criterion 5.1: The relevant national and local rules and laws will be upheld regarding waste management, usage of agrochemicals (fertiliser and pesticides), mineral management, prevention of soil erosion, environmental effects report and company audits. At the utmost minimum the Stockholm convention (12 most harmful pesticides) must be upheld, even when the relevant national laws are missing.

Criterion 5.2: The formulation and application of a strategy aimed at sustainable soil use to prevent and combat erosion, to retain the balance of nutrients, to retain organic matter in the soil and to prevent soil salination.

Criterion 5.3: The use of agrarian rest products will not come at the cost of other essential function to maintain the soil quality (such as organic matter and mulch).

6. **When producing and processing biomass, soil and surface water will not be exhausted and the water quality will be maintained or enhanced**

Criterion 6.1: The relevant national and local rules and laws will be upheld regarding the usage of water for irrigation, the usage of soil water, the usage of water for agrarian purposes in flow areas, water purification, environmental effect reports and company audits.

Criterion 6.2: A strategy focusing on sustainable water management regarding efficient water usage and responsible use of agrochemicals will be formulated and applied.

Criterion 6.3: Water irrigation for the processing of biomass will not originate from non-sustainable sources.

7. **When producing and processing biomass the air quality will be maintained or enhanced**

Criterion 7.1: The relevant national and local rules and laws will be upheld regarding air emissions, waste management, environmental effect reports and company audits.

Criterion 7.2: A strategy focused on minimising air emissions regarding production and processing and waste management will be formulated and applied.

Criterion 7.3: Burning of land is a practice that will not be used when developing or managing biomass production units unless in specific situations, such as described in ASEAN guidelines or other regional good practices.

8. **Production of biomass will add to the local welfare**

Criterion 8.1: A report will be written which describes the direct added value to the local economy, the policy, practice and budget regarding local suppliers of biomass, the procedure for the appointment of local personnel and the share of local senior management. This will be based on the Economic Performance Indicators 1,6 & 7 of the GRI (Global Reporting Initiative).

9. **The production of biomass will add value to the welfare of the employees and local population**

Criterion 9.1: The tripartite declaration of principles concerning multinational enterprises and social policy, as established by the International Labour Organisation, will be upheld.

Criterion 9.2: The Universal Declaration of Human Rights from the United Nations will be upheld.

Criterion 9.3: No land will be used without the consent of sufficiently informed original users. Land use will be described in detail and officially registered. Official ownership, usage and rights of the domestic population will be acknowledged and respected.

Criterion 9.4: A report will be written describing the programmes and practices initiated to determine and manage the effects of business activities on the local population. This will be based on the Social Performance Indicator SO1 of the GRI (Global Reporting Initiative).

Criterion 9.5: A report will be written describing the amount of training and risk analysis to prevent corruption and the actions that will be taken to respond to cases of corruption. This will be based on the Social Performance Indicator SO_2, SO_3 and SO_4 of the GRI (Global Reporting Initiative).

Annex Table 1. **Overview of the US farm economy**

(Billions of US dollars, unless otherwise indicated)

Item	**2002**	**2003**	**2004**	**2005**	**2006F[a]**	**2007F[a]**
1. Cash receipts	195.0	215.5	237.9	238.9	242.7	258.7
Crops[b]	101.0	109.9	114.3	114	121.6	133.5
Livestock	94.0	105.6	123.6	125	121.2	125.2
2. Government payments	**12.4**	**16.5**	**13.0**	**24.3**	**16.3**	**12.4**
Fixed direct payments[c]	3.9	6.4	5.2	5.2	5.2	5.3
Counter-cyclical payments	0.2	2.3	1.1	4.1	4.1	1.6
Marketing loan benefits[d]	2.8	1.3	3.5	7.0	2.0	0.8
Conservation	2.0	2.2	2.3	2.8	2.9	2.9
Ad hoc and emergency	1.7	3.1	0.6	3.2	0.4	0.7
All other[e]	1.9	1.2	0.2	2.1	1.7	1.1
3. Farm-related income[f]	14.8	15.7	16.9	17.6	18.0	18.7
4. Gross cash income (1+2+3)	222.2	247.8	267.8	280.9	277.1	289.8
5. Cash expenses	171.6	177.8	186.3	199.7	210.4	222.6
6. NET CASH INCOME (4-5)	50.7	70	81.5	81.2	66.7	67.2
7. Total gross revenues[g]	233.6	260.9	296.2	299.8	298.4	318
8. Total production expenses[h]	193.4	200.4	210.8	226	237.8	251.3
9. NET FARM INCOME (7-8)	40.2	60.4	85.4	73.8	60.6	66.6
Farm Assets	1 304.0	1 378.8	1 584.8	1 805.3	1 919.4	1 994.3
Farm Debt	193.3	196.1	204.7	215.6	226.2	235.5
Farm Equity	1 110.7	1 182.7	1 380.1	1 589.6	1 693.2	1 758.8
Debt-to-asset ratio (expressed as %)	14.8%	14.2%	12.9%	11.9%	11.8%	11.8%
10. Ethanol production (10^9 gallons)	2.1	2.8	3.4	3.9	4.9	7.1
11. Federal tax loss from $0.51/gal. ethanol excise tax exemption or credit (billions of US dollars)	1.1	1.4	1.7	2.0	2.5	3.6
12. Biodiesel production (10^9 gallons)	neg	neg	neg	0.08	0.25	0.45
13. Federal tax loss from $1/ gal.biodiesel excise tax credit (billions of US dollars)	na	na	na	0.1	0.2	0.4
14. Total of Government Payments + biofuel tax credits (billions of US dollars)	**13.5**	**17.9**	**14.7**	**26.4**	**19.0**	**16.4**

na = not available; neg = negligible.

a. F = forecast.

b. Includes Commodity Credit Corporation (CCC) loans.

c. Direct payments include production flexibility payments of the 1996 Farm Act through 2001, and fixed direct payments under the 2002 Farm Act since 2002.

d. Includes loan deficiency payments, marketing loan gains and commodity certificate exchange gains.

e. Peanut quota buyout, milk income loss payments, and other miscellaneous program payments.

f. Income from custom work, machine hire, recreational activities, forest product sales, and other farm sources.

g. Gross cash income plus inventory adjustments, the value of home consumption, and the imputed rental value of operator dwellings.

h. Cash expenses plus depreciation and perquisites to hired labour.

Source: • **Items 1-9 in Table:** Randy Schnepf (2007), "The US Farm Economy", Updated of 21 February 2007, Congressional Research Service, Washington, DC. Original data from USDA, Economic Research Service, briefing rooms: *Farm Income and Costs: Farm Sector Income*, and *Costs: Farm Sector Income*, available at <www.ers.usda.gov/Briefing/FarmIncome>; US farm income data updated as of 14 February 2007;

• Ethanol production: Renewable Fuels Association <http://www.ethanolrfa.org/industry/statistics/#A > and Food and Agricultural Policy Research Institute (FAPRI);

• Biodiesel production: National Biodiesel Board and FAPRI <www.fapri.org/outlook2007/tables/7USTables.xls>

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SUSTAINABLE BIOFUELS FOR THE TRANSPORT SECTOR

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SUMMARY

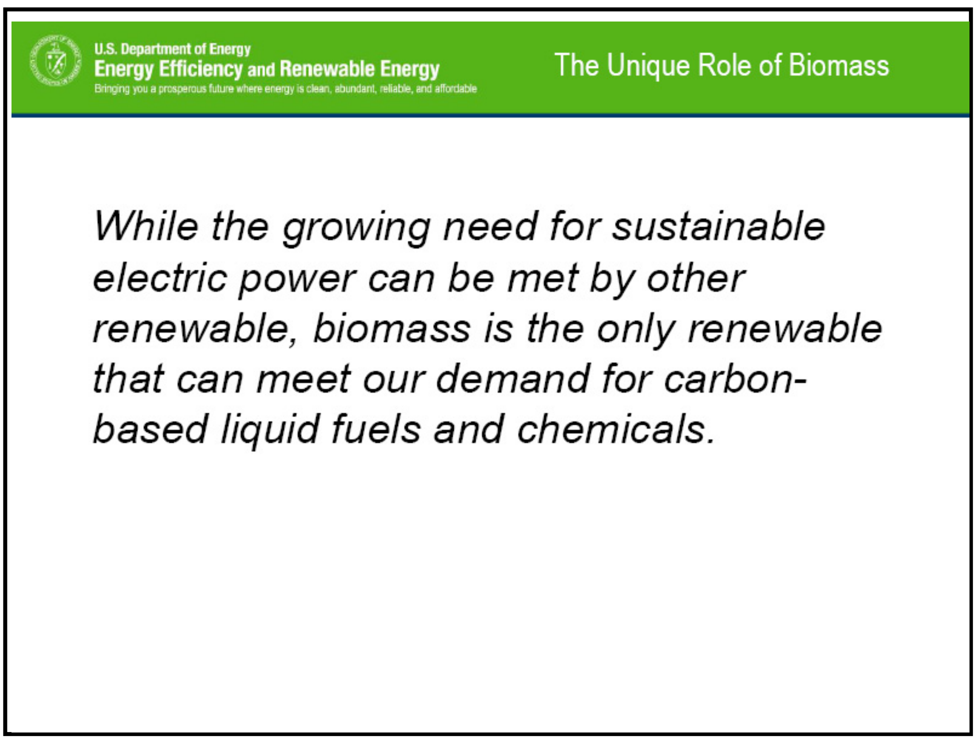
Copenhagen, May 2007

1. INTRODUCTION

The transport sector is almost fully dependent on oil-derived products and in both the United States and in Europe this sector contributes to about one-third of total energy consumption and about 30% of CO_2 emissions. The transport sector is forecast to contribute to 90% of the increase in CO_2 emissions projected for the EU in 2010. With the growing use of oil for transport in China, India and other Asian countries, the rush for oil has resulted in increasing oil prices and a push for production of oil substitutes.

Finding alternatives is a key issue, and biofuels are expected to be the easiest alternative fuel, as no significant changes in infrastructure or in established vehicles and engines are required. Biomass plays a unique role as a raw material for the production of transport fuels, as outlined by the US Department of Energy, Figure 1.

Figure 1. **Statement from US Department of Energy**

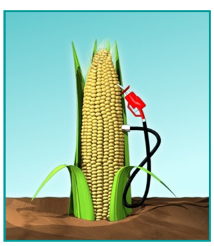


2. FIRST GENERATION VERSUS 2ND GENERATION BIOFUELS

It is important to understand that biofuels are not always "bio"– and in some situations large–scale production will lead to a larger overall use of fossil fuels and thereby a larger emission of carbon dioxide. Biodiesel produced from rapeseed and bioethanol produced from corn might be questionable when it comes to the net energy produced. Furthermore, production of these types of biofuel will occupy land which might be used for food production, and it can further lead to loss of rainforests or deforestation in parts of the world where new opportunities open for land development.

"Biofuel" is a common term for fuel made from biological materials. Normally it includes biodiesel – produced from rapeseed, soybeans and palm-seeds – or bioethanol, produced from sugar cane, corn or wheat. Using conventional crops for producing a biofuel is known as 1st generation biofuels, as opposed to 2nd generation biofuels where the raw material will be agricultural or wood residues, waste or other lignocellulosic materials such as energy crops (Figure 2).

Figure 2. **Bioethanol production technologies**



Current technology:

Starch-based ethanol

Biomass: Corn, grain, sugar

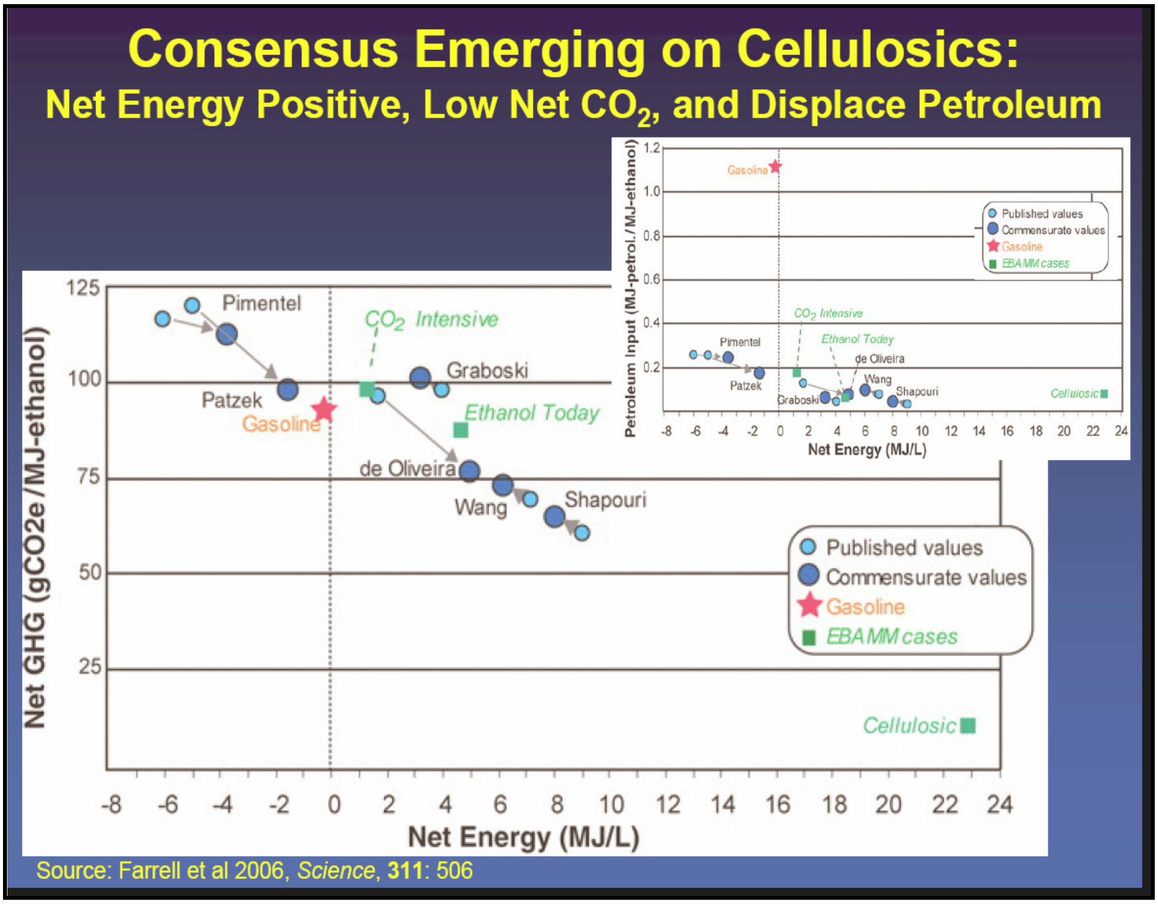
The future technology:

Lignocellulose-based ethanol

Biomass: Corn stover, straw, bagasse, wood etc.

Producing biofuels from a residue results in a much higher net energy output compared to producing biofuels by 1st generation technology. The reason is a much higher energy use for making the raw material in 1st generation technology compared to using a waste material, where the main energy use comes from collection and processing of the material during production of biofuels. Figure 3 shows a comparison of the values for 1st and 2nd generation biofuels, which have been published by the authors indicated below.

Figure 3. **Comparison values for 1st and 2nd generation biofuels**

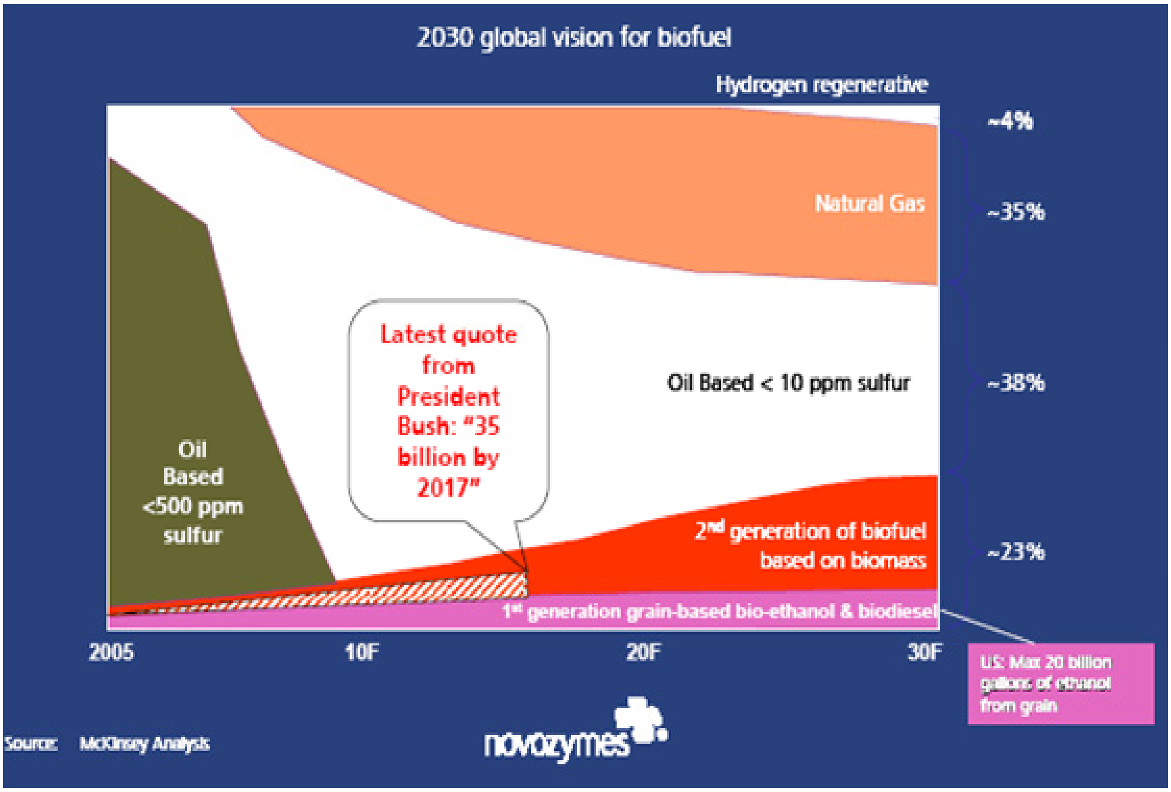


The figure shows the relationship between greenhouse gas emissions and net energy per litre of biofuel compared to gasoline (star), and represents some of the major studies which have been carried out over the last ten years. As can be seen from the figure, the ethanol we produce today results in a slight decrease in greenhouse gas emissions compared to gasoline – and the net energy of using a biofuel is low compared to gasoline. Using lignocellulosics as raw material will, however, be much more favourable, as shown by the square to the far right of the figure.

3. POLITICAL GOALS FOR 2ND GENERATION BIOFUELS IN THE USA AND THE EU

The competition for land between food and fuel production has increasingly been sharpened during the last year. The so-called "tortilla-crisis" is known to the broad world public, and recently Cuba's President declared "war" against bioethanol. In accordance with this, President Bush has declared a 20% reduction of gasoline usage in the United States over the next ten years. To reach this goal, 35 billion gallons of bioethanol are needed by 2017, of which 20 billion gallons of ethanol derived from cellulosics.

Figure 4. **2030 global visions for 2nd generation biofuels**



Source: McKinsey Analysis.

The quantitative policy for promoting biofuels has also been imposed in the European setting. The EU has prolonged their current goal of using 5.75% biofuels in year 2010 to a production target of 10% by volume in year 2020. As in the USA, the EU has further set the scene for conversion to 2nd generation biofuels. The goal is now subject to: "sustainable 2nd generation biofuels becoming commercially available".

While the technology for 1st generation biofuels derived from sugar, corn or oil-producing crops are well known, lignocellulosic biomass makes use of several new processing steps, which are not matured to the same extent. In July 2006, the US Department of Energy (DOE) published a "roadmap" for bringing 2nd generation bioethanol to the market. The 200-page scientific "roadmap" cites recent advances in biotechnology that have made cost-effective production of ethanol from cellulose, or inedible plant fibre, an attainable goal. The report outlines a detailed research plan for developing new technologies to transform cellulosic ethanol into an economically viable transportation fuel. In accordance with this roadmap, much of the technology needs to be improved, including better energy crops, improved pre-treatment methods, hydrolysis including better enzymes, better fermentation microbes and processes, etc.

The DOE is currently investing a large amount of funds into lowering the cost of 2nd generation biofuels through a directed research programme (the GTL Bioenergy Centers – with more than USD 400 million) and a demonstration programme where six projects have recently been approved, for a total of up to USD 385 million, see Table 1.

Table 1. **The six selected cellulosic ethanol projects for DOE funding, February 2007**

PROJECT	DESCRIPTION
Abengoa Bioenergy Biomass of Kansas, LLC of Chesterfield, Missouri, up to USD 76 million	The proposed plant will be located in the State of Kansas. The plant will produce 11.4 million gallons of ethanol annually and enough energy to power the facility, with any excess energy being used to power the adjacent dry grind corn mill. The plant will use 700 tons per day of corn stover, wheat straw, milo stubble, switchgrass and other feedstocks.
ALICO, Inc. of LaBelle, Florida, up to USD 33 million	The proposed plant will be in LaBelle (Hendry County), Florida. The plant will produce 13.9 million gallons of ethanol a year and 6 255 kilowatts of electric power, as well as 8.8 tons of hydrogen and 50 tons of ammonia per day. For feedstock, the plant will use 770 tons per day of yard, wood and vegetative wastes, and eventually energy cane.
BlueFire Ethanol, Inc. of Irvine, California, up to USD 40 million	The proposed plant will be in southern California. The plant will be sited on an existing landfill and produce about 19 million gallons of ethanol a year. As feedstock, the plant would use 700 tons per day of sorted green waste and wood waste from landfills.
Poet Energy (formerly Broin Companies) of Sioux Falls, South Dakota, up to USD 80 million	The plant is in Emmetsburg (Palo Alto County), Iowa and, after expansion, will produce 125 million gallons of ethanol per year, of which roughly 25% will be cellulosic ethanol. For feedstock in the production of cellulosic ethanol, the plant expects to use 842 tons per day of corn fibre, cobs and stalks.
Iogen Biorefinery Partners, LLC, of Arlington, Virginia, up to USD 80 million	The proposed plant will be built in Shelley, Idaho, near Idaho Falls, and will produce 18 million gallons of ethanol annually. The plant will use 700 tons per day of agricultural residues, including wheat straw, barley straw, corn stover, switchgrass and rice straw as feedstocks.
Range Fuels (formerly Kergy Inc.) of Broomfield, Colorado, up to USD 76 million	The proposed plant will be constructed in Soperton (Treutlen County), Georgia. The plant will produce about 40 million gallons of ethanol per year and 9 million gallons per year of methanol. As feedstock, the plant will use 1 200 tons per day of wood residues and wood-based energy crops.

