UNITED NATIONS
UNCTAD

United Nations Conference on Trade and Development

The Biofuels Market: Current Situation and Alternative Scenarios

This report provides a contribution to the Global Bioenergy Partnership (GBEP). It was produced with the support of the Italian Ministry for the Environment, Land and Sea.

United Nations
Geneva and New York, 2009

Note

UNCTAD/DITC/BCC/2009/1

Contents

Page

Boxes

Figures

Tables

Foreword

UNCTAD started working on the trade and development implications of the biofuels sector in 2005. Since then, many events have had an impact on the sector. However, the fundamentals that have pressed countries – developed and developing alike – to promote biofuels as a new or expanding component of their energy mix are still there. Oil prices, though recently decreasing, are still relatively high and extremely volatile. Present geopolitics keep the quest for enhanced energy security high on the policy agenda of many countries. The challenges that climate change and global warming represent for the sustainable development of all countries still need to be addressed through concerted and individual actions. The rural sector in most developing countries has an unprecedented need for appropriate policy measures to overcome economic stagnation. Finally, many impoverished developing countries are looking for new market openings and new investments as beneficial tools to stimulate their economic growth.

At present the biofuels sector is going through turmoil and some analysts question whether biofuels will be able to keep their promises. The eventual outcome will depend on the policies that countries have already put in place and those that may be implemented in the future.

The purpose of this volume is to present possible scenarios for the biofuels industry. Each chapter describes how the sector could evolve depending on the policy and strategies that individual countries may select. However, the assumption is that individual choices may have global impacts. Each scenario therefore tries to provide insights on the global economic, energetic, environmental and trade repercussions of specific policy developments.

The compilation of this book was made possible by the generous financial contribution of the Ministry of Environment, Land and Sea of the Government of Italy. This publication is a contribution to the programme of work of the Global Bioenergy Partnership (GBEP), initiated by the Group of Eight (G8) countries at the 2005 Summit at Gleneagles with the secretariat based in Rome at the Food and Agriculture Organization of the United Nations. UNCTAD wishes to express its thanks to the Government of Italy and hopes that additional opportunities for cooperation will materialize in the future.

Activities related to this publication were undertaken within the framework of the UNCTAD Biofuels Initiative, coordinated by Lucas Assunção. Simonetta Zarrilli was responsible for organizing the research work and for the final review and editing of the book. She was supported in these tasks by Laura Zoratto and Paola Maniga. Administrative support was provided by Lalen Lleander. The cover page was designed by Sophie Combette.

This publication provides a contribution to the analysis of a new and dynamic sector of the world economy. We hope it will encourage further research into an area where much still needs to be investigated.

Lakshmi Puri

Lakshmi Puri

Director, Division on International Trade in Goods and Services, and Commodities

Overview

The term biofuels is commonly used with reference to liquid transportation fuels − i.e., ethanol and biodiesel − derived from agricultural, forest or any other organic material (feedstock). Current global concerns about fossil fuel prices and availability, a renewed quest by many countries for energy independence and widespread awareness of the need to reduce greenhouse gas (GHG) emissions have been the main reasons for many countries – developed and developing alike – to look for alternative energy sources. Biofuels have captured considerable attention because of the relative abundance of feedstocks in all regions, their easy utilization in combustion engines for transportation and compatibility with existing fuel distribution infrastructure and because they can provide a new end market for agricultural commodities, therefore revitalizing rural areas.

The first significant large-scale push for the production and use of biofuels occurred in Brazil and the United States, as a response to the 1973 oil export embargo imposed by the Arab members of OPEC (Organization of the Petroleum Exporting Countries) against Japan, the United States and Western European countries. The export restriction resulted in a dramatic increase of oil prices, from \$3 to \$12 per barrel.

The United States invested in biofuels as a way to address the fuel shortages induced by the embargo and to reduce dependence on imported oil. Brazil's objective was to reduce the pressure on its balance of payments due to the rising cost of fossil fuel imports. Although Brazil and the United States launched their ethanol programmes more than 30 years ago, only Brazil made it a priority to build upon the initial efforts and make ethanol a significant component of the domestic fuel supply.

At present biofuels are once again at the centre stage of the debate on energy, partially in response to circumstances similar to those that occurred more than 30 years ago, namely high and volatile oil prices and oil supply instability. However, the present oil shock is demand driven, contrary to the shocks of the 1970s that were supply driven. In addition, a strong global consensus nowadays advocates for reductions in GHG emissions as a crucial step to combat rising global temperatures. Governments seeking to curb emissions are now promoting biofuels because of their potentially cleaner emissions profile as compared to fossil fuels.