4. NEW POLICY NEEDED FOR PROMOTION OF SUSTAINABLE BIOFUELS

The quantitative policy approach does not contain direct goals for sustainability and, to ensure this, additional regulation will be necessary. New policies based on quality of biofuels have, for instance, been proposed in California in January 2007 through "low carbon standards", whereby a 10% reduction in "well to wheel" greenhouse gas emissions per litre of transport fuel has been forecast by the year 2020 compared to the present day. To meet these goals, 2nd generation ethanol technology is expected to achieve an 80% reduction in GHG emissions compared to gasoline, whilst current ethanol produced from corn only reduces GHG emissions by 20% compared to gasoline.

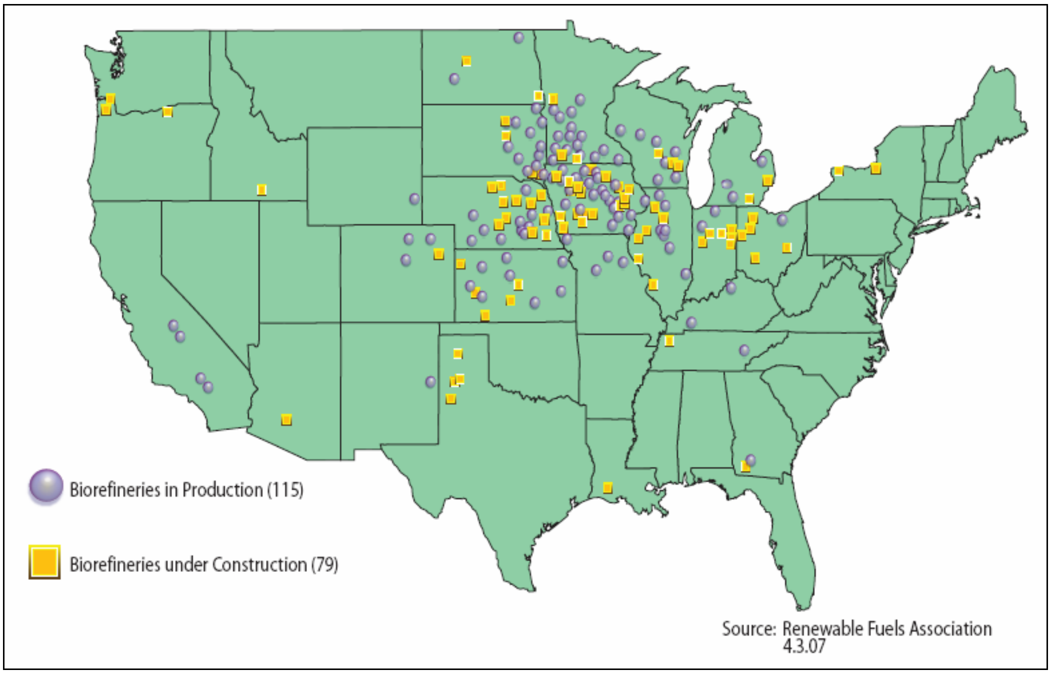
Similar targets are currently being discussed in the EU Commission, where lifecycle greenhouse gas targets for petrol and diesel could impose the increased use of sustainable rather than less-sustainable biofuels. One option for reducing the 10% greenhouse gas burden from the transport sector is to improve the oil production process, but this will only give decreases of between 1-2%.

The major impact can only be met by using efficient biofuels. The burden of proof will lie with the fuel supplier, and an audited reporting system will be necessary to ensure that the fuel introduced really emits fewer greenhouse gases than the fuel previously used. This will mean that biofuels will need a ***climate certification***. A climate quality approach to transport fuel will tackle many problems at the market level rather than at the end of the pipeline. This approach can further be improved to avoid problems such as a decrease in biodiversity, competition for resources, etc., when producing biofuels.

5. ESTIMATED FUTURE BIOFUELS PRODUCTION IN THE USA AND THE EU

Profits through 1st generation bioethanol production have been substantial during the last five years in the USA, and many factories have been established or are under construction at the moment. Figure 5 shows the map of bioethanol facilities in the USA, both those in operation and those under construction.

Figure 5. **Bioethanol facilities in the USA**



The EU's production of biofuels amounted to 2.4 million tonnes in 2004, approximately 0.8% of EU gasoline and diesel consumption. Bioethanol totalled 0.5 million tonnes and biodiesel 1.9 million tonnes. In Europe, the use of biodiesel has overshadowed the use of bioethanol in a number of countries such as Germany and Austria. However, bioethanol production from grain is in place in many EU countries such as Spain, France, Sweden and Germany; but the number of factories is small compared to the amount needed to fulfil the 2003 EU target of 5.75% biofuel production by 2010. Today, Brazil supplies the EU with ethanol made from sugar cane, and this import might increase in the future if the pace of construction within Europe does not increase.

The massive interest and funding for 2nd generation biofuels has resulted in the development of several pilot and demonstration projects within this field, especially in the USA. Using cost sharing as a model, it has been possible to get a large number of 1st generation bioethanol producers interested in investing in the upcoming field. In the EU, substantial funding for the 2nd generation biofuels demonstration project is mainly a result of national funding, and the current EU Research Programme has not proved to be suited for this type of development, which demands a substantial amount of funding and which is much more focused than the typical EU project. A list of companies active within the 2nd generation bioethanol field is shown in Table 2, along with a description of their upcoming demonstration projects.

Table 2. **Companies active within the 2nd generation**

COMPANY	2ND GENERATION PROJECTS
Abengoa (Spain)	Abengoa is among the World's largest ethanol producers. During the summer of 2007, Abengoa will have a 2G demonstration plant in operation in Salamanca-Spain. The plant will, on a daily basis, convert 70 tonnes of agricultural residues (such as wheat straw) into ethanol. The plant will produce 5 million litres of ethanol per year.
BioGasol (Denmark)	BioGasol opened its pilot plant in September 2006; the capacity of the fully integrated pilot plant is 16 400 litres of ethanol per year. BioGasol has started the design of a 2G demonstration plant with a capacity of 10 million litres of ethanol per year. The complete plant will be in operation in April 2009.
Celunol (US)	In November 2006, Celunol put an ethanol plant in operation in Jennings. During the summer of 2007, a 2G plant at the same site will produce 5.3 million litres of ethanol per year. In January 2007, Celunol opened a small 2G pilot plant in Japan, producing 1.4 million litres of ethanol per year, based on wood residues.
Iogen (Canada)	Iogen has a 2G pilot plant and has plans for a full-scale plant that will be in operation by the summer of 2007, producing 75.7 million litres of ethanol per year.
Mascoma (US)	In the State of New York, Mascoma plan to start construction of a pilot plant with a yearly capacity of 1.9 million litres of ethanol. The plan is to put the plant in operation late 2007/early 2008.
Poet Energy (US)	Poet Energy is among the World's largest ethanol producers and the US's second largest producer. Poet Energy plans to build a 2G plant in Iowa in 2009 with a capacity of 190 million litres of ethanol per year. The plant will later be expanded to produce 473 million litres of ethanol per year.
SunOpta (Canada)	SunOpta has developed a pre-treatment process. Together with GreenField, they have plans for a 2G demonstration plant in Ontario or Quebec. SunOpta also has plans for a 2G demonstration plant in China, in cooperation with China Resources Alcohol Corporation. This plant will be in operation late 2007, producing 6.4 million litres of ethanol per year.
TMO (UK)	TMO has plans for a 2G demonstration plant in Rotterdam, The Netherlands. The plant will be in operation early 2008, producing about 12 million litres of ethanol per year.
Xethanol (US)	Xethanol will build a 2G demonstration plant in Augusta, producing 189 million litres of ethanol per year from the summer of 2007. Xethanol will also build a pilot plant in Bartow, Florida. The feedstock is composed of residues from citrus production. The pilot plant will initially produce 0.2 million litres of ethanol per year, increasing to 1.9 million litres of ethanol a year after first production.

6. BIOFUELS TECHNOLOGY

Bioethanol production by 1st generation technology results in production of a feed product besides bioethanol. In a dry mill, approximately one-third of the raw material ends up as feed, one-third as bioethanol, while the rest will end as carbon dioxide during the conversion process. The feed product is of relatively low quality – it is composed of denaturised proteins, a low-quality starch and some lignocellulose. Its value as a feed is mainly limited to cattle, and the price of the product is under pressure along with the increasing amounts being produced. The feed product might, however, be used as a raw material for 2nd generation biofuels production, resulting in a higher outcome of ethanol per tonne of corn kernels. Integration of 1st and 2nd generation technology will therefore be a promising way of adding 2nd generation bioethanol into a 1st generation bioethanol plant (Figure 6).

The extra investment needed for using the feed fraction will have a low payback time, and the new technology will be introduced using a rather easily convertible raw material compared to, for instance, corn stovers, which can be gradually introduced after the new process is in function.

Sustainable 2nd generation biofuel production demands that more fuels or products than bioethanol are produced. Bioethanol can only be produced from carbohydrates, meaning that 25-40% of the raw material will be left as waste if not used for other purposes. The MaxiFuels Concept is constructed to maximize the outcome of energy products and make use of the whole biomass for their manufacture (see Figure 7).

Figure 6. **Add-on plant based on 2nd generation process technology**

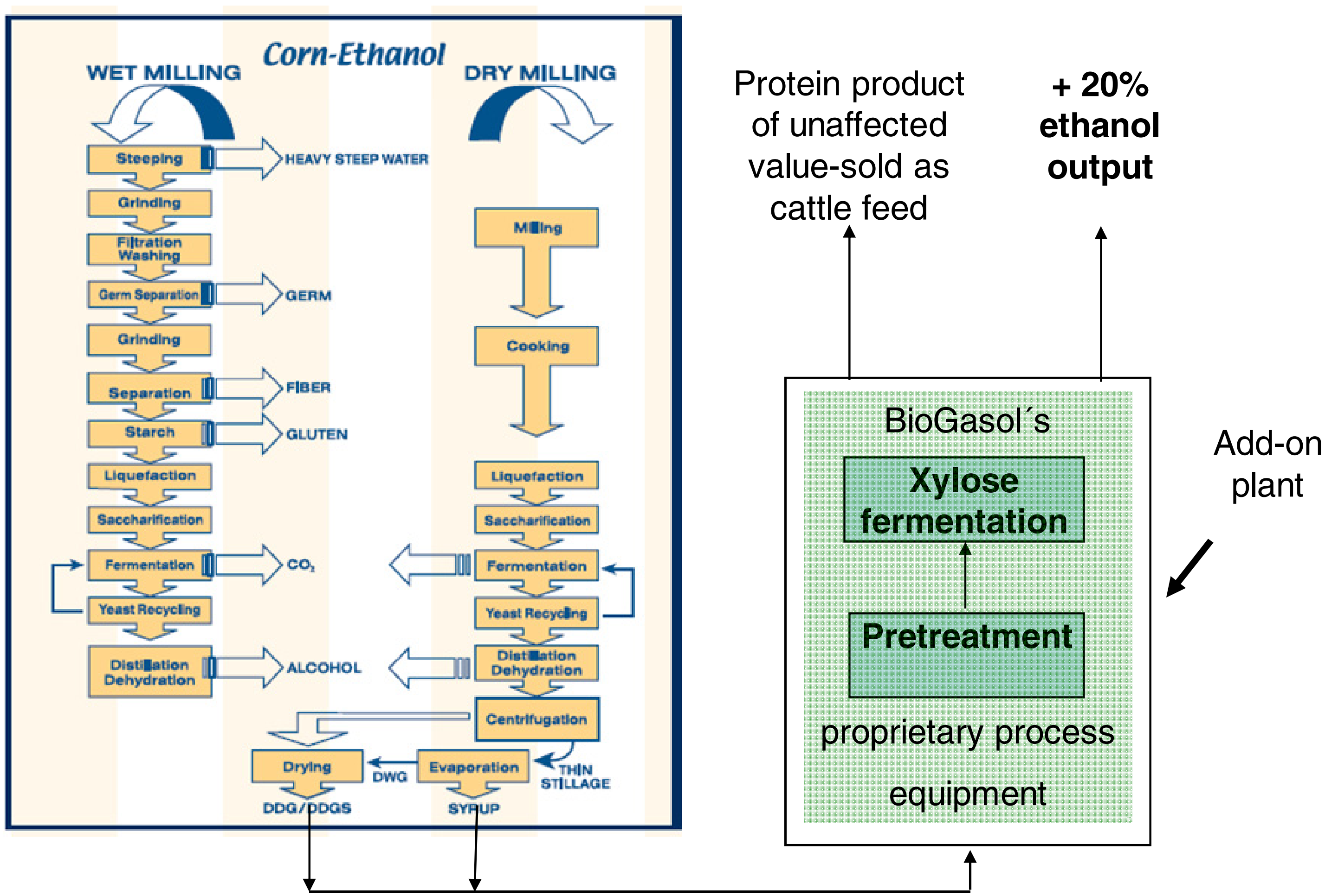
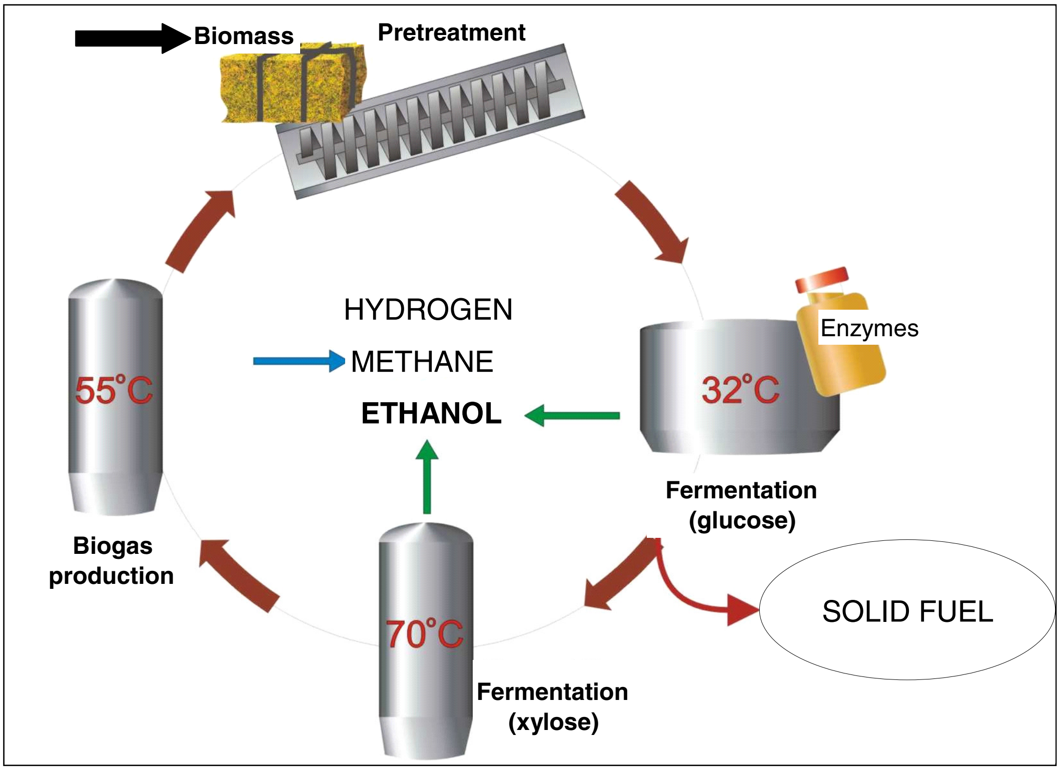
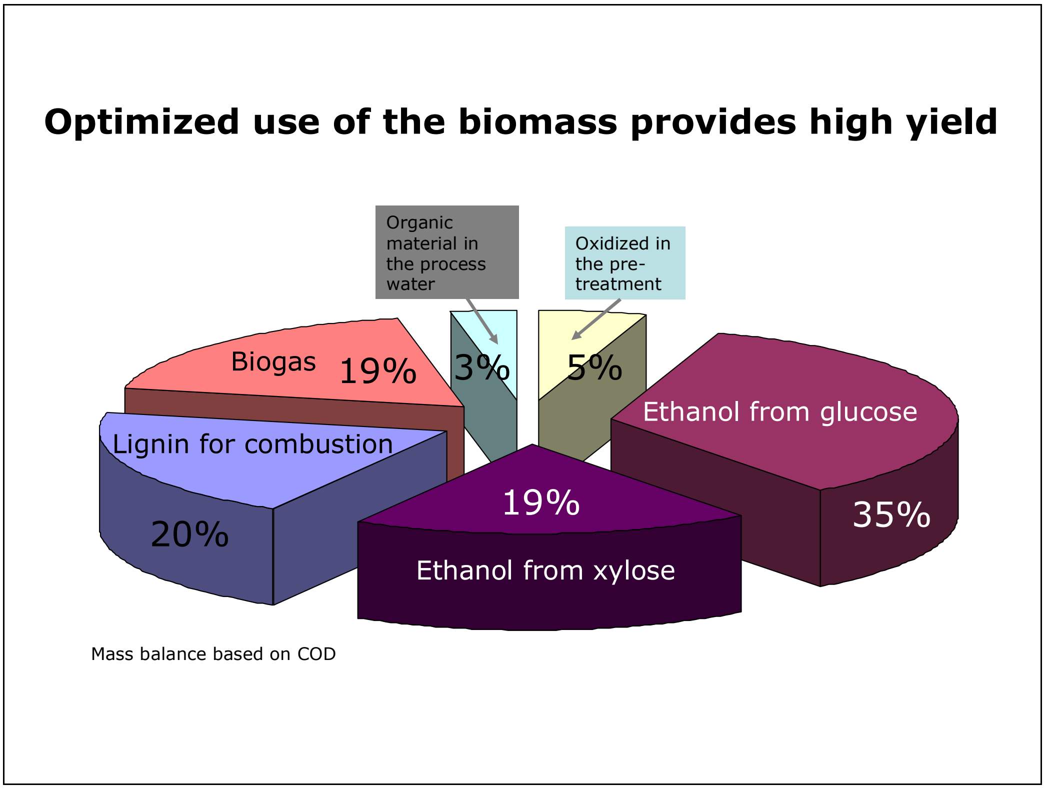


Figure 7. **The MaxiFuels Concept**



In this concept, a solid fuel (the lignin fraction), hydrogen and methane are produced in addition to ethanol. Water is further reused in the concept and nutrients are taken out as fertilizer. By using all available carbon in the raw material, the outcome will be a low-cost ethanol made by an environmentally secure method. Furthermore, the process has a high net energy conversion and is thus an example of a type of process that should set the standard for the future production of 2nd generation biofuels.

Figure 8. **Outcome of the MaxiFuels concept**



7. CONCLUSION

The future is bright for 2nd generation biofuels. Substantial funding is necessary to bring this technology to the market and furthermore to ensure that industries in the EU can compete with US industries, which right now have major financial support. EU Research Programmes need to be more focused and better suited for supporting demonstration projects linked to specific Member States.

THE PERFORMANCE OF BRAZILIAN BIOFUELS: AN ECONOMIC, ENVIRONMENTAL AND SOCIAL ANALYSIS

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SUMMARY

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INTRODUCTION

The increase in oil prices and the worsening of climate change are fostering biofuels programmes around the world. Brazil has a long tradition in biofuels. The country has been a large-scale producer of ethanol since the 1970s. In 2006, ethanol was responsible for 17% of all vehicle fuel supply in Brazil[1]. Brazil's ethanol production from sugarcane is also recognised for its economic performance. In 2005, the Brazilian Government launched a biodiesel programme.

The aim of this report is to make a critical review of the Brazilian ethanol and biodiesel programmes. It provides lessons about the potential competitiveness of biofuels *vis a vis* traditional fuels. The document also presents the potential social and environmental impacts of biofuels in Brazil. The analysis made in this report has been based on an extensive literature review on the subject of biofuels in Brazil. Interviews with experts have also been carried out in order to clarify some particular issues.

The report is divided in two parts: the first part is focused on ethanol and is divided into the following sections: i) economic performance; ii) environmental performance; iii) social performance; iv) energy security performance; and v) Brazil as a world-class ethanol exporter. The second part of the report is on biodiesel and is divided into the following sections: i) economic performance; ii) environmental performance; and iii) Brazil as a world-class biodiesel exporter.

1. PERFORMANCE OF BRAZILIAN ETHANOL

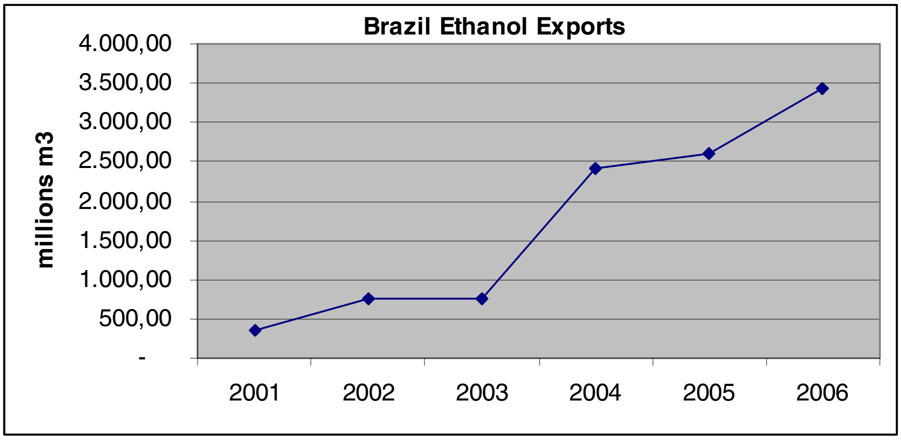
Brazil has a history of 500 years of sugarcane plantation for sugar production. Since the 1930s, sugarcane has also been used for producing fuel-ethanol, to be blended with gasoline at a 5% rate on average[2]. In 1975, the Brazilian Government launched the Pro-Alcohol Program with a view to mitigating the macroeconomic impacts of oil price increases. The programme can be divided into two phases. The first is the period in-between the oil shocks, in which the Government created incentives to boost ethanol production from sugarcane and introduced mandatory ethanol blending at a 10% rate. In the second phase, a new set of incentives to both carmakers and car buyers allowed the development of an ethanol-dedicated car market. In 1988, almost 100% of passenger cars produced were ethanol-dedicated[3]. However, the decrease in oil prices in the mid-1980s and price spikes in the international sugar market affected ethanol economics and resulted in a fuel shortage. This affected the credibility of the ethanol programme. Ethanol-dedicated car sales almost ceased in the 1990s.

The collapse of the ethanol-dedicated car market resulted in a reduction in ethanol production in Brazil. After 2001, ethanol production entered a new phase of expansion, related to three main factors: an oil price increase, the recovery of the Brazilian ethanol market and international demand.

As for domestic demand, the main drive was the introduction of Flex-Fuel Vehicles (FFVs). FFVs can use any mix of gasoline and ethanol, so drivers can choose the fuel based on relative pump prices. This technology has profoundly changed the context of the ethanol market in Brazil, as it eliminates the risk of ethanol shortages, with no additional cost in relation to gasoline-only cars. Due to the increase in international oil prices, ethanol prices became attractive to end-consumers. Since 2003, 2.8 million FFVs have been sold, accounting for 80% of car sales in 2006. According to our estimates, FFVs could make up 27% of the Brazilian car fleet in 2010 and 43% in 2015.

In 2006, ethanol production was estimated at 17.7 billion litres (Ministry of Agriculture, 2007). About 80% of this production was consumed domestically. Ethanol exports have also increased at a rapid pace since 2003 (Figure 1). In 2006, Brazil exported some 3.5 billion litres, with the United States being the main destination (60%). Due to import barriers, a significant share of these exports reaches the US through third countries under the Caribbean Basin Initiative (CBI). Ethanol is exported to Central American or Caribbean countries, from where it is re-exported to the US without import duties (ethanol sold directly from Brazil to the US is charged a USD 0.54 tax per gallon)[4]. Two other important destinations are the Netherlands (the entry port for Europe), importing 10% of Brazilian ethanol, and Sweden which imported 6% of total exports.

Figure 1**. Evolution of ethanol exports – Brazil (million litres)**



Source: Unica (2007) and Ministry of Agriculture.

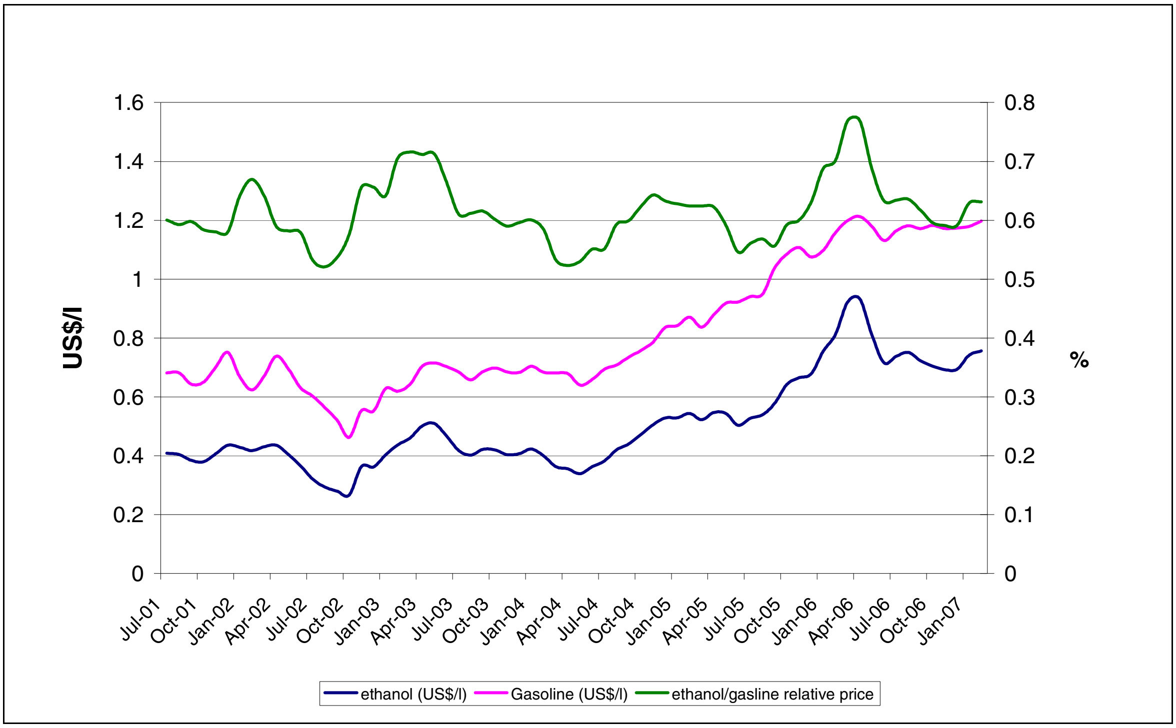
1.1 The economic performance of ethanol

Sugar and ethanol production in Brazil represents an important economic sector, responsible for about 3.6 million jobs and 3.5% of GDP. In 2005-2006, Brazil produced 25% of the world's sugarcane (440 million tons), using about 6 million hectares. Currently, ethanol accounts for 50% of the total sugarcane produced. About 70% of sugarcane is cultivated directly by the 370 sugar and ethanol mills, and the rest is produced by 70 000 independent farmers.

Until 1997, the Government controlled ethanol prices by fixing a price cap at 60% of gasoline prices at the pump. This price relation was guaranteed by subsidies. Fuel market liberalization in Brazil was a gradual process that ended in 2002 with the total liberalization of gasoline, diesel and LPG prices.

To be attractive to FFV consumers, because of the difference in energy content the price per litre of hydrated ethanol should not be higher than 70% of that of a litre of gasoline. As shown in Figure 2, after fuel market liberalization, prices for hydrated ethanol have followed gasoline prices. However, relative prices have varied over time and the ethanol price was more than 70% of the gasoline price on two occasions in the period 2001-2007.

Figure 2. **Evolution of gasoline and hydrated ethanol prices in Brazil 2001-2007**



Source: National Petroleum Agency.
Note: prices include taxes.

It is worth mentioning that ethanol end-user prices vary between the different states of Brazil, due to tax differences and logistics costs. Differences in ethanol prices between regions/states can be as large as 60%.

1.1.1 Evolution of ethanol production costs

The production cost of ethanol is determined by three main factors: the cost of sugarcane production, the cost of its processing and the rate of its conversion into ethanol. Brazil has achieved large productivity gains in sugarcane production. The average sugarcane productivity in the State of Sao Paulo increased from 66 tons per hectare (tons/ha) in 1977 to 80 tons/ha in 2003. The evolution of overall national productivity followed the same trend, and has reached 73 tons/ha. Sugarcane quality has also increased; the concentration of sucrose rising from 14% in 1988 to 14.6% in 2003. These results are from a significant study on sugarcane agronomics undertaken in particular by the Brazilian Research Center for Agriculture – Embrapa.

During the 1980s and 1990s, the cost of biomass processing decreased significantly as the efficiency of conversion improved. Over the past five years, ethanol productivity has stabilized as the technology reached maturity (Macedo and Nogueira, 2005). Considering the two kinds of productivity gains in the same indicator – litres of hydrated ethanol per hectare – we see that productivity has grown steadily at about 4% a year in the last 29 years, reaching 6 000 litres per hectare (Nastari, 2005).

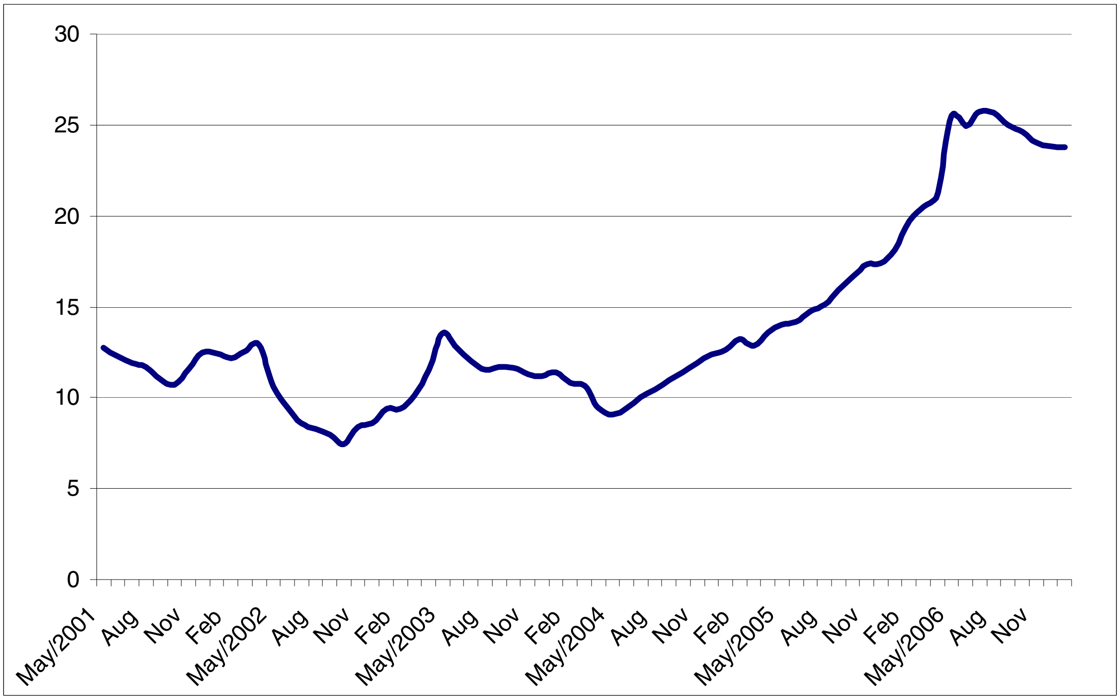
Since the liberalization of ethanol prices, few cost estimation studies have been made and most of the cost analyses refer to the same study. This study was carried out by the Brazilian Ministry of Science and Technology (MC&T), based on 1990 data, and pointed to a production cost of USD 0.23 per litre (MC&T, 2002). This study was used as a reference in the International Energy Agency's study on Biofuels (IEA, 2004). Since then, most references on the cost of ethanol in Brazil point to the same value, despite significant variations in exchange rates, costs of sugarcane and oil products and other important cost items.

Macedo and Nogueira (2005) updated the cost structure and estimated the ethanol cost in the Centre-South region of Brazil at USD 0.21 per litre. The World Bank suggests average production costs in Brazil in the range of USD 0.23-0.29 per litre (Kojima and Johnson, 2006). All these studies suggest that Brazilian ethanol is competitive with oil prices, at about USD 30 per barrel.

Indeed, estimating the current cost of ethanol production in Brazil is quite a difficult task. First, costs vary significantly in different production areas, given the differences in productivity and cost of sugarcane production. Second, estimating the cost of the sugarcane is crucial to the ethanol cost estimation. Most studies on Brazilian ethanol have estimated the sugarcane production cost at USD 10 dollars per ton, which gives a cost of roughly USD 0.10 per litre of ethanol. However, a recent study by the consulting firm IDEA, which specialises in sugarcane production, suggests that the cost of sugarcane production is as high as USD 15.70 per ton, that is USD 0.18 per litre of ethanol, considering a productivity rate of 85 litres per ton of sugarcane.

We must also consider the opportunity cost of sugarcane feedstock. Sugarcane prices vary according to sugar and ethanol market conditions. Currently, the price of sugarcane in Sao Paulo State is about USD 23 per ton or USD 0.27 per litre of ethanol (see Figure 3). Since most mills are vertically integrated, most studies on ethanol costs have considered a vertically-integrated plant as a reference for cost calculations. However, in most cases, ethanol producers organise their sugarcane supply as follows: one-third of the sugarcane is directly farmed on the ethanol producers' land; another third is planted on rented land; and one-third is bought from independent farmers. Therefore, when the sugarcane price goes up, the price of land rent also increases. Another point to be considered is that 77% of Brazilian ethanol mills also produce sugar (Souto, 2006). Since mills can shift to sugar production, one should consider the value of sugarcane rather than its production cost.

Figure 3. **Sugarcane market price – USD/ton**



Source: Unica.

Based on the data gathered by Unicamp (2006) on capital and operational costs for a standard project, we estimated the production cost for new ethanol production in Brazil. Our aim was to estimate an "indifference" price: a minimum attractive ethanol price for new investors. We considered both the capital and the sugarcane opportunity costs[5]. The standard project considered has the following characteristics: i) an ethanol-dedicated mill with a processing capacity of 2 million tons of sugarcane per year; ii) ethanol productivity of 85 litres per year; iii) production of 40 kWh of electricity per ton of sugarcane. The capital costs of this project are presented in Table 1. Investment in sugarcane production does not include the cost of land acquisition. It is assumed that the ethanol producers will rent land or outsource the sugarcane production. The capital expenditure for sugarcane production includes only the acquisition of machinery to assist farmers in the sugarcane harvesting and plantation[6]. Total O&M costs are estimated at USUSD 0.07 per litre of ethanol (IDEA, 2007).

Although the current sugarcane market price is around USD 23 per ton, we considered the estimated average production cost for Brazil (USD 17.7 per ton) as a good estimate for the sugarcane cost of new ethanol mills. Most of these projects are located in areas with lower sugarcane opportunity costs, and these new producers are mostly ethanol-dedicated. Finally, we estimated the cost of capital, considering: an internal rate of return of 12%; a dept/equity ratio of 50% with an 8% interest rate; and the selling of the surplus power at USD 57 per MWh. Based on these assumptions, we estimated the capital cost at USD 0.13 per litre. Therefore, we estimate that the average production cost of new ethanol projects in Brazil is USD 0.37 per litre. In this sense, Brazilian ethanol is currently competitive at an oil price of USD 42 a barrel.

Table 1. **Cost of production in a standard ethanol project in Brazil**

Sugarcane productivity	71.5 t/ha
Sugarcane consumption	2 000 000 tons/year
Harvesting days	167
Ethanol productivity	85 litres per ton
Ethanol production	170 170 000 litres per year
Surplus power produced	40 kWh/ton of sugarcane
Investment cost in the mill	USD 97 million
Investment cost for sugarcane production	USD 36 million
O&M costs	USD 0.07
Sugarcane costs	USD 0.17
Capital costs	USD 0.13
Total costs	USD 0.37

Source: Unicamp (2005) and author's elaboration.

Currently, the mills produce almost all the energy they need through bagasse-based, co-generation power plants. Each ton of sugarcane crop produces 280 kg of bagasse and 90% of this bagasse is used as fuel for heat and power generation[7]. In addition, about 160 kg of straw is produced per ton of sugarcane. This part of the biomass produced has no economic use at the present time.

The use of more efficient generation technologies at co-generation power plants[8] has allowed the mills to sell surplus power in the market. In the last electricity bid organised by the Brazilian Government, 119 MW of bagasse-based generation capacity was sold, for delivery from 2009 onwards[9] (CCEE, 2006).

The evolution of ethanol costs will depend mainly on productivity gains and on technological innovations. Concerning the first aspect, there are few perspectives for substantial efficiency gains with the sugarcane processing technology. Industrial efficiency in conversion is about 85% and it is expected to increase to 90% in 2015 (Unicamp, 2006). The most significant productivity growth can be obtained in sugarcane production, where it is expected to grow from the current 70 tons/ha. to 96 tons/ha. in 2025. The quality of sugarcane is also expected to improve, with the sucrose content growing from 14.5% to 17.3% in 2025. All productivity gains together could allow an increase in the production of ethanol from 6 000 litres/ha. to 10 400 litres/ha. in 2025.

The second aspect regards the development of hydrolytic processing. This process allows the production of ethanol from biomass residues (bagasse and sugarcane straw), and can further reduce ethanol costs. Recent technological developments allow the production of about 100 litres of ethanol per ton of bagasse. According to Macedo and Nogueira (2005), the conversion of 50% of the straw to ethanol by advanced hydrolysis processes would increase the mills' revenues by 30%. Currently, straw is burned in the field before the harvesting of sugarcane. With the adoption of harvesting innovations, it would be economically feasible to recover 40-50% of the straw produced (Macedo and Nogueira, 2005).

Both aspects together would result in a 55% increase in total ethanol productivity by 2015 and 130% by 2025 (see Table 2). Considering this latter level of productivity, it would be possible to increase current ethanol production from 17 billion litres to 100 billion litres by increasing the area of sugarcane plantations for ethanol from approximately 3 million hectares to 7.2 million hectares.

Table 2. **Impacts of hydrolysis on ethanol productivity (hydrolysis of bagasse and straw)**

	2005		**2015**		**2025**	
Technology	**l/ton of sugarca**	**l/ha**	**l/ton of sugarca**	**l/ha**	**l/ton of sugarca**	**l/ha**
Conventional	85	6 000	100	8 200	109	10 400
Hydrolysis	-	-	14	1 100	37	3 500
Total	85	6 000	114	9 300	146	13 900

Source: Unicamp (2006).

The use of more advanced power generation technologies – such as condensing turbo-generators with steam extraction and bagasse, and straw gasification and Combined Cycle Gas Turbines (CCGT) – would enable the attainment of at least 100-150 kWh/tonne of surplus electricity production. This generation technology is already available in the market and its use could allow surplus electricity production to increase to as much as 200-300 kWh per tonne of sugarcane. Assuming the sale of 140 kWh per ton of sugarcane and considering the current electricity price in Brazil (R$150 per MWh), ethanol producers could increase their revenues by 25%.

1.1.2 Brazilian ethanol as compared to ethanol in other countries

Brazilian ethanol is recognised as the cheapest in the world. All studies on compared ethanol costs indicate that Brazil has the highest competitiveness due to its feedstock cost. In addition to having the highest productivity in sugarcane production, sugarcane culture in Brazil needs almost no irrigation. Regarding the compared feedstock costs, F.O. Lichts (2004 – see Table 3) estimated the cost of sugarcane as ranging from USD 0.10 to USD 0.12 per litre of ethanol, while the cost of beet or corn is estimated at USD 0.20-USD 0.35 per litre of ethanol (no opportunity cost considered)[10]. Other cost items like labour and machinery are also estimated to be cheaper in Brazil than in Europe or the USA.

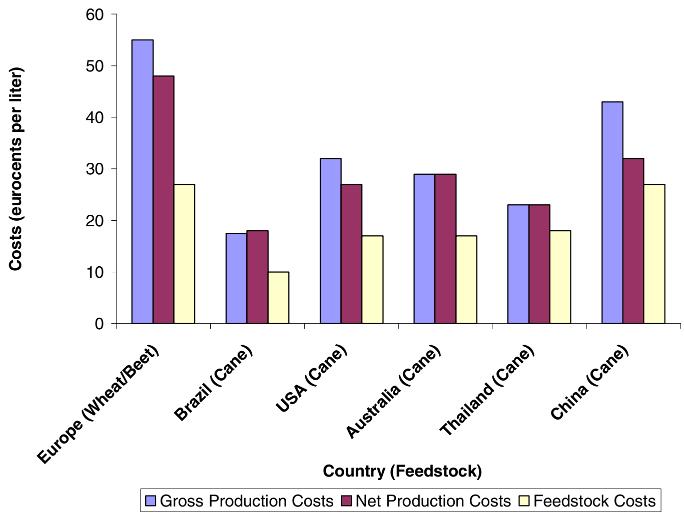
Table 3. **Ethanol estimated production costs in different countries**

	USA	Germany		Brazil
	Corn (EUR/hl)	**Wheat (EUR/hl)**	**Beet (EUR/hl)**	**Sugarcane (EUR/hl)**
Buildings	0.39	0.82	0.82	0.21
Equipment	3.40	5.30	5.30	1.15
Labour	2.83	1.40	1.40	0.52
Insurance, rates and other	0.61	1.02	1.02	0.48
Raw material	20.93	27.75	35.10	9.80
Operational costs, Other	11.31	18.68	15.93	2.32
Total production costs	39.48	54.96	59.57	14.48
By-products sales	-6.71	-6.80	-7.20	-
Federal and state subsidies	7.93	-	-	-
Net production costs	24.84	48.16	52.37	14.48

Source: F.O. Lichts (2004).

Another study by Lichts analysed the comparative cost of ethanol production in different countries/regions, indicating Brazilian ethanol as the cheapest option (Figure 4).

Figure 4**. Ethanol production costs without subsidies**



Source: O. Henniges and J. Zeddies (2006).

However, these studies share two main problems. First, they underestimate the opportunity cost of sugarcane production. Second, logistics and transportation aspects have not been considered. In this regard, it should be noted that sugarcane cannot be stored, and ethanol production is limited to the harvesting season. Therefore, substantial storage capacity is required, adding a significant cost to ethanol supply.

1.1.3 Direct and indirect subsidies to ethanol

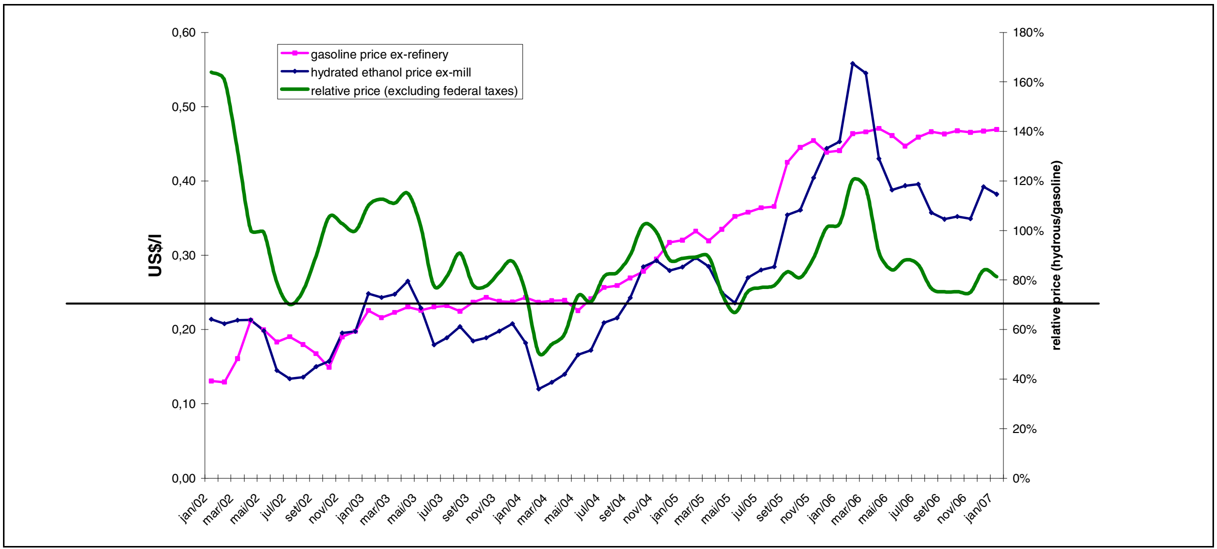
Brazilian ethanol production was heavily subsidized in the 1980s. Subsidies through loans and price support totalled some USD 16 billion (in 2005 dollars) from 1979 to the mid-1990s, when subsidies were phased out (Bear Stearns, 2006)[11]. Nowadays, there are no specific direct subsidies for ethanol production.

However, ethanol still receives two kinds of tax exemption. The first one concerns the difference between the value of federal taxes charged on gasoline ex-refinery, and hydrated ethanol ex-mill. Federal taxes include the excise tax (CIDE) and social contributions. First of all, ethanol has been exempted from excise tax since 2004. In addition, social contributions are higher for gasoline than for ethanol. Federal taxes charged on gasoline total USD 0.26 per litre compared to USD 0.01 per litre for ethanol. The second kind of tax exemption is the difference in the VAT charged on gasoline and ethanol in the different states.

In order to access the role of tax exemptions on ethanol economics, we compared the price of ethanol ex-mill without taxes to gasoline ex-refinery without taxes (Figure 5). The pump prices will also depend on other factors such as: percentage blend between gasoline and anhydrous ethanol; the VAT charged on the different fuels; transportation costs; and the distribution margin. Nevertheless, we can expect that if ethanol was charged tax at the same level as gasoline, both on federal and state levels, the same pattern of relative price identified at the producers' level would remain in end-user prices.

Comparing the prices for the State of São Paulo, the main ethanol producer, we can see that the relative prices of ethanol/gasoline pass the 70% test (accounting for the lower energy content of ethanol) only very rarely.

Figure 5. **Comparison of ethanol and gasoline prices excluding taxes**



Source: Author's elaboration based on National Petroleum Agency.

In addition to federal taxes, fuels are charged with VAT, the level of which is decided by the State. The tax advantage of ethanol varies significantly from state to state. The largest advantage is in São Paulo State, where taxes represent 47% of the gasoline end-user price, as compared to 22% of the ethanol price. In Rio de Janeiro State, the fiscal advantage of ethanol is significantly lower: the level of taxes in the gasoline end-price is estimated at 50% compared to 36% for ethanol (Cavalcanti, 2006). We estimated the amount of overall tax incentives to ethanol at USD 977 million per year.

1.2 Environmental performance

Several studies (De Oliveira *et al*., 2005; Macedo and Leal, 2002; Macedo *et al*., 2003; among others) have estimated the potential reduction of GHG emissions with the use of ethanol on a life-cycle basis[12]. The results vary substantially due to methodology differences in emission assessment. Nevertheless, all studies show that sugarcane ethanol has the highest potential for GHG emissions reduction. Sugarcane ethanol can reduce GHG emissions by more than 80%, while ethanol generated from other feedstocks can only reach 50% in the best case.

It is worth noting that if no fossil fuel were involved in biofuel production, its consumption would not contribute to CO_2 emissions, since the CO_2 emitted in combustion would all be captured by new biomass growth. Macedo *et al.* (2004) estimate that for each MJ of fossil fuel used in the process of growing, collecting and processing sugar cane, 8.3 to 10.2 MJ of ethanol are produced and in the best cases, this value can reach 12[13]. The number widely accepted for corn-ethanol produced in the USA is 1.34[14] while the energy balance for wheat or beet-based ethanol is estimated at 2.

La Rovere (2004) shows that the use of fossil fuels for Brazilian ethanol production in 1991-92 contributed to the emission of 1.2 million tons of carbon. On the other hand, the ethanol and bagasse produced avoided the emission of 10.6 million tons of carbon by replacing gasoline in transport and fuel oil in power generation. In terms of value, this corresponds to USD 94.5 million. Macedo (1997) performed the same exercise, also taking into account emissions due to straw burning before harvest, and indicated a reduction of 12.7 million tons of carbon. This represented a value of USD 120.74 million per year[15].

De Oliveira *et al.* (2005) present a more pessimistic energy balance to sugarcane ethanol production. The main differences between Macedo (2004) and De Oliveira *et al.* (2005) concern the assumptions about ethanol yield and the type of fertilizer used. Macedo considers the use of distillation residues, vinasse, as fertilizer, while De Oliveira assumes a much higher use of chemical fertilizers. In the worst scenario, De Oliveira *et al.* (2005) find an input/output ratio of 3.14. De Oliveira's life-cycle analysis suggests that a net CO_2 contribution from the ethanol industry is 3.12 tons of CO_2 equivalent per ha.

The studies on GHG emissions made for sugarcane-based ethanol do not generally consider the emissions related to the burning of sugarcane straw before harvesting. The reason is that the resulting CO_2 emissions are recaptured by sugarcane growth. However, Neto (2005) calls attention to the fact that straw burning also liberates other GHGs. Neto (2005) estimates that 12 kg of CO_{2eq} are emitted for each ton of sugarcane burned before harvesting.

1.2.1 Ethanol, deforestation and GHG emissions in Brazil

Brazil accounts for 3% of global GHG emissions. Deforestation in the Amazon region accounts for 75% of these emissions of CO_2, while fossil fuel consumption contributes 23% (Neto, 2005).

At first sight, we cannot establish a direct relation between the expansion of sugarcane production and the deforestation process in Brazil. Sugarcane plantations are located in the South-East and North-East, far from the northern region where the Amazon forest is located (see Figure 6). The main economic activities causing deforestation in the Amazon area are timber exploration and cattle-raising (Nepstad *et al.,* 2006).

Currently, about 20% of Brazilian cattle are raised in the northern region. The area dedicated to this activity in the region tripled between 1990 and 2005, as the number of cattle increased from 13 million to 41 million head. If we consider that the average productivity in Brazilian cattle-raising is 0.9 animals per hectare, we can estimate that cattle-raising alone was responsible for the loss of about 30 million hectares of forest in the Amazon between 1990 and 2005[16].

More recently, soybean plantations are also contributing, albeit indirectly, to deforestation of the Amazon. According to Morton (2006) intensive mechanized agriculture (mainly soybean) in the Brazilian Amazon region grew by 3.6 million hectares during 2001-2004. Soybean expansion is responsible for an increase in the price of the land, thus cattle raisers sell their land for soybean plantation and then tend to reinvest in new forest areas, exploiting timber and preparing new land for cattle-raising through burning.

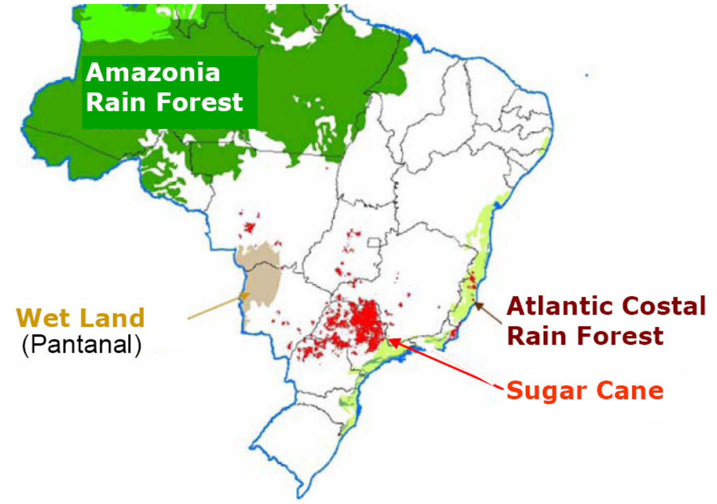
This process presents a particular dynamic that seems to be independent from sugarcane expansion, primarily because cattle-raising expansion in Brazil is a process related to the low cost of land, and to land availability in the country. The cost involved in preparing land for cattle-raising is much smaller than for crops. The availability of cheap land is the main factor in the expansion of this extensive activity.

Second, the expansion of sugarcane plantations has occurred through the replacement of other traditional crops (oranges[17], beans and pasture, for example), mainly in the State of Sao Paulo and, to a lesser extent, in the Minas Gerais and Parana states. Another expansion frontier is the replacement of cattle-raising in the Brazilian savannah (central part of Brazil). Third, ethanol production requires the existence of an adequate infrastructure for storage and transportation. This infrastructure is very scarce in the regions near to the Amazon forest.

The association between the expansion of sugarcane plantations in the southern part of the country and the Amazon deforestation process is still an open research question. The studies on Amazon deforestation have focused on the direct deforestation vectors (timber, cattle-raising and soybeans). Additional studies on the potential impacts of sugarcane on deforestation will be necessary in relation to Brazilian ethanol exports. Without these studies, ethanol tends to face questioning from environmental organisations in OECD countries regarding its environmental advantages.

Brazil has a very modern environmental regulatory framework regarding the use of land and deforestation. Nevertheless, Brazil's environmental performance is still poor due to weak government capacity for law enforcement.

Figure 6**. Location of sugarcane plantations in Brazil**



Source: Guerreiro (2006).

Brazil is one of the few countries in the world that still has large areas of land available for agriculture. Brazil is the fifth largest country in the world, with a total area of 851 million hectares. The Amazon rain forest and protected areas occupy 47% of the country's total area. About 31% of the territory is used as farmland (275 million hectares). Of this, the large majority (78%) is used as pasture for cattle-raising. Taking away urban areas, about 10% of the Brazilian territory is still available for farmland, or about 90 million hectares. The Brazilian Ministry of Agriculture believes that there are still 22 million hectares available in Brazil suitable for sugarcane plantation. This area is 3.5 times the area currently occupied by sugarcane.

According to Mr. da Silva, an agronomist engineer from Embrapa (Brazilian company for agricultural research) and a specialist in land management, 30% of the land dedicated to pasture in Brazil (63 million hectares) is degraded, with low productivity of about 0.5 animals per ha. This means that if sugarcane expansion occurs in degraded pasture areas, a positive carbon balance can be obtained. Degraded pasture has lower green biomass than the sugarcane culture that would replace it. In addition, sugarcane expansion can occur simultaneously with an increase in the productivity of cattle-raising. This effect deserves more detailed analysis, in order to quantify the impacts.

1.2.2 Ethanol's local environmental impacts

The preservation of water resources is an important concern in Brazil. Sugar and ethanol production was traditionally associated with the discharge of acidic distillation residues (vinasse) in rivers. This practice has been prohibited, and a common practice today is to neutralise the vinasse with lime and use it as fertilizer in the sugarcane plantations. This practice is contributing to the reduction of the use of mineral fertilizers, which has been stable since the 1970s (Macedo and Nogueira, 2005).

Most Brazilian sugarcane production is rain-fed, but the production process consumes water. According to Walter (2007), new legislation and technological innovations are promoting the reduction of water collection. Water consumption in ethanol production has been reduced from

5.6 m3/t in the 1990s to 1.83 m3/t in 2005 at São Paulo's mills. Walter believes that new technologies will allow a further reduction to less than 1 m3/t water collection and (close to) zero effluent release rates, through re-use of water.

Usually, ethanol producers do not pay for the water used in the production process. Legislation on a water charge for rural users is new and its application is not yet widespread. Each river basin is now required to create a committee which is in charge of establishing a tariff for water usage according to opportunity costs. In the states of Sao Paulo and Rio de Janeiro, the river basin committees have fixed the cost of non-treated water collected from major rivers at around R$0.01 per cubic metre. If we apply this water price to all sugar mills in Brazil, the total water cost would be around USD 4.5 million per year. The water cost for a typical mill would be around USD 40 000 per year. In addition, a tariff for polluted water discharges has been set at between R$0.07 and R$0.1 per kilo. This tariff makes it cheaper to treat polluted water before discharge.

Another source of local environmental impacts is the use of herbicides in the sugarcane plantations. Again, the use of herbicides has been reduced by the development of new breeds of sugarcane more resistant to pests. Currently, about 4.6 kg of herbicides are used per hectare of sugarcane. Agricultural research has been an important source of pest control, through the development of more resistant sugarcane breeds. It is important to note that the restrictions on sugarcane burning for harvesting are a source of concern with regard to pest control. The annual straw burn provided a form of pest control, and it is not clear what the impacts of mechanical harvesting will be in terms of the development of more resistant pests.

Nowadays, the main local environmental impact from ethanol production is the practice of burning sugarcane straw. The large majority of mills still employ manual harvesting and, to increase productivity, sugarcane straw is burned before harvesting[18]. The plantation fires project a large concentration of smoke and particulates on the cities nearby (see Table 4).

Table 4. **Emissions related to straw burning for harvesting**

Emission	Grammes per kg of dry straw	Kg/ton of sugarcane	Thousand tons per year*
CH4	0.41	0.05	15
CO	25.48	3.19	917 280
Nox	1.40	0.18	50 400
SO2	0.62	0.08	22 320
Particulates	5.60	0.70	201 600
Particulates 10	5.40	0.69	194 400
Particulates 2,5	5.00	0.63	180 000
N2O	0.12	0.015	4 320

* Considering the production of 360 million tons of sugarcane.
Source: Neto (2005).

Local movements against sugarcane burning have resulted in new legislation on this topic in the state of Sao Paulo. In 2002, Sao Paulo State Law No. 11.241 created a schedule for a progressive introduction of mechanised harvesting. This schedule varies according to the characteristics of the land used. For flat areas, all harvesting should be mechanised by 2021. For the non-flat areas, the deadline is fixed for 2031. Producers should increase the mechanised areas by

20% each five years. Currently, about 35% of the harvesting in São Paulo state is already mechanised. This rate is about 30% for the Centre-South region. In the North-East, however, the rate of mechanisation is very low.

Ethanol has also had a positive impact on local air pollution. The blending of ethanol in gasoline has allowed the elimination of lead in gasoline, the elimination of 100% of sulfur dioxide and carbon particulate emissions, and a reduction of about 20% of carbon monoxide emissions. According to Nogueira and Macedo (2005), the reduction in local emissions has avoided social costs of about USD 500 million per year.

1.3 The social dimension

The social impacts of ethanol production in Brazil are one of the main reasons behind government support for the ethanol industry. The industry has created an estimated 700 000 direct and 200 000 indirect jobs (La Rovere, 2004; Macedo and Nogueira, 2005).

These figures hide important issues regarding the quality of the jobs created. The majority of jobs created are for sugarcane plantation and harvesting activities, which are low-quality jobs, since they involve insalubrious activities (manual harvesting). Another problem on the sugarcane plantation is the seasonality of the production process. Therefore, most of the workers dedicated to sugarcane harvesting work only seven months per year. Workers' payments are tied to harvesting productivity in tons per day. In order to maximise payments, some workers choose to work very long hours (10-15 hours per day), during which they can harvest as much as thirty tons a day. The heat during the harvesting season and the straw burning[19] are also associated with health problems.

The Ministry of Labor has strengthened the regulations on working conditions. Although working conditions have improved considerably in the last decades it is still a controversial subject. According to the producers' representatives, 92% of the workers in São Paulo are hired formally, while the average in Brazil is only 46%[20]. Sugarcane workers can be considered well paid, when compared to other activities requiring the same level of skill, as they earn 85% more than rural workers in the country (Macedo and Nogueira, 2005).

The introduction of mechanised harvesting is expected to improve working conditions. Average productivity and salaries will rise. However, the labour intensity of ethanol production will decrease, thus impacting on the unemployment rate. A 20% increase in sugarcane productivity in manual or mechanised harvesting and 50% mechanisation in the North-East and 80% in the Centre-South regions, would eliminate 290 000 jobs. This employment reduction can be compensated by the sector's expansion: for each 100 million ton expansion in sugarcane production, 125 000 direct and 136 000 indirect jobs will be created (Macedo and Nogueira, 2005).

1.4 Brazil as a world-class ethanol exporter

The role of Brazil in the world ethanol market will depend on the evolution of three factors: i) Brazilian ethanol production; ii) domestic ethanol demand; and iii) the development of an international ethanol market.

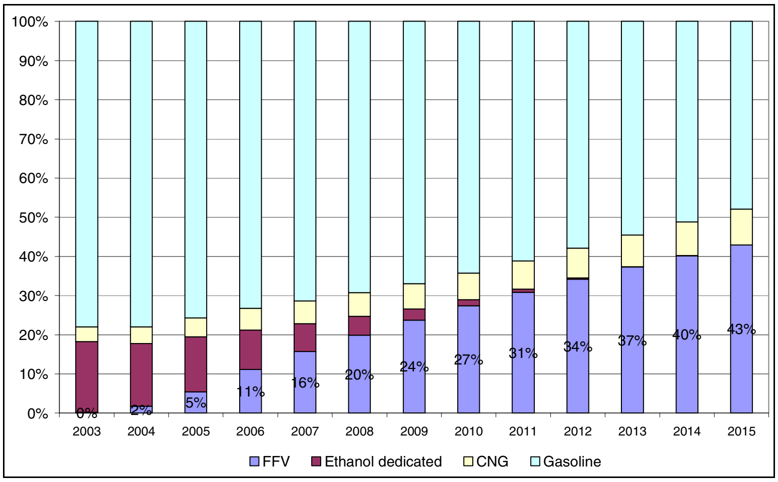
According to the University of Campinas, if ethanol replaced 5% of all gasoline demand by 2025, it would require 1.2 billion tons of sugarcane to reach a production of 104.5 billion litres of ethanol. Considering current best productivity levels, the study indicates that the area required for sugarcane production would be 21.5 million hectares, seven times the current area occupied by sugarcane for ethanol production (Unicamp, 2006). The overall investment required to meet this target would be USD 4 billion per year. This expansion in ethanol production would allow the generation of 50 TWh per year, which is equivalent to 15% of the country's total power generation in 2005. In addition, the ethanol sector alone would create about 5 million direct and indirect jobs, and ethanol exports would reach USD 31 billion. This potential for ethanol production is attracting new investment. About 25 new mills will come on stream in 2007 and about 90 projects have been announced for the period 2008-2014.

We estimated ethanol production in Brazil based on a scenario of sugarcane production elaborated by the producers' representatives (UNICA). According to this scenario, Brazil is expected to reach 570 million tons of sugarcane production in 2010 and 731 million tons in 2015. We assumed that 60% of the sugarcane will be directed toward ethanol production, a higher proportion than at present, given that most of the mills under construction or planned are ethanol-dedicated. In addition, we assumed that industrial productivity would increase from the current 80 l/ton to 90 l/ton[21]. We expect that ethanol production will reach 39 billion litres in 2015. While there is substantial convergence regarding the medium-term projection for ethanol production in Brazil, many uncertainties remain regarding how much ethanol Brazil will be able to export. Brazilian exports will also depend on the evolution of domestic ethanol consumption.

In this regard, FFVs are responsible for half of domestic ethanol consumption. This consumption depends on the competitiveness of ethanol vis-à-vis gasoline. Therefore, in order to forecast domestic ethanol demand, we need to analyse the evolution of FFV sales in Brazil and explore different scenarios for ethanol and gasoline prices.

We estimated the evolution of the FFV fleet in Brazil using available data for the current fleet, projected sales and vehicle performance. We assumed that FFVs will represent 75% of total car shares between 2007 and 2015. We also assumed that the ethanol dedicated fleet, which represents 13% of the current light vehicle fleet[22], will progressively disappear, given that this fleet is already old (nine years on average). Finally, we assumed that the fleet of compressed natural gas (CNG) vehicles will continue to grow at an annual rate of 10% over the period, which is less than the actual annual growth rate of 25%. The future composition of national light car fleets is shown in Figure 7.

Figure 7. **Evolution of the composition of light vehicle fleets in Brazil**

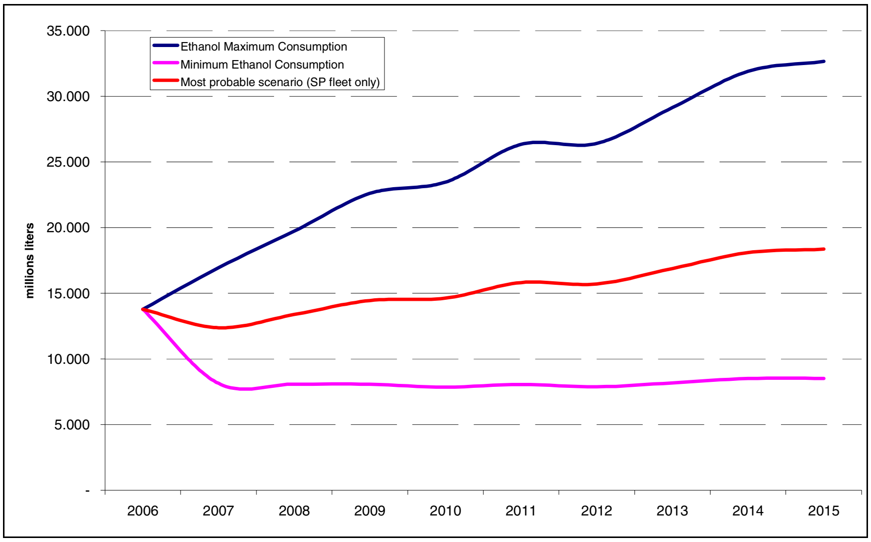


Source: Author's elaboration, based on data from Denatran and Sindipeças (2006).

After estimating the evolution of the FFV fleet in Brazil, we were able to estimate the amount of ethanol potentially consumed by this fleet. Meyer (2001) estimates new vehicles in Brazil run on average 22 000 km per year, while 10-year old vehicles run 13 000 km per year. Lastly, we assumed a performance of 7 km/l when running on ethanol.

We projected three scenarios for ethanol consumption in Brazil. In the first scenario, we assumed that ethanol prices in Brazil would be attractive (less than 70% of gasoline prices) and that all of Brazil's FFV fleet would run only on ethanol in the period 2007-2015. In the second scenario, we assumed ethanol prices to be unattractive to FFVs and that all FFVs would run on gasoline between 2007 and 2015. Of course, these are two extreme scenarios, neither of which is very likely. In the third scenario, we tried to define an intermediate and more likely domestic ethanol demand. In this scenario, we assumed that part of the FFV fleet would consume ethanol, despite the fact that ethanol prices in the international market tend to be higher than 70%[23]. We think that fiscal incentives will make ethanol cheaper than 70% of gasoline prices in the state of Sao Paulo. Given the growing importance of FFVs in Brazil, projected ethanol demand in 2015 could vary between 8.5 and 32 billion litres (Figure 8).

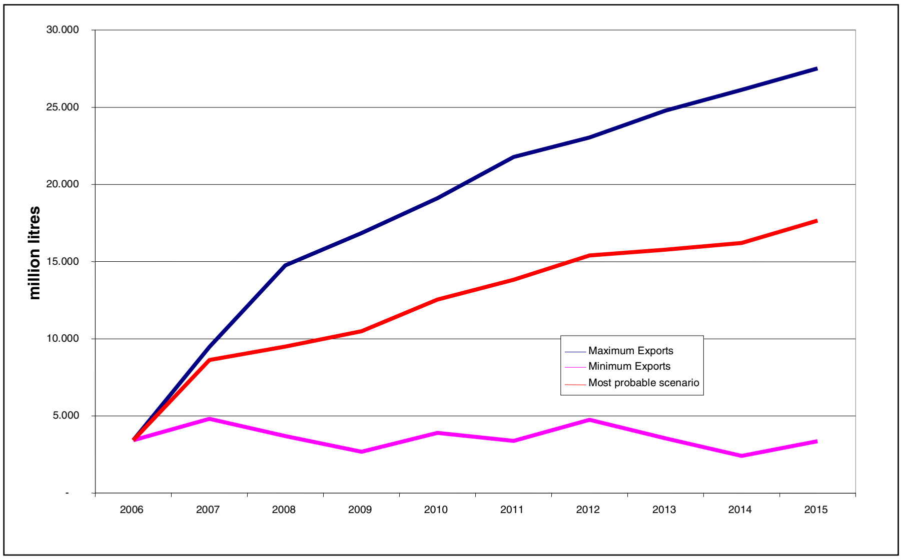
Figure 8. **Ethanol demand scenarios for Brazil**



Source: Author's elaboration.
SP = Sao Paulo.

This demand gap represents by how much Brazilian ethanol exports could vary, depending on the evolution of relative gasoline and ethanol prices. As shown in Figure 9, Brazilian exports can vary from between 3.3 billion and 27 billion litres per year. Our analysis shows that if the Brazilian ethanol-gasoline price ratio remains lower than 70%, there will be no room for increasing exports until 2015, because domestic demand will increase at a rapid pace in response to the diffusion of FFVs. However, we believe it is more likely that Brazilian ethanol exports will follow the intermediate scenario, reaching 17 billion litres in 2015.

Figure 9. **Ethanol export scenarios for Brazil**



Source: Author's elaboration.

Knowing how much ethanol Brazil will be able to supply to the world is just one side of the equation. Although Brazil produces the cheapest ethanol in the world, the role of Brazil in the international market development of ethanol is not clear. Currently, biofuel policies in Europe and in the US emphasize the development of domestic production. The international trade in ethanol still faces important barriers: i) The high concentration of export capacity in Brazil raises issues of security of supply; ii) Trade barriers and subsidies to domestic production in Europe and the US are also an obstacle to the development of an international market; iii) Doubts/questions are being expressed regarding the environmental impacts of Brazilian ethanol.

Regarding ethanol's international market, Brazil is practically the only country to export significant volumes of ethanol to OECD countries. Despite the import duties imposed by some of the largest potential consumers of Brazilian ethanol (US, EU), we think that international demand for Brazilian ethanol will soar, driven by rising environmental concerns and tightening environmental regulations. Increasing evidence of climate change is driving mandatory targets on biofuel markets.

Most of the countries that are setting mandatory fuel consumption levels have small or insufficient potential for producing biofuels. Japan, for instance is seeking to reach an agreement to make Brazil its main ethanol supplier. India and China, European the Union and the US will probably have problems to produce all the ethanol necessary to comply with the mandatory target demand.

Finally, a necessary condition for the large-scale exports of Brazilian ethanol will be the environmental certification process. Since environmental issues form the main motivation for importing Brazilian ethanol, importers should be assured that ethanol production in Brazil is not associated with significant environmental and social impacts, such as deforestation and poor labour conditions. An important research effort will be required for the development of a certification process.

2. PERFORMANCE OF BRAZILIAN BIODIESEL

The increase in oil prices and the development of biodiesel technologies in Europe and the US have aroused Brazil's interest in biodiesel. In 2004, the Brazilian Government launched the National Program for Production and Use of Biodiesel – NPPUB. In 2005, the Government enacted Law 11.097, mandating a blend of 2% of biodiesel in mineral diesel for 2008 and 5% for 2013, for diesel sold for transport. This mandatory blend will require the production of 1 billion litres in 2008 and 2.4 billion litres in 2013.

There are two political motivations for the NPPUB: fuel supply diversification and social development. The Government is expecting to create 200 000 new jobs, with incentives for biodiesel production by small farmers. Decree 5297 created a Social Fuel Certificate: only producers who have this certificate are qualified to sell biodiesel to the Government with favourable conditions, such as tax exemptions and access to cheap financing by the BNDES (National Development Bank) and the PRONAF (National Program for Family-based Agriculture) (PNPB, 2007).

Currently, there are 14 biodiesel plants operating with a production capacity of 600 000 ton/year. B2 diesel is offered by 2 000 gas stations, and some local schemes, using B30 diesel (30% biodiesel) for bus fleets, are under development. About sixty projects for new biodiesel plants have been announced. Government and private projections foresee achievement of the same technological and economic performance as for ethanol production.

2.1. Economic performance

Biodiesel can be produced by transesterification of vegetable oil or animal fat, using some type of alcohol (in general, methanol) as a reagent in the process. This technology was initially commercially developed in Europe using mostly oil from rapeseed (canola). In Brazil, a large number of feedstocks have been considered for oil production: soybean; palm fruit and kernels, sunflower; castor nuts, Jatropha, peanuts, cotton seeds, tallow etc.

The business model for biodiesel production in Brazil does not vary according to the feedstock chosen. Biodiesel plant technology can be dedicated to one type of feedstock, or capable of using more than one type of oil. The production process can be continuous or in batches. The alcohol solution employed can be methanol or ethanol. The efficient production scale is not yet clear. Currently, a plant of 100 000 tons per year can be considered large by Brazilian standards. However, in the US, plant sizes from 200 000 to 300 000 t/y are frequent and Chevron has announced the construction of a 400 000 t/y plant. Different types of investor are involved in the sector: energy companies; soybean producers; meat producers; independent investors, financial groups, etc.

The technological and economic diversity of the biodiesel sector is a characteristic of the low level of maturity of this industry in Brazil, which could be said to be in the initial phase of its life cycle. Several technological options are in competition for a dominant design that could put the industry on a cost-reduction trajectory. Analysis of the current performance of biodiesel in Brazil is not necessarily a reliable guide to its development potential.

The analysis of the biodiesel production costs has two dimensions: the cost/price of feedstocks and the cost of biomass processing. Currently, vegetable oil represents approximately 80% of biodiesel costs. In the transesterification process, the capital cost represents only about 25%. So, the challenge for biodiesel production today is to reduce the cost of biomass production.

2.1.1 Biodiesel feedstock economics

One of the major differences between the Brazilian biodiesel programme and the US and European experiences is the potential for using different feedstocks, and especially the development of new types of feedstock that could be cultivated in land not presently used for food. Currently, the most important vegetable oil plants in Brazil are: soybean, castor bean, palm tree, Jatropha and animal fat from abbatoirs (tallow). In this context, plant feedstock flexibility is considered an important source of competitiveness.

Soybean has been the feedstock choice for most of the biodiesel produced in Brazil, because of its availability. Brazil is one of the largest soybean producers, with a total production of 51 million tons in 2005. Agronomic research has increased soybean productivity from 1 700 tons/hectare in 1990 to 2 200 tons/hectare in 2005[24]. Given this productivity increase, soybean has been identified as the cheapest feedstock for biodiesel production in Brazil (Barros *et al.*, 2006). However, vegetable oil is not the main product of the soybean, and its international price varies according to the demand for alternative uses.

Castor bean oil has been suggested as the most promising feedstock for the Brazilian biodiesel programme, mainly due to the low technological requirements for its production. The castor bean can be grown on poor quality land with low levels of rain and fertility, making it a good option for family-based agriculture in Brazil's dry north-eastern region, which is the poorest part of Brazil. However, this initial vision has proved to be over-optimistic, and several obstacles to large-scale castor production have emerged.

Low production levels and lack of agronomic research have contributed to low castor yields in Brazil compared with international levels. India's productivity, for instance, is 1.5 times higher than that of Brazil. Brazilian castor production is very unstable, with about 168 000 tons produced in 2005. Another important obstacle to castor-based biodiesel is the international price for castor oil. Castor oil is used as a lubricant in cars and planes as well as in the chemical industry. The current price of castor oil on the international market is higher than the price of biodiesel. In April 2007, the price of castor oil in Brazil was R$2.85 per litre, while the biodiesel price set in public auctions was R$1.75 per litre.

Currently, the volumes of castor oil demanded in the international market can be considered small (800 000 tons). Some biodiesel producers have encountered technical problems when processing castor oil using current plant technology developed for rapeseed or soybean oils. These relate to castor oil's viscosity, which could limit the addition of more than 2% of biodiesel to diesel.

Regarding palm oil, its international market is as large as soybean oil, as it is widely used in the food industry, in particular in Asia. Currently, about 25 million tons of palm oil are produced internationally. Brazil is a small palm oil producer and consumer at the international level (0.5%). However, the country has an important potential for palm oil production, considering the climate and land quality. The cost of palm oil production in Brazil has been estimated at between USD 200 to USD 230 per ton, while the international price of palm oil is about USD 600 per ton. According to Macedo and Nogueira (2005), Brazil has about 70 million hectares suitable for palm production in the Amazon region. About 40% of this area is highly suitable for palm production. Palm plantation and harvesting is labour-intensive, with high potential social impacts.

Brazil is already experimenting with biodiesel production using palm oil as feedstock. The Agropalma project is producing biodiesel by buying palm oil from small farmers in the North of Brazil. This project is responsible for the creation of 3 000 direct jobs, with 33 000 hectares of palm plantations. Nevertheless, large-scale production of palm oil will require more agronomic research.

Jatropha is a tree from the same family as castor, with no commercial use at present. The Brazilian agronomic research institute (EMBRAPA) has experimented with planting Jatropha in dry regions, with excellent results. The plant has low levels of soil and water requirements, and has a good oil content (30-40%). One of the most important advantages of this plant is its low production cost. The plant can produce for 40 years without replanting. Castor, in contrast, must be replanted every two years. Therefore, Jatropha is being pointed to as the future biodiesel feedstock in Brazil.

As the biggest meat producer in the world, Brazil produces a large amount of tallow which can be used for biodiesel production. Brazil produces about 1 million tons of tallow per year. This amount would be enough to supply all biodiesel production to reach B2 mandatory standards. This product has alternative uses, e.g., in soap production. Some small biodiesel producers are using tallow as biodiesel feedstock. There exists a project for tallow-based biodiesel production with a capacity of 100 000 tons per year (Frigorifico Bertin). The prospects for the growing use of tallow for biodiesel production has fostered a rapid increase in the price of tallow, increasing from R$550/t in February 2006 to R$1.100/t in January 2007. This price increase is jeopardizing the economics of tallow-based biodiesel.

Table 5 synthesizes the main economic characteristics of different feedstock alternatives for biodiesel in Brazil. Palm oil productivity is 8-10 times higher than for other feedstock options. Brazil has a huge potential to produce several types of palm tree varieties for oil production, but few projects are going forward due to the lack of agronomic experience.

Table 5. **Economic characteristics of main source of feedstocks for biodiesel in Brazil**

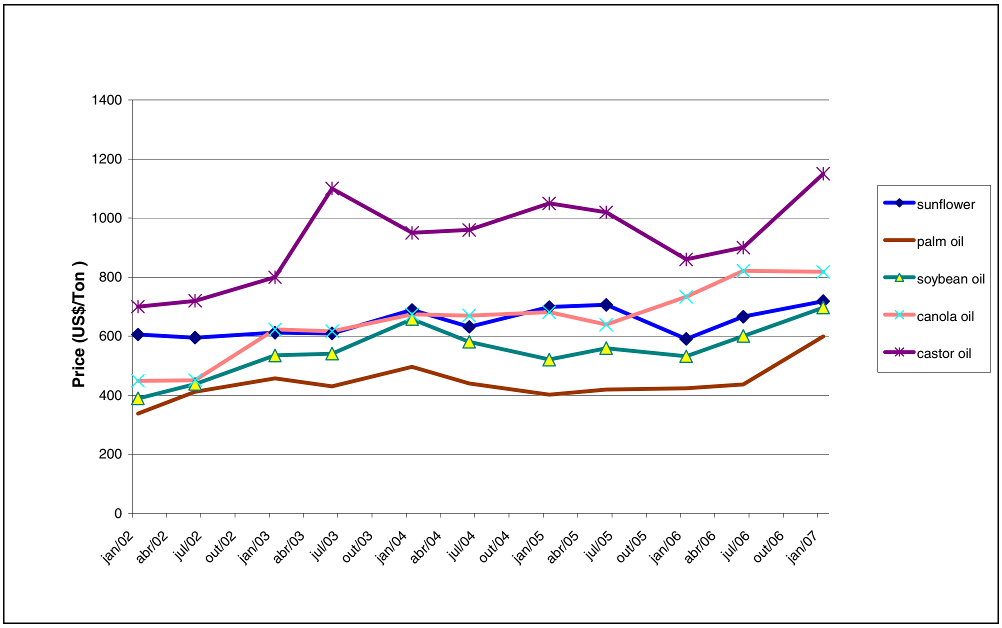
Feedstock	**Current availability**	**Agronomic research base**	**Potential social benefits**	**Oil content***	**Biomass productivity (tons per hec)**	**Oil productivity (litres per hec)**	**Production (1 000 tons – 2005)**
Soybean	Assured	High	Low	20	2 230	440	51 182
Tallow	Significant	n. a.	Low	-	-	-	1 000
Palm	Limited	Low	High	20	20 000	4 000	151
Jatropha	Non existent	Low	High	30-40	n.a.	n.a.	0
Castor	Limited	Low	High	47	730	343	168
Cotton	Significant	High	High	15	3 000	450	3 666
Sunflower	Limited	High	Low	40	1 500	630	23

Source: Author's elaboration, based on data from the Ministry of Agriculture, Brazil.

* % of dry weight.

Figure 10 shows the international prices of different types of vegetable oil. This represents the opportunity costs for using these oils in biodiesel production. Currently, most castor oil originally produced for biodiesel in Brazil is instead exported.

Figure 10. **Evolution of vegetable oil prices in the international market**



Source: FAO, www.fao.org.

In 2005, Petrobras announced the development of a new refining process that can produce diesel from renewable raw material. In this process, named H-Bio, vegetable oil is fed into the Hydrotreatment Unit of the old refinery for processing with the mineral oil. The vegetable oil contributes to the improvement of diesel quality, and the main advantage is that the process uses existing refineries to transform vegetable oil.

According to Petrobras, this technology represents an economically effective way of producing diesel using vegetable oils as partial feedstock. No additional refining investment is required for the H-Bio process. The vegetable oils are mixed in a refining stream employed in standard diesel production.

2.1.2 Biodiesel plant technology

Biodiesel technology employs a catalytic process – transesterification – using methanol or ethanol. Producing 1 000 kilos of biodiesel requires 993 kilos of vegetable oil or animal fat, 110 kilos of ethanol (or methanol) and about 5.5 kilos of catalyst. In addition to biodiesel, this produces about 117 kilos of glycerine (Dedini, 2006).

The diversity of the feedstock supply in Brazil has significant impacts on the processing technology being developed in Brazil. While international experience with the transesterification process is based on the use of methanol[25], Brazil is trying to develop new technological options for transesterification based on ethanol. In fact, Brazil imports 50% of the methanol currently consumed in the country. The high natural gas price in Brazil leaves small room for significantly increasing the domestic production of methanol. Currently, just one project has managed to produce biodiesed with ethanol-based transesterification.

According to ICIS (2006), there were 58 biodiesel plants operating in the world in 2005. The majority of these plants have a capacity lower than 50 000 tons per year. However, 20% of the plants have capacity above 100 000 tons. ICIS (2006) emphasizes the fact that the plant scale of new projects announced is increasing significantly. Of 170 biodiesel projects announced in the World by 2006, 94 have a plant capacity above a 100 000 tons per year, 23 plants have announced a capacity of around 200 000 tons/year and three of between 300 000 and 400 000 tons/year. This trajectory gradually changes the investor profile. Recently, large companies from the fields of energy and agribusiness have announced new projects in the biodiesel sector (Cargill, Bunge, Repsol, Petrobras, Sasol, Eastman, Chevron, Marathon, BP, Du Pont, Shell).

According to Aranda (2006), recent biodiesel plant technology now being offered in Brazil presents significant scale economies. The cost of plants producing 100 000 tons/year is only 18% higher than for plants producing 50 000 tons/year[26]. However, this potential cost reduction with scale seems to be insufficient to cope with uncertainties related to the cost of feedstock. The average scale of the projects announced in Brazil is about 50 000 tons per year. Feedstock diversity is giving rise to other types of technological strategies. Some projects have chosen plants with capacities of between 10 000 and 20 000 tons per year, emphasizing feedstock flexibility. In this sense, the technological trajectory in Brazil seems to emphasize flexibility, the use of ethanol and batch production, explained largely by government intervention (see following section).

Currently, there are 21 biodiesel plants ready to operate in Brazil, with an estimated total production capacity of 780 million litres per year. From this total, there are five plants commissioned but still not operating. There are 63 projects in different phases of development, totalling 800 million dollars in investments. If all these projects come on stream, Brazilian biodiesel capacity will reach about 4 billion litres per year by 2009. If we consider all the projects under construction in Brazil, biodiesel production capacity is already enough to comply with the 2% mandatory biodiesel blending requirement in 2008. The Government is considering introducing a 5% mandatory requirement for 2010.

2.1.3 Biodiesel competitiveness as compared to diesel

Because of the risk of supply not being able to meet projected demand in 2008, the National Petroleum Agency – ANP – has set up public auctions until 2008, with a view to organising the market and stimulating investment in production capacity. The authorised sellers are biodiesel producers – or companies holding biodiesel production projects – which are recognised by the Ministry of Agrarian Development (MDA). Sellers must possess a "Social Fuel Seal", which certifies that a certain biodiesel project will acquire a minimum percentage of its raw material from family-grown crops. The minimum required percentage is set at 50% for the North-East regions, at 30% for the South and South-East regions and at 10% for the North and Centre-West. The authorised buyers are diesel producers (domestic refiners) and official diesel importers (authorised by ANP). Thus far, the buyers have been Petrobras (93% of volume) and REFAP (7% of volume).

The ANP has organised five biodiesel auctions, buying 885 million litres up until February 2007. The Government sets a maximum price and accepts bid proposals. Table 6 summarizes the results so far. It shows that prices dropped progressively between the first and fourth auctions, due to increasing competition from new entrants. The fifth round concentrated on installed capacity, and thus fewer competitors participated, resulting in higher prices.

When 2% blending becomes mandatory, distributors will buy the biodiesel needed directly. The objective is that the biodiesel market should follow the structure of the ethanol market, where distributors negotiate directly with ethanol producers.

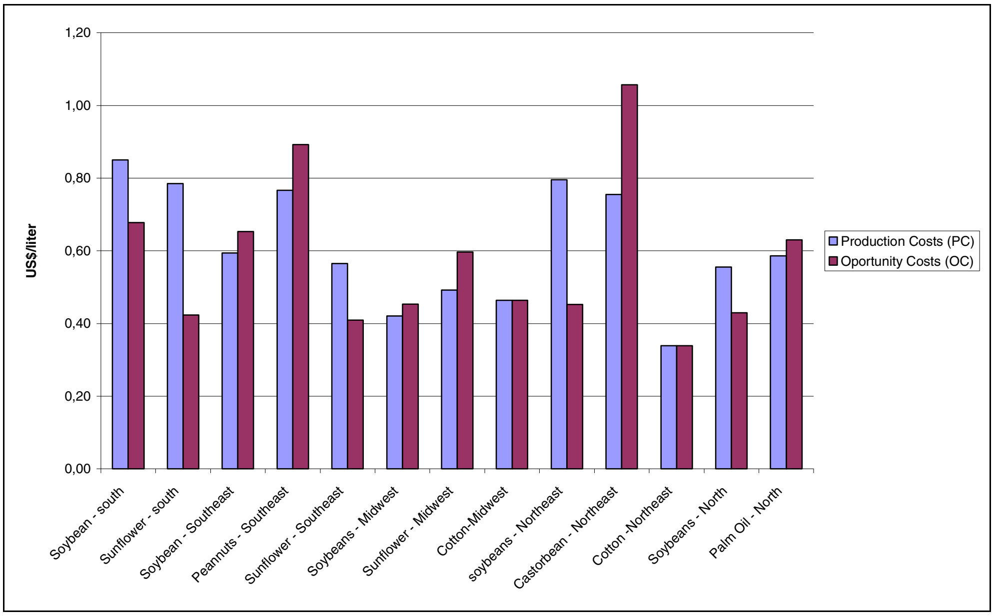
Table 6. **Public purchase auctions of biodiesel, 2005-2007**

	Sellers	Total supply (10^3 m^3)	Volume acquired (10^3 m^3)	Reference price (USD/m^3)	Average price* (USD/m^3)	Delivery date From/to
1st auction (11/2005)	8	92	70	914.29	907.12	01/2006 to 12/2006
2nd auction (03/2006)	12	315	170	908.57	886.15	07/06 to 06/07
3rd auction (07/2006)	6	125	50	907.07	840.42	01/2007 to 12/2007
4th auction	25	1 141	550	906.67	837.38	01/2007 to 12/2007
5th auction 02/2007	3	50	45	906.67	887.39	Immediate
Total volume			885		854.98	

Source: National Petroleum Agency (average exchange rate R$2.1 per USD).

According to CEPEA, for a biodiesel plant of 40 000 tons/year in Brazil, biodiesel production costs vary from USD 0.34 to USD 0.85. The most competitive raw material is cotton in the North-East. Figure 11 illustrates biodiesel production costs in different regions of Brazil, showing feedstock production costs and market prices for vegetable oils.

Figure 11**. Estimated biodiesel production costs according to feedstock and producing regions – 2005 (40 000 tons/year)**



Source: Barros *et al.* (2006).

As we can see, in some cases, production costs exceed market prices (soybean in the southern, north-eastern and northern regions; and sunflower in the southern and south-eastern areas).

Comparing biodiesel production cost estimations to the ANP auction prices, we can see that auction prices have been more than 100% higher than biodiesel production costs. This attractiveness is driving a biodiesel rush in Brazil, attracting investors from the soybean sector, interested in improving their profitability but not necessarily committed to biodiesel's long-term development.

2.1.5 Direct and indirect subsidies to biodiesel

Biodiesel production in Brazil is strongly subsidized. The most important incentives are the prices paid in the auctions (as seen above) and tax exemptions. Concerning the first incentive, it is worth noting that the ex-refinery price of conventional diesel is about USD 0.54/ litre, including federal taxes, and that the average pump diesel price in Brazil is USD 0.85. Therefore, biodiesel is not competitive with conventional diesel, even in cases where biodiesel is totally exempt from taxes.

Several levels of tax incentive are offered to biodiesel producers with a view to promoting regional development and sustaining family-based agriculture. Federal taxes applied to conventional diesel include excise tax (CIDE) and social contributions (PIS/COFINS). Currently, mineral diesel is subject to total federal taxes of approximately USD 0.10 per litre. As a general rule, biodiesel would be charged the same amount of federal tax as conventional diesel. The exceptions are:

i) biodiesel produced in the North and north-eastern regions – poor regions but with agricultural potential – from intensively farmed castor bean and palm oil plantations, is granted a federal fiscal exemption of 31% in order to stimulate economic activity in the region;

ii) Biodiesel production based on raw materials produced by family crops throughout the country is granted a 68% reduction in federal taxes.

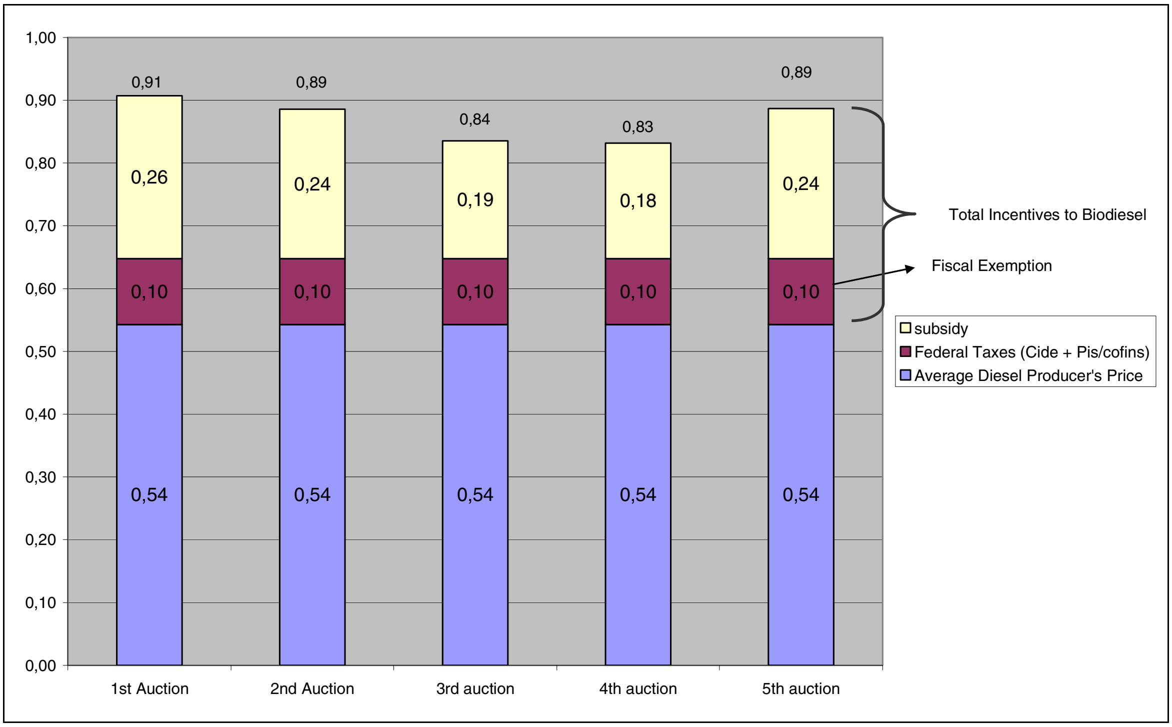
These incentives seek to sustain small, family-based agricultural output;

iii) Biodiesel production that meets both of the aforementioned conditions – that is, biodiesel production from castor or palm raw material supplied by small farmers (family crops), located in northern, north-eastern or semi-arid regions (some cities located in the South-East region present the same climate and social structure as those in the countryside of the North-East that are included in this classification) are totally exempt from federal taxes. These federal taxes are collected at the biodiesel refinery. Producers have to present a certificate that guarantees that biodiesel output meets some of these conditions.

Figure 12 shows the average price paid by refiners in the public auctions as compared to the average diesel producer's prices without federal taxes (data from 2006). The difference can be considered as the total incentive given to biodiesel producers in order to develop the biodiesel market. Part of this incentive takes the form of fiscal exemptions, and part is a direct revenue transfer from refineries to biodiesel producers.

Without considering the fiscal exemptions, subsidies offered to biodiesel producers totalled USD 180 million in the ANP auctions. The amount of subsidies from tax exemption is more difficult to estimate, due to different levels of exemption according to region and type of feedstock.

Figure 12. **Subsidies to biodiesel production in Brazil (USD per litre)**



Source: Author's elaboration, based on ANP data.

2.2. Environmental performance

Biodiesel global environmental performance depends on the energy balance of biodiesel production on a life-cycle basis. This energy balance varies according to the type of feedstock, the production conditions, and feedstock productivity and type of processing technology.

Few studies have been dedicated to the analysis of the environmental performance of biodiesel in Brazil, and most of them are out of date. Goldemberg (1982) analysed the energy balance of soybean biodiesel and found a ratio of 1.43 for the energy in the biodiesel compared to the fossil energy used in producing it, without taking into account the energy content of the byproducts sold to the food market (soybean flour). This element can change the results considerably. For instance, the energy balance for soybean biodiesel in the US is 3.2 (NREL, 1998). A yield of 3 is widely accepted as a good indication for the soybean biodiesel energy balance.

Neto *et al.* (2004) studied the energy balance of castor oil biodiesel in Brazil and found it ranged from between 2 to 2.9. They assumed an average productivity of 1 800 kilos of castor per hectare, which is rather optimistic given that current productivity is less than 1 000 kilos per hectare. Martins and Teixeira (1985) found an energy balance of 5.63 for biodiesel from palm oil in Brazil. More recently, Costa *et al.* (2005) also studied the energy balance of palm oil biodiesel in Brazil and found a more optimistic figure, ranging from 7 to 10. Finally, the energy balance for Jatropha oil biodiesel has been estimated to range from between 5 and 6 (see Table 7).

All these figures can be seen as a preliminary indication. Based on the literature so far produced on the topic, palm tree biodiesel seems to present the best emissions reduction potential.

Table 7. **Energy balance for different types of biodiesel feedstock**

Feedstock	Energy input/output
Soybean	1.5-3.2
Palm tree	5-10
Jatropha	5-6
Castor beans	2-2.9
Sunflower	3

Source: Author's elaboration, based on the literature quoted above.

The impact of biodiesel on the reduction of CO_2 emissions has not yet been studied in the Brazilian context. The IEA (2004) presents estimates for net GHG emission reductions from rapeseed-based biodiesel. Studies on well-to-wheels net CO_2 emissions show a reduction ranging from 40% to 60%. Smith (2004) has made a life-cycle analysis of soybean, rapeseed and tallow-based biodiesel emissions. He found a reduction in emissions of about 63% for rapeseed and soybean and of about 90% for tallow biodiesel. In the case of Brazil, there is a potential for improving the CO_2 reduction levels using feedstocks with a better energy balance. In addition, if ethanol is used instead of methanol in the transesterification process, a significant reduction in emissions can be obtained.

According to La Rovere (2006), each litre of mineral diesel in Brazil emits about 2.7 kg of CO_2. If we assume that most Brazilian biodiesel will come from soybeans (with a 60% reduction in CO_2 emissions), the Brazilian biodiesel programme will contribute towards avoiding about 1.3 million tons of CO_2 per year in 2008 (B2) and about 3.9 million tons in 2011 (B5). However, as the share of other types of biodiesel feedstocks increases in Brazilian production, further reductions in CO_2 emissions can be obtained.

2.2.1 Other environmental impacts

The potential contribution of biodiesel production to deforestation should be studied carefully. As far as castor bean and jatropha are concerned, the potential contribution towards deforestation is less important, since these plants are cultivated in semi-arid zones with few remaining forest regions. The objective of the Brazilian biodiesel programme is to create an economic alternative for these economically depressed areas of the country.

Several varieties of palm tree are native in the humid zones of Brazil. The Government has announced that the objective is not to replace forests by palm tree plantation, but to create an alternative for already deforested areas. Palm oil culture is one of the most criticised cultures in the world concerning its impacts on deforestation. This is mainly because it can only be planted in tropical zones (Malaysia, Indonesia, South Africa, and now in Brazil) and its expansion can damage eco-sensitive areas like tropical forests. In 2004, an association called the "Roundtable on Sustainable Palm Oil" was created, aimed at promoting the growth and use of sustainable palm oil through co-operation within the supply chain and open dialogue with stakeholders. This Association involves a wide range of organisations, such as the World Wildlife Fund (WWF) (Switzerland), United Plantations (Malaysia), Marks & Spencer (England), Sainsburys (England), Unilever (Holland) and MPOA (Malaysia). After an intense debate, the Association came to a consensus about the principles and criteria that sustainable palm oil production should attain (RPSO, 2005). Agropalma, a Brazilian company that produces biodiesel from palm oil, is involved in developing the criteria with a pilot project, and the results will be analysed by November this year.

Because the biodiesel programme is a recent initiative, there is as yet no detailed research on other environmental issues regarding the growing of vegetable oil related to biodiesel production. Embrapa is implementing a research project to measure the environmental impacts of plantations for biodiesel production. The first project will be focused on 24 oil plant producers around two cities: Catanduva in the State of Sao Paulo and Cassia in the State of Minas Gerais. This project started in February 2007 and there are as yet no available results.

In this context, we decided to make a brief assessment of the major environmental issues related to the main oil plant grown in Brazil: soya.

2.2.2 Local environmental impacts of soya production

The expansion of soybean cultures in Brazil raises many environmental issues. The first one concerns the risk of deforestation. As mentioned before, soybean production has expanded to the frontiers of the Amazon forest. Grath and Diaz (2006) stress that the main impact on deforestation is indirect: soybean producers prefer using areas already deforested by cattle-raising activity, mainly because this lowers the cost of preparing arable land. However, soybean production tends to displace cattle-raising activity to forest areas. Another possible indirect impact is on the remaining forest cover near soybean production. Grath and Diaz (2006) show that soybean production uses firewood to dry the grains: 0.03 m^3 of firewood for each ton of soybeans. However, the impact of soybean production in the Amazon area is an open area of research because it is a recent development.

Currently available assessments of potential risks have analysed the impacts that have occurred in savannah areas. The first type of impact regards soil erosion and silt accumulation in rivers. According to Mr. Peres Filho, from the Geosciences Institute of the University of Campinas (Unicamp, 2003), the expansion of soybean production in Brazilian savannahs has exploited soils not adapted to mechanized monoculture. These are soils containing less than 15% clay (they are mainly composed of quartzite sand) and with a declivity of more than 2%, poor in calcium and potassium. In these areas, the substitution of native vegetation with pasture or soybean production accelerates soil erosion. By the action of rain and wind, this eroded material is deposited in rivers, forming sand banks. This erosion process can be so deep that it can jeopardize groundwater resources. Another element that contributes to the erosion process is mechanization, since it compresses the soil and impedes the development of plant roots. Novaes (2000) and Barreto (2004) estimate an average loss of 10 kgs of soil per kg of soybean produced.

As production advances over poorer soils, the use of fertilizer for soybean production becomes more intense than in other cultures. Macedo (2002) compares the use of potassium and phosphates in the production of both sugarcane and soybeans. The use of potassium per ton in soybean production is almost twice its use in sugarcane production (805 kgs/ton in soybean production). For phosphates, this ratio increases to three times: soybean production requires on average 690 kgs/ton as compared to 202 kgs/ton for sugarcane. Soybean plantations do not, however, need the addition of nitrogen, since the plant produces it itself with nitrogen-fixing bacteria.

The expansion of a monoculture implies a decrease in biodiversity. In terms of pesticide control, monoculture leads to the mutation of pests that become more resistant to pesticides. According to Scorza Junior (2002), a study of the use of pesticides in the state of Mato Grosso showed that among the cultures present in the state (soybean, corn, wheat, tomato, rice), soybean employs the largest amount of pesticide. Dores and Freire (2001) highlight the fact that the use of pesticides in soybean production coincides with the rainy period in the Midwest and increases the risk of water contamination. The reduction in the use of pesticides (mainly herbicides) in soybean production might be achieved through the introduction of genetically modified soybeans.

2.2.3 Environmental impacts of mineral diesel replacement

Diesel consumption is the most important contributor to the poor air quality in large Brazilian cities, as transportation systems are based on diesel trucks and buses. Brazilian diesel quality is still poor if we compare it with European or US standards. While diesel vehicles in Europe comply with the Euro IV standard since 2005, Brazil will adopt this norm only in 2009.

Comparing 100% biodiesel with American diesel, EPA (2002) shows that the particulate and carbon monoxide (CO) emissions decrease by 50%, while hydrocarbon (HC) emissions are reduced by 70%. However, NO_x emissions increase by 10%. Petrobio (2006) has estimated the potential benefits of using B5 diesel in large Brazilian cities. This study found significant reductions in emissions and estimated the avoided social cost at USD 75 million.

2.3. Brazil as a world class biodiesel exporter

As mentioned before, projects under implementation have already sufficient production capacity to comply with B2 mandatory standards. Currently, there are about 60 projects announced but not yet implemented. These projects could add a capacity of 3 billion litres to the current production capacity levels, which exceeds the domestic requirement (2.4 billion litres) to meet the 5% blending (B5) standard.

In order to assess this potential, we built the following scenario. Brazil would dedicate the same area as currently dedicated to sugarcane (6 million hectares) to new types of biodiesel feedstocks (castor, palm, sunflower, jatropha) with equal area distributions (1.5 million hectares each). In addition, about 20% of current soybean production would be dedicated to biodiesel[27]. Based on these assumptions, Brazilian biodiesel production could attain about 11 billion litres per year:

Table 8. **Brazilian biodiesel production – A speculative scenario**

	Area (million hectares)	**Biodiesel Productivity (l /ha)**	**Annual production (million litres)**
Castor beans	1.5	556	834
Palmtree	1.5	3 600	5 400
Jatropha	1.5	360	540
Sunflower	1.5	937	1 405
Soybean	4.4	662	2 913
Total	10.4		11 082

Source: Author’s elaboration.

We can conclude that Brazil could produce enough biodiesel to supply current domestic demand, even with a B10 blend (about 5 billion litres), and export significant amounts of biodiesel (also about 5 billion litres).

The mandatory biofuels standards in Europe represent an important market potential for Brazil. Nevertheless, significant trade obstacles need to be overcome. Biodiesel specifications are not yet in place to allow the development of an international market. As with ethanol, biodiesel programmes emphasize domestic production and have not been conceived to allow biodiesel consumption based on imports.

NOTES

1. Vehicle fuel supply in Brazil includes gasoline C (a blend of 23% ethanol anhydrous and 77% gasoline), ethanol hydrous, diesel and B2 (a blend of 2% biodiesel and 98% mineral diesel). It excludes other fuels such as LPG, kerosene and fuel oil. Ethanol accounts for 13% of total fuel supply.

2. From 1934 to 1973, the proportion between ethanol and gasoline consumption varied between 4% and 6% (Dias Leite, 1997).

3. These ethanol-dedicated cars were not flex-fuel; i.e. they could only burn ethanol. There are two types of ethanol: FFVs, or ethanol-dedicated cars that run on hydrated ethanol. Anhydrous ethanol is mixed with gasoline in a variable proportion up to 25%.

4. Two other important destinations are The Netherlands (the entry port for Europe), importing 10% of Brazilian ethanol, and Sweden which imported 6% of total exports.

5. Most studies do not consider the capital opportunity cost, but only the capital depreciation.

6. It is very common to have commercial agreements between farmers and ethanol mills, where the mill offers all the machinery for sugarcane production in exchange for long-term contracts of sugarcane supply. These agreements vary from land rent to machinery rent to farmers who sell their sugarcane at market price.

7. The rest is sold as cattle livestock feed, or burned.

8. In the last few years, a growing number of ethanol producers have replaced the old 22-bar boilers with ones with 60-bar pressure. This has improved the thermodynamic efficiency of generating systems by 85%.

9. Brazil recently reformed its electricity sector regulatory framework. According to the model, all power distribution companies must buy electricity through a bidding process organised by the Government. This bidding process has significantly reduced the transaction costs for small electricity producers.

10. Bear Stearns (2006) shows that, if we compare US corn ethanol with Brazil sugarcane ethanol, for the same amount of ethanol production, corn-based ethanol requires 66% more land.

11. The impact of these subsidies on the national budget is the subject of intense political struggle in the country. Even though the practice of direct subsidy ended in the 1990s, the ethanol producers' image in Brazilian society is quite negative even today. The public in general still sees ethanol producers as a privileged class of entrepreneurs.

12. See Macedo and Leal (2002).

13. Differences in sugarcane productivity are one of the factors that can explain energy balance variations. If the productivity is higher, less fossil fuel will be consumed for each unit of ethanol produced.

14. IEA (2004) and Andress (2002) summarize all relevant research papers on the energy balance of corn-ethanol and show that energy balance estimates vary from 0.73 to 1.4. Some authors maintain that ethanol from corn presents a negative net energy balance (Morris, 2005 and Pimentel, 2003). However, recent studies have given support to the 1.4 figure (cf. Shapouri, 2002).

15. We assume a price of US$10 per ton of CO_2.

16. It is conservative to consider productivity in the Amazon area to be the same as the Brazilian average.

17. Orange plantation in Brazil is encountering obstacles for its expansion. The USA, the main market for Brazilian orange juice, has imposed importation taxes that reduce Brazil's competitiveness.

18. Workers often suffer cuts from sugarcane leaves. As well as clearing the area of dangerous animals, burning makes cutting and transporting the sugarcane much easier.

19. Straw burning causes lung diseases due to ash production.

20. Formally hired workers obtain benefits such as vacations, unemployment insurance, food stamps and health care.

21. This productivity increase assumption is also adopted by Unicamp (2006).

22. Sindipeças (2006).

23. Note that Brazil is the only market where FFVs are relevant. Most ethanol consumers use ethanol mixed with gasoline. If up to 10% ethanol is mixed in the gasoline, vehicle performance is not affected. Therefore, ethanol's value is equivalent to gasoline in these markets. However, mandatory ethanol consumption tends to make ethanol prices higher than gasoline.

24. In fact, one of the most important contributions of agronomic research was the development of new soybean varieties that can be cultivated in tropical areas. Until the 1980s, Brazilian soybean production was limited to the colder zones in the southern areas of the country.

25. Methanol is usually produced from natural gas.

26. The cost reduction in plants due to scale increases is much higher than normal in the chemical industry. In general, doubling the plant capacity should increase the investment cost by 50%.

27. The speculative scenario considers that only a small part of soybean production could be economically dedicated to biodiesel. The increase in soybean demand by biodiesel plants would inevitably affect the soybean price in the international market. Therefore, we assumed a scenario for soybean consumption equivalent to 20% of current demand.

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THE ENVIRONMENTAL CERTIFICATION OF BIOFUELS

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SUMMARY

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1. INTRODUCTION

Bioenergy, including biofuels[1], could become a substantial tool for mitigating greenhouse gas emissions, locally and globally, possibly providing a large fraction of global primary energy supply by 2020. Exactly how large that share will be is not possible to predict with any precision, being dependent on a complex array of physical, social, economic, technical (innovation) and environmental factors. In addition, there will be competition for biomass resources between the different bioenergy sectors (electricity, heat, transport) and alternative uses, e.g. for chemical feedstocks and materials. There will be synergies too, particularly arising through advanced polygeneration and biorefinery supply chains that could help to raise primary productivity and raise resource-use-efficiencies.

Assessing the actual environmental impacts of increased bioenergy and in particular, biofuel usage, will depend sensitively on the scale and mix of technology options employed and on location. Location is important, as the fundamental factors that govern biomass productivity vary significantly according to site, e.g. soil type and climate, including water availability and temperature. Across a range of indicators one biofuel may not be the same as another, even where the final fuels are chemically and physically identical, e.g. anhydrous ethanol derived from wheat, sugarcane, sugar beet, cassava or from residues.

This heterogeneity in impacts and opportunities arises because the feedstock production, conversion and end-fuel supply chains for biofuels are often longer (geographically and technically) and considerably more complex than existing or alternative transport energy supply chains. There is also uncertainty in a range of potentially important factors that govern the assessment of the net impacts of biofuel production and use which can be divided into three categories:

1. Uncertainty resulting from the complexity of a biofuel supply chain. This can be resolved by more detailed accounting methodologies.

2. Uncertainty resulting from unresolved methodological and scientific issues. This can only be resolved through additional research.

3. Uncertainty arising from differing current and future societal concerns and changing environmental parameters, for example, a better understanding of the nitrogen cycle and therefore of the indicators and criteria that will need to be developed, measured and monitored.

In practice, very substantial differences are seen in existing biofuel supply chains in terms of environmental impacts. These include the GHG performance and wider impacts, such as on biodiversity, water use, nitrogen use and flows, air and water quality impacts, and impacts on amenity. This variance in impacts has spurred development in the UK, the Netherlands and Germany of assurance and certification systems for biofuels. Should such assurance and certification systems prove viable and valid, it would then be possible to reward individual biofuel supply options (e.g. by batch), based on their actual performance. Such a system could provide a powerful and flexible mechanism for incorporating externalities and encourage an evolutionary approach towards improved productivities, efficiencies and decreased impacts.

Despite the advantages outlined, a number of questions remain about the application of assurance and certification to biofuels in this way. The questions centre on the level of detail and therefore regulation needed, and the nature and validity of the indicators that might be used to demonstrate compliance with minimum environmental standards. Further doubts exist about the scope and coverage of the institutions around the world that are currently involved in environmental and social certification (mainly of food and timber) and their ability to expand their coverage to include the production and supply of biofuel feedstocks and fuels.

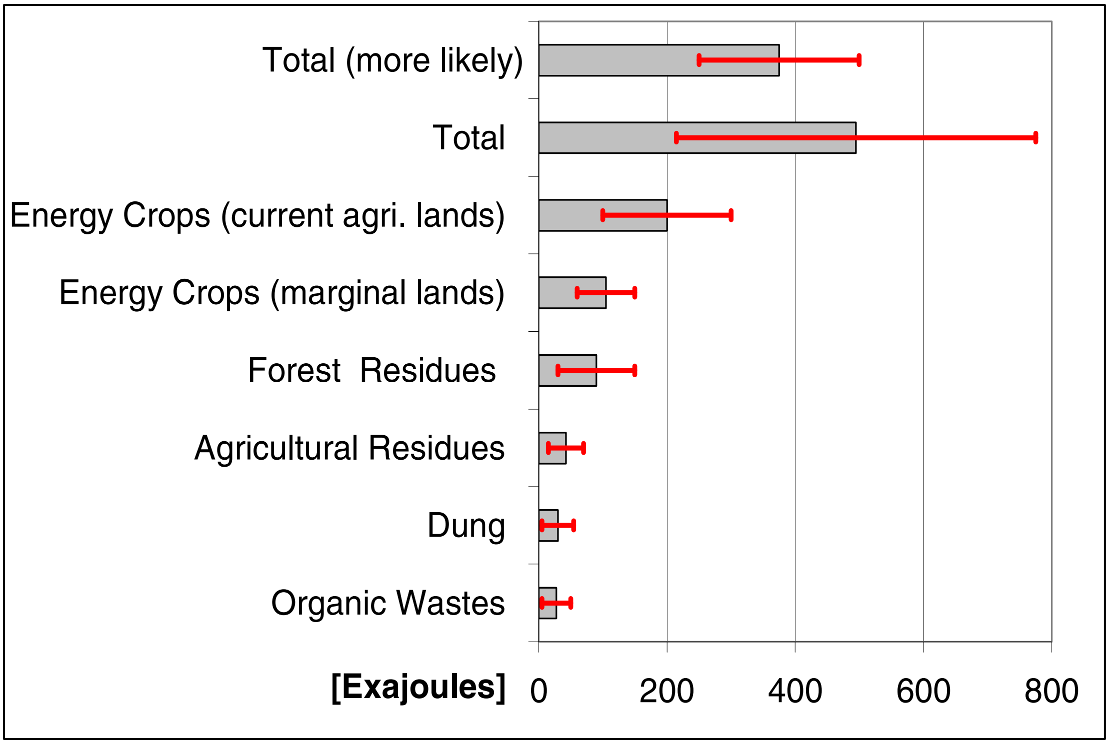
The rapidly expanding global biofuel market reflects the high current oil prices and the expectation that these high levels will be maintained, which is driving a political agenda that is sometimes in advance of the evaluation, monitoring and policy environment. New institutions, methodologies and science will be needed to ensure that biofuels can meet new demands for supply without causing major social and environmental damage. There is an opportunity to configure such systems to encourage innovation, and thus improve efficiencies and lower inputs and impacts. This paper explores these issues, and assesses national and regional assurance and certification schemes for biofuels.

2. GLOBAL CONTEXT AND RESOURCES

In many OECD countries, a combination of high population densities, high per capita energy demand, particularly for transport, and existing exploitation of much of the potential agricultural land, appears to preclude any significant expansion of land area devoted to biofuel feedstock production. In practice though, land allocation is driven by the opportunity costs of land use, which in turn is a function of the market value of the products, regulations for land management and governmental policies, including subsidies for specific products. Even where existing production is assumed to be unchanged, there may still be “space” for the production of bioenergy feedstocks, as highlighted by a recent European Environment Agency report (EEA, 2006). This report concluded that about 16-17% of projected European 2030 energy demand could be met from biomass resources even when applying “strict environmental constraints”.

There is now a growing consensus that the theoretical global potential resource base for bioenergy supply is extremely large, possibly as large as the current total global primary energy consumption (see Figure 1; Rokityanskiy *et al.,* 2006; IEA, 2006; Juergens & Mueller, 2007). This remains to be the case even where allowances are made for future food production and where protected land areas are excluded.

Figure 1. **Bioenergy potential categorised by biomass feedstock: different scenarios, year 2050 EJ/yr**



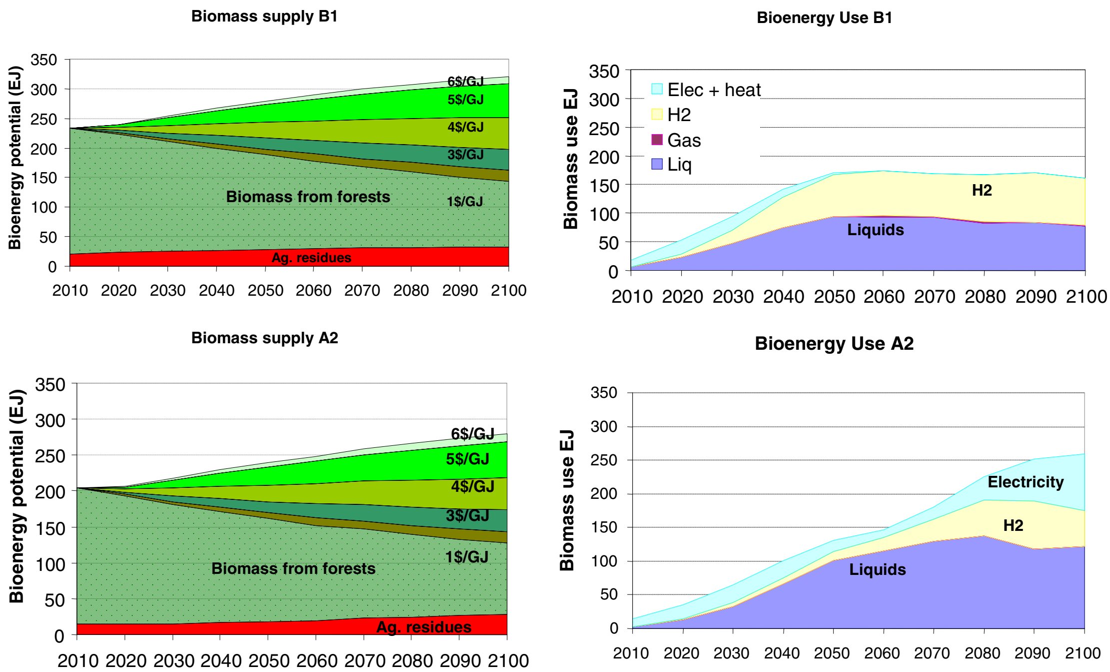
Source: Juergens and Mueller, 2007.

A detailed assessment by the International Institute of Applied Systems Analysis (IIASA, 2006) indicates that the supply of biofuels for transport applications may consume a substantial share of the bioenergy potential, as outlined in Figure 1. The main rationale driving this larger share of the biomass supply going to biofuels is the lack of realistic supply-side alternatives to biofuels in the near to medium term for the cost-effective substitution of gasoline and diesel, see Figure 2. Demand-side alternatives, including more efficient vehicles (e.g. hybrids) and behaviour change, may be difficult to achieve in the short to medium term. In addition, the energy security and rural development options provided by biofuels create powerful political motivations for the provision of support mechanisms such as subsidies and import tariffs. Such support mechanisms may distort markets and result in perverse outcomes, for example, the poor GHG performance of the US corn-ethanol programme.

In the IIASA analysis (Raihi *et al.,* 2006; Figure 2), energy market development is driven by the IPCC SRES scenarios for global development, in both the "a2" scenario, closer to business-as-usual, and the "b2" scenario (more ecologically/resource-use-efficiency driven). In both these scenarios, the demand for liquid biofuels is projected to increase by between 25 and 50 EJ by 2030, representing more than 20% of the projected global transport primary energy demand.

Basic calculations indicate that these levels of demand will require nominally between 0 and 300 Mha of land (depending on whether residues are used exclusively or if energy crops yielding the equivalent of 8 000 litres of ethanol per hectare are used instead). For comparison, the total area of land dedicated to wheat production globally is about 250 Mha.

Figure 2. **Projections for the supply and use of biomass for energy - 2010 to 2100**



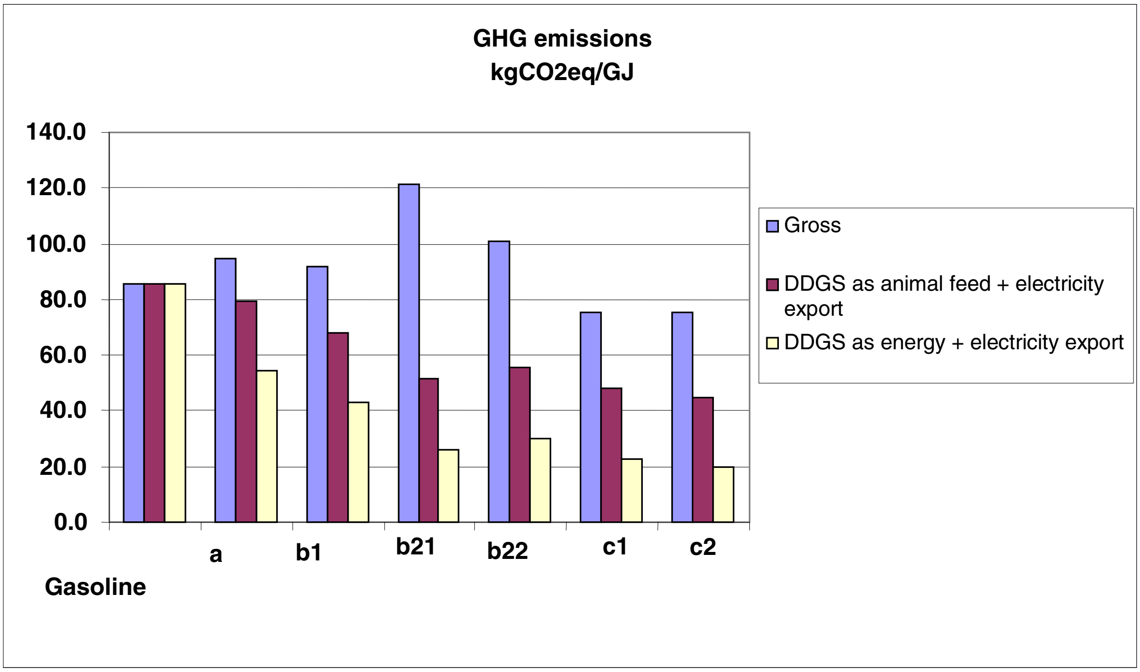
Source: Riahi, 2006, for biomass supply graphs on left;
IIASA, 2007 for projected biomass use graphs on right.

2.1. GHG emissions from biofuels

Detailed life-cycle assessments in the US and EU have highlighted that the GHG reduction benefits from biofuels cannot be taken for granted. The results from these assessments are based on current and possible future biofuel production chains. The results published vary from at best marginal reductions in GHG emissions when biofuels are used, to reductions of greater than 80% per km driven, or unit of transport energy used (Figure 3; Rickeard *et al.*, 2004; Woods & Brown, 2005; JEC, 2006; Farrell *et al.*, 2006).

Despite there now being a number of long-running and therefore mature biofuel programmes around the world, e.g. the Brazilian and US fuel-ethanol programmes, emerging developments in feedstock production, conversion and use technologies could lead to substantial reductions in GHG impacts. Indeed, employing good/best management agronomic practices and crop selections might result in substantially improved GHG and energy balances and decreased environmental impacts.

Figure 3. **GHG emissions from 6 different models of a wheat-to-ethanol conversion plant**



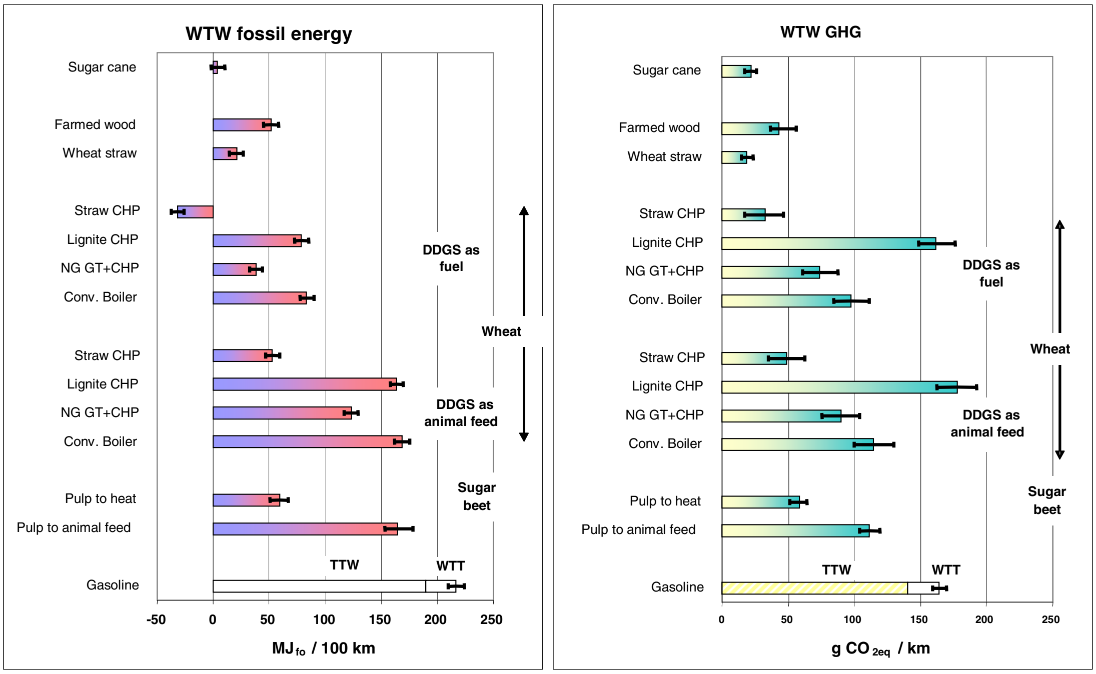
Source: Rickeard *et al.*, 2006.

Note: Model "a": Natural gas-fired boiler and "imported" grid electricity (no CHP).
"b": Add CHP capability to this basic configuration. "b1" adds a steam turbine, "b21" replaces the boiler with a gas turbine + steam recovery from exhaust, "b22" adds co-firing with natural gas to the steam generator. "c": Uses straw as an energy source, "c1" straw-fired CHP plant with a steam turbine, "c2" adds a condensing turbine.

Figure 4 highlights the variations in the average GHG emissions associated with the production and use of bioethanol as a vehicle fuel when calculated on a full life-cycle "well-to-wheel" (WTW) basis. It shows that the average GHG emissions associated with the use of Brazilian sugarcane-derived ethanol would result in about 25 gCO_{2eq} being emitted per km driven by a 1.6 litre vehicle. By comparison, the GHG emissions resulting from the use of standard European gasoline under the same conditions and with the same vehicle would have been *ca.* 170 gCO_{2eq} per km driven. Although not shown, when US corn (maize)-based ethanol is used the emissions would be between 150 and 170 gCO2eq/km, i.e. a less than 10% reduction compared to gasoline on a full life-cycle basis.

The use of wheat grain and/or straw or sugar beet, grown and converted to ethanol in Europe, has a wider potential variation in WTW GHG emissions than sugarcane. One study, (Rickeard *et al.*, 2004) which included representatives from CONCAWE (the European Oil Research body), ExxonMobil, EUCAR (The European Council for Automotive Research and Development), JRC (European Joint Research Centre), British Sugar, Imperial College London and North Energy (LCA experts), calculated that the life-cycle GHG emissions from wheat-to-ethanol ranged from a 7% to over 77% reduction compared to gasoline (Figure 3). The actual reduction in GHG emissions depended most strongly on the way energy was generated and used in the conversion plant and the way co-production (particularly distillers' dried grains with solubles, DDGS) were used, for example, as animal feed, for internal energy generation in the conversion plant, or as a fuel in a large existing electricity generation plant.

Figure 4. **A comparison of energy (MJ/100km) and GHG balances (gCO2eq/km) for different bio-ethanol supply chains (JEC, 2006)**



Although the Rickeard *et al.* study used standard UK-derived wheat agronomic factors, it has emerged that substantial reductions in the emissions arising from the feedstock production could be achieved if different, e.g. high starch/feed varieties of wheat were used for ethanol production (Smith *et al*., forthcoming). In particular, reductions in the use of nitrogen per unit of ethanol produced can lead to significant reductions in overall GHG emissions, both from reduced nitrous oxide (N_2O) emissions in-field and at the fertiliser manufacture plant, and in improved fermentation efficiency in the ethanol production plant due to the lower protein content of the wheat grain. An important conclusion of this analysis was that the lowest GHG-emitting ethanol production chains were also the most capital intensive. Therefore, policies that simply promoted biofuels on a volumetric basis were likely to give relatively greater incentives to the worst performing ethanol producers rather than the best.

The wide range in the possible impacts, including those often sited as the main reasons for promoting biofuels, is the prime motivation for the requirement to implement measurement and monitoring systems. Over the last two decades, the rise of consumer-led demands to know the origin and environmental impacts of the products they purchase has resulted in the emergence of certification systems aimed at guaranteeing environmentally and socially benign products. The application and/or revision of these certification systems to biofuels are the main focus of this paper. The following sections assess the fundamental applicability of such schemes to biofuels and the practical issues of implantation and monitoring.

3. NATIONAL DEVELOPMENTS IN BIOFUEL ASSURANCE AND CERTIFICATION

A range of global to local factors are driving the increasing demand for biofuels, as outlined below. Although there is potential conflict between new policies designed to target individual drivers, flexible and carefully designed policies can be developed to provide incentives for biofuel provision systems that meet all or many goals simultaneously. However, such policy frameworks are unlikely to happen without careful and detailed planning and implementation.

Figure 5 outlines the diversity of policy drivers from the global to the local that have driven the emergence of bioenergy, and biofuels in particular. At the global level, these range from the relatively more recent climate change mitigation and adaptation treaties, to long-running subsidies to agricultural production as "rural development" funding. There may be conflicting policy aims between the global and local/end-user perspectives. For example, "rural development" or "energy security" incentives to biofuels could result in biofuels which are worse than the fossil fuels that are being substituted in terms of GHG emissions or air-quality impacts. From the end-user perspective, even environmentally-minded purchasers of vehicles will not buy them if they are liable to break down because of the use of biofuels. For drivers wishing to reduce their individual (or fleet) GHG emissions, tradeoffs may need to be made in terms of increased emissions of acetaldehyde, ozone precursors in general or even particulates.

Figure 5. **Global and local drivers for bioenergy and biofuels**

National / Regional / Global	Local / End User
1. Climate Change 2. Energy Security 3. Rural Development (Macro-economic costs)	1. Usability 2. Cost 3. Environment, e.g. air quality/ health/welfare/biodiversity?
← Sustainability → health / welfare / environment	

In developing policies to address this diverse set of drivers, an overarching framework is needed to underpin any environmental certification scheme. With a view to avoiding duplication and to minimizing costs, existing assurance and certification schemes/institutions have been evaluated as possible implementing institutions (Bauen *et al*., 2004; Tipper *et al*., 2005; Ecofys, 2006). These evaluations were carried out for the UK's Low Carbon Vehicles Partnership, on behalf of the UK Government, as part of the development of its Renewable Transport Fuels Obligation (RTFO) which comes into force in April 2008. In parallel, the Netherlands' Government has been investigating a similar system and now, together with the UK and German governments, concerted efforts are being made to develop a single, over-arching, super-national standard and legislative approach, as described below (UK DfT, 2007; Cramer Commission, 2007).

Despite the existence of publicly respected certification schemes, such as the Forest Stewardship Council (FSC), such schemes have been developed to provide assurance for non-biofuel products (mainly forestry-based timber products). Other emerging schemes, such as the Round Table on Sustainable Palm Oil (RSPO), EUREPGAP, UK ACCS, LEAF, FSC, Roundtable on Responsible Soy Oil (RRSO) and others, have also been evaluated (ECOFYS, 2006; RSPO, 2005; FSC, 2005; ISO, 2006). It was found that no existing certification scheme has sufficient coverage to be adopted, as is the case for biofuel certification. As a result, a meta-standard approach was proposed by Tipper *et al.* (2006), which has provided the basis for the current developments in the application of "sustainability" assurance for biofuels under the UK RTFO.

Much of Europe is densely populated, with relatively high per capita energy usage, not least for mobility. Indigenously produced agricultural feedstocks are expensive compared to global commodity prices, and so meeting any substantial internal biofuel supply targets will require significant levels of imports of either biofuel feedstocks or the finished biofuels, or a combination of both. Moreover, to avoid conflict with international trade rules, any incentive system applied must be able to be equally applicable anywhere around the world.

Providing answers on the effectiveness of biofuels in meeting each of these drivers has required the careful and parallel development of policy, the meta-standard methodology and the meaningful interaction of the main stakeholders that are likely to be involved in delivering significant volumes of biofuels into the UK and the Netherlands. The balance of representation in the stakeholder group is an important component of the validity, and therefore public acceptability, of the approach. Stakeholders for the UK RTFO's advisory boards include: biofuel suppliers; oil majors; supermarkets (also major fuel distributors in the UK); government departmental representatives (including Transport, Trade and Industry, Environment, Food and Rural Affairs); agricultural representatives [National Farmers' Union, Home Grown Cereals Authority (HGCA)]; academics (primarily LCA experts); and Green NGOs (RSPB). A similar set of stakeholders was convened in the Netherlands under its Cramer Commission (Cramer Commission, 2007).

3.1. International trade implications

Most OECD countries are now engaged in the international trade in biofuels or potential biofuel feedstocks, many of which are predominantly traded as part of the food supply chain. This cross-over between food and fuel commodities poses significant problems to international trade rules, particularly where different categorisations might be applied to the same physical commodity. In particular, by linking national policies that promote and regulate biofuels to assurance and certification systems, new barriers to trade could be erected.

For consumer-led assurance and certification schemes where compliance with the standards of the scheme is voluntary, the WTO has no jurisdiction. However, where government policies direct compliance, WTO and regional trade rules have jurisdiction, and understanding the vulnerability to challenge by potential biofuel-exporting countries has played a significant role in guiding the design of new UK and Netherlands' policies on biofuels. The focus has been on the treatment of "like products" and on tariffs and support mechanisms applied to a biofuel or its associated co-product(s).

According to the IPC and REIL (Renewable Energy and International Law) (2007), a wide range of governmental support mechanisms are relevant to WTO jurisdiction, including:

- Fuel excise tax exemptions and rebates, full or partial;
- Mandates for the production of specified levels of biofuels;
- Mandates for compulsory blending with fossil fuels to a certain percentage by federal and subnational entities;
- Government procurement preferences and purchase mandates;
- Local, state/provincial and federal fleet requirements, specifying some level of required or subsidized usage of biofuels in the relevant government fleets.
- Environmental legislation, mandating certain specific types of fuel additives (typically for fuel oxygenation) related to reducing vehicle exhausts. This has resulted in higher demand for ethanol, either as a blending agent or for manufacture into ETBE as a substitute for the more environmentally hazardous MTBE;
- Subsidies not normally associated directly with biofuels, such as agricultural farm supports in the US, the EU and elsewhere; and
- Government-supported R&D for biofuels, ranging from basic research to technology demonstration plants.

Mandatory measures applied through national policy, such as the linking of support to compliance with environmental or social standards, may be construed as a “technical barrier to trade”.

4. ASSURANCE AND CERTIFICATION

The European Commission has introduced the concept of minimum environmental (including GHG) standards. It is considering asking Member States to award less support relative to a standard rate for biofuels produced from biomass, grown on lands converted from high carbon stock areas or from high biodiversity-value areas before 2005, as well as to ethanol produced from wheat, using lignite-fired CHP (combined heat and power).

To achieve these aims, a workable, globally applicable system will need to emerge that aims to ensure and verify the origins of the feedstocks for biofuels production. We use the following definitions for such an assurance and certification system (Bauen *et al.,* 2005):

-- A “***standard***” refers to a set of principles and criteria to be used consistently as rules, guidelines, or definitions of characteristics to ensure that materials, products, processes and services meet their purpose. The “standard” will also define indicators and methods that are used to measure compliance with principles and criteria.

-- "***Certification***" refers to the issuing of written assurance (the certificate) by an independent, external body – a certification body – which has audited an organisation's management system and verified that it conforms specifically to the standard.

-- "***Accreditation***" refers to the formal recognition by a specialised body – an accreditation body – that a certification body is competent to carry out certification.

-- Finally, "***assurance scheme***" generally refers to the overall framework relating to the development of a standard, the accreditation of certification bodies, and the certification of products and services.

In practice a certificate is issued when a producer of a product (or process) has answered, or confirms that it is capable of answering a set of standardized questions categorised by the principles that make up the standard as follows:

-- "**Principles**": which are defined as *"general tenets of sustainable production";*

-- "**Criteria":** *"Conditions to be met to achieve these tenets"* and which help to define the indicators to be answered;

-- "**Indicators":** the individual questions that show h*ow a farm, producer or company could prove that a particular criterion is met.*

Therefore, it is the indicators that need to provide sufficient detail to ensure that the principles underpinning the standard are being adhered to. However, in complex systems, a "value judgment" may be necessary to set the detail, total number and complexity of the indicators. With too much detail the certification procedure becomes too unwieldy, expensive and difficult to administer. With too little detail, serious doubts will be raised about the ability of the scheme to assure that its products meet the standard.

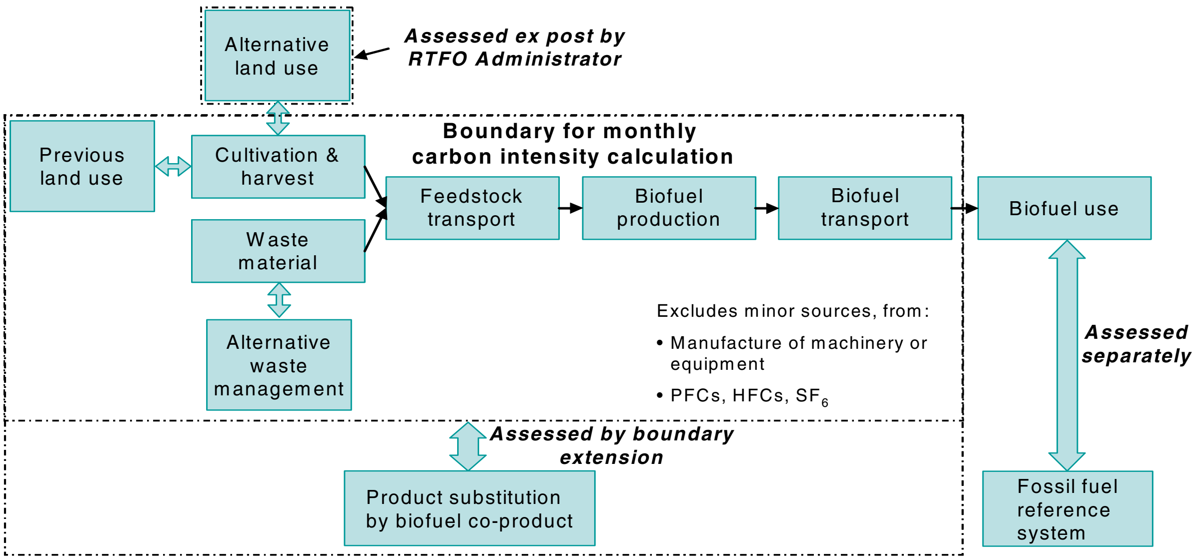
This balance between coverage, detail and simplicity can only be met by a transparent decision process that uses a "representative" set of stakeholders, encompassing a "balance of interests" to define the principles, criteria and indicators of the standards. More often than not, for consumer-based environmental and social assurance schemes, the public credibility of a scheme is a function of the degree of participation of high profile NGOs in the decision-making process.

A final, but critical issue for the credibility of certification, often as perceived by the major NGOs, is verification. This credibility is a function of the nature of the principles and indicators that make up the standard, but also of the verification procedures. "Verification" requires a detailed set of protocols to be developed and implemented by the certification bodies which, in turn, must be accredited by an accepted accreditation body. Verification protocols must be developed as an agreed part of the "standard" under which the assurance and certification scheme works. However, the nature of the indicators included in the standard will define the complexity of the auditing procedures that lead to the issuance of the certificates, and therefore the complexity and expense of the verification procedure.

4.1. Assurance and reporting methodologies

The proposed UK-Netherlands assurance scheme has two core components: i) a GHG reporting system (quantified); and ii) a sustainability reporting system (threshold-based). Draft technical guidance, for companies wishing to comply with the "reporting" requirements of the UK's Renewable Transport Fuels Obligation (RTFO), was issued in February 2007. The boundaries of the GHG reporting, as proposed for the RTFO scheme (LowCVP/E4Tech), are outlined in Figure 6.

Figure 6. **System boundaries for biofuels (E4Tech, 2006)**



A life-cycle assessment methodology has been adopted for calculating the GHG impacts associated with individual batches of biofuels being passed through the UK fuel-duty points. In order to comply with WTO regulations, a multi-tier, flexible approach has been developed.

4.2. Standards and principles

In 2005, in anticipation of the impending implementation of the RTFO, the UK's Low Carbon Vehicle Partnership commissioned work to develop a draft biofuels standard that would provide environmental assurance for the production of biofuels (Tipper *et al*., 2006). This work established that it would be possible to apply a "meta-standard" approach to the implementation of sustainability assurance (including environmental aspects) to biofuels supplied in the UK.

The meta-standard was developed by comparing the standards, principles, criteria and indicators developed by the existing and emerging voluntary standards around the world, including the Forest Stewardship Council (FSC), the Roundtable on Sustainable Palm Oil (RSPO), EUREPGAP, etc. Seven basic principles were identified, as shown in Table 1, with each principle including a number of criteria and indicators designed to assess the extent to which the feedstock produced in accordance with each scheme can be considered sustainable under the RTFO.

Table 1. **Environmental and social principles**

	Environmental principles
1	Biomass production will not destroy or damage large above- or below-ground carbon stocks.
2	Biomass production will not lead to the destruction of or damage to high biodiversity areas.
3	Biomass production does not lead to soil degradation.
4	Biomass production does not lead to the contamination or depletion of water sources.
5	Biomass production does not lead to air pollution.
	Social principles
6	Biomass production does not adversely affect workers' rights and working relationships.
7	Biomass production does not adversely affect existing land rights and community relations.

Thus, the meta-standard approach enables the use of existing voluntary assurance schemes around the world by the obligated companies, minimizing the cost and administrative burden of compliance.

Detailed technical guidance has now been prepared by Ecofys (2006) for the "sustainability reporting" under the RTFO. These principles and the methodology included in the guidance parallel those proposed by the Netherlands' Cramer Commission (2007), thus establishing coherence between the two national schemes. There has also been recent detailed interaction with the German Government, with the intention to harmonize activities between the three countries. In turn, the aim is to help provide the basis for a single EU standard and methodology, and collaborate with activities aimed at developing a global standard. Mechanisms to develop a global standard are also emerging under the auspices of the Global Bioenergy Partnership, established by the G8 after the Gleneagles Summit, the UN-FAO through its Global Bioenergy Platform and through the newly-formed Global Roundtable on Sustainable Biofuels.

4.3. Criteria and indicators

The environmental criteria relate to: carbon storage, biodiversity, soil quality, water quality and quantity and air pollution (see below). They also include reporting on land-use change (displacement effect and carbon report). These environmental principles are based on the ECCM Report (2006), the Dutch criteria defined by the Cramer Commission as well as existing standards. A reference year of 2005 is adopted for carbon and biodiversity baselines. The criteria relevant to soil, water and air are related to compliance with existing laws and national/GAP (Good Agricultural Practice) guidelines, for example, as stipulated under the EU's cross-compliance rules.

The social criteria include child labour, freedom of association, discrimination, health and safety, forced labour, wages, working hours, contracts and subcontractors and, finally, land rights. These criteria must provide equal treatment for all countries, and extensive agriculture is proposed to be exempted for labour conditions. Such social criteria are not discussed further here.

The land-use change carbon intensity measurement proposed by E4Tech is based on the IPCC's 2006 methodology (International Panel on Climate Change) Tier 1 calculation. Depending on the climate, the ecological zone, the soil and the management practices, land-use change carbon intensity can be measured and reported by complying companies, using this methodology. Emissions/stocks from land-use change are assumed to be equal to the change in carbon stocks from biomass, in dead organic matter and in mineral or organic soils or wetlands.

There are problems linked to uncertainty in a biofuels certification scheme, since emissions of important GHGs such as N_2O (nitrous oxide) and CH_4 (methane) from agriculture are very difficult to monitor. Furthermore, changes in biomass stocks (from deforestation) and in soil carbon are very badly measured.

Nevertheless, several on-farm studies reveal that most GHG emissions in agriculture come from the input of nitrogen fertilizer. Furthermore, GHG emissions are higher when the straw is removed than when the straw is simply ploughed back.

The main goal of the UK-RTFO is to deliver incentives for low GHG biofuels which are not environmentally or socially destructive. At its most comprehensive level, detailed farm-to-garage forecourt assurance and certification tools might be used. For example, in the UK a proposed "bolt-on" audit to the ACCS (Assured Combinable Crops Scheme) is being developed and tested. A second farm trial (performed by HGCA, Imperial College and CMi) is being carried out in 2007 covering at least one hundred farms.

5. CONCLUSIONS

Biofuel supply chains can be very complex. They are often geographically long and dispersed, with almost all countries likely to be self-producers for internal consumption as well as for exporting. For example, over the last decade, Brazil has both exported and imported bioethanol, Sweden has exported and imported wood chips and Spain (Abengoa) uses a mixture of internally produced wheat grain and imports for bioethanol production, some of which it also exports.

The biofuel supply chains are very diverse and are likely to become increasingly so as new technologies for feedstock supply, conversion and use come onto the market. The situation is further complicated by the main biofuel feedstocks also being food feedstocks, introducing difficult issues of product categorisation under international trade rules and their associated tariffs. In addition, international trade rules do not allow direct discrimination against imported products; for example, national policy cannot simply categorise a product such as Malaysian palm oil biodiesel, as not acceptable and so ban it (fuel or feedstock) from being imported. However, categorisation of a product using environmental criteria may be possible as long as it is not discriminatory and the systems which verify the categorisation are, in turn, not discriminatory.

For a number of important potential environmental indicators with regard to the above categorisation, biofuel production and supply chains can range from significantly better than to worse than the fossil fuel being replaced. Such indicators cover a very broad range of potential impacts, both direct and indirect. Narrow policies which target one issue may well cause unintended and negative impacts elsewhere. For example, producing biofuels as a tool for energy security is likely to result in poorly performing biofuel production chains from the perspective of GHG emissions.

Volumetric or production-based policy support can result in a highly competitive market but also in biofuels with poor GHG performance. Low GHG biofuels require highly integrated and therefore efficient energy supply systems in their production facilities, which entail additional capital investment. From an economic perspective, unless there is value in reducing GHG emissions such investments will not occur.

The combination of rising oil prices and public support mechanisms coupled with improved efficiencies in the feedstock supply and conversion industries has resulted in biofuels becoming price-competitive. As a result, biofuel markets are growing rapidly, from a small base, around the world. If mitigating climate change is a major policy target and existing policies are likely to result in poorly performing biofuels from the perspective of their GHG emission, then urgent action is required to establish new systems that ensure/assure low GHG biofuels – doing nothing is not an option.

This report outlines how such "assurance and certification" systems could act as the basis for a highly targeted carbon-tax or other performance-based reward systems. However, such certification schemes require:

- Robust and practical methodologies able to deal with the complexity and heterogeneity of biofuel production, supply and use chains;

- The continued and active involvement of the main stakeholders, including scientists, NGOs, producers, consumers and national, supra-national and global institutions. Only then are biofuels likely to be publicly acceptable in the medium to long term.

Fortunately, existing examples of voluntary environmental assurance schemes capture most (if not all) of the indicators necessary, including PEFC and FSC in the forestry sector. However, environmental assurance and certification does not provide a "silver bullet" solution to the existing unsustainable trends in the transport sector. For environmental assurance specifically, leading academics as well as NGO representatives have stated that:

– In forestry, environmental assurance has not led to tangible reductions in deforestation or improvements to management outside the certified areas;

– Environmental assurance is unlikely to solve socio-environmental problems such as conflicts over resources;

– It is not an effective substitute for good governance and regulation of natural resources. The best outcomes are achieved where good governance and environmental assurance go hand-in-hand;

– Environmental assurance does not protect smallholders from the deflation of global commodity markets. Assurance schemes tend to advantage larger players: "group assurance schemes" can facilitate small producer entry.

- The credibility of environmental assurance schemes, as perceived by major NGOs, is largely dependent on the degree of participation and consultation in standard development;

- "Good practice" in the development of environmental standards has been set out by ISEAL. (http://www.ifoam.org/partners/partners/iseal.html)

Such environmental and broader "sustainability" assurance schemes are beginning to emerge in important subsectors, for example, the Round Table on Sustainable Palm (RSPO). However, to be successful, most if not all of these subsector schemes must, as a minimum, be compatible with each other. There is now a growing movement to standardize environmental assurance schemes in general (see ISO, 2006). In addition, biofuel-specific activities are being led by national governments in the European Union as well as through international bodies. It is becoming clear that the development of international environmental assurance and certification systems is becoming tightly linked to the development of "sustainable" biofuels. In order to account for critical but indirect impacts of biofuels, such systems are likely to expand to become land-use- rather than product-specific, encompassing integrated food, fuel and materials production and supply chains. Biofuels are likely to be a significant but relatively small component of such future land use.

NOTE

1. Biofuels are assumed to be liquid and gaseous fuels derived from organic materials used for transport, such as bioethanol, biodiesel and biogas.

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BIOFUELS: LINKING SUPPORT TO PERFORMANCE

Biofuels received USD 15 billion in subsidies in OECD Member countries in 2007, but did they deliver benefits in terms of climate change or oil security? Present policies make no link between support for biofuels and their environmental performance, and biofuels do not all perform equally well. In fact, much of the current ethanol and biodiesel production may result in higher overall emissions of greenhouse gases than using conventional transport fuels – gasoline and diesel.

The papers published in this report examine the economics of biofuels and assess the potential of conventional biofuel production in OECD countries, Brazilian ethanol exports and some second generation biofuels to supply world markets with transport fuels.

The Round Table analysed the critical issues for governments in determining support for biofuels, particularly the level of greenhouse gas emissions throughout the life-cycle of these fuels and the wider environmental impacts of farming biomass. It also reviewed recent progress in developing certification systems for biofuels – an essential tool for tying support to achievement in reducing greenhouse gas emissions, although certification cannot be expected to prevent rainforest destruction for the development of biofuel crop plantations.

The report concludes with a short list of recommendations for policy reform if support for biofuels is to contribute effectively to mitigating greenhouse gas emissions.

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