More specifically, two major factors triggered the latest renaissance of biofuels. First, methyl tertiary butyl ether (MTBE) was eliminated as a gasoline oxygenate in California, and later in all states in the United States, as it was found to be a serious groundwater pollutant. Ethanol was the next oxygenate available to the oil refinery industry to comply with the Clean Air Act of 1990. Second, the European Union (EU) decided to use biofuels as a tool to comply with its commitments under the Kyoto Protocol. It is worth noting that both triggers were based on environmental concerns. Rising oil prices and the related concerns about economic growth in the United States and in the EU pushed the production and use of biofuels even further.

Thereafter, the case for the rapid development of biofuels essentially became the case for the opportunity they could offer, in particular to developing countries, to build up a local supply of energy, increase and diversify exports, enhance rural development and reduce poverty. Moreover, since the areas with the highest biomass productivity are located in the tropics, biofuels were perceived as a new export-driven sector in which developing countries would have a significant comparative advantage. Indeed, the awareness that any country or region that has agricultural and forest resources could participate in this emerging energy sector has awakened tremendous interest worldwide.

However, biofuels are currently at a crossroads. The rapid increase in agricultural and food prices, partially fuelled by the use of grains and oilseeds for the production of ethanol and biodiesel,[1] is calling into question the ethics of diverting land and crops to energy production. Moreover, there are concerns that the expansion of agricultural activities – to produce simultaneously food, feed, fibre and fuel – could encroach into environmentally sensitive areas with the consequence of nullifying or severely reducing the actual contribution of biofuels to GHG reductions. In addition, large-scale biofuel feedstock production could lead to considerable environmental degradation, for example loss of biodiversity, excessive use of pesticides or overexploitation of water resources. There are also claims that current biofuels policies are not geared toward energy conservation. Conversely, they may end up encouraging more fossil fuel consumption in the transportation sector, since the presence of even tiny percentages of biofuels into the fuel mix may give consumers the false impression that driving does not contribute to the release of GHG emissions.

Whether biofuels will move ahead of the current deadlock will depend on the decisions that governments will take. The path each country chooses will ultimately determine the costs and benefits that biofuels will bring to individual countries and globally. Countries pursue different objectives when engaging in pro-biofuel policies; energy independence, climate change stabilization, rural development and new export opportunities are among the reasons for considering biofuels. Which of these objectives is prioritized depends on the social, economic, environmental and energetic situation of individual countries. However, the implications of the biofuels policy put in place by a country may be global and the trade-offs that are acceptable for such a country may not be so for another.

A forward-looking vision should focus on the instruments and preconditions that would make biofuels a win-win solution for the environment and for rural development, while contributing to expand the supply of sustainable transportation fuels.

The intent of this publication is to present and discuss alternative decision paths that countries may follow and the possible implications as a contribution to the programme of work of the Global Bioenergy Partnership. There is no attempt to develop a single consistent scenario across the different chapters. The discussions will zero in on mechanisms and issues that need to be addressed when designing and implementing sound biofuels strategies.

The most commonly used tool to introduce or expand production and consumption of biofuels is the imposition of biofuels blending or utilization targets. By ensuring that there is a market for biofuels, these measures bring stability and predictability for new investments. Accordingly, the first chapter of this report analyses the possible roles that these policy measures may play in the coming years.

The role and implications of biofuels blending and utilization targets

Chapter I[2] assesses whether the production capacity of the biofuels industry is able to fulfil the demand resulting from the implementation of biofuel blends and utilization targets. The installed capacity and the actual production of ethanol and biodiesel by individual countries are

[1] "UNCTAD's position on biofuels policies and the global food crisis" discusses this issue in more detail. http://www.unctad.org/Templates/Page.asp?intItemID=4526&lang=1.

[2] Chapter I was prepared by Daniel G. De La Torre Ugarte, University of Tennessee, United States.

considered, as well as plants currently being built. For almost all countries analysed, there is a gap between potential demand and production capacity.

Three alternative scenarios related to the role and implications of including blending or utilization targets within domestic biofuels policies are analysed: these mechanisms can be used to stimulate the production of biofuels (scenario 1) or to serve as a safeguard for an already established industry (scenario 2). The third scenario assumes the absence of such measures, i.e., biofuels' share in the domestic energy mix is solely determined by market signals, such as oil and feedstock prices and the cost of converting feedstocks into fuels. While scenario 1 reflects the thrust of many present biofuels policies, this chapter discusses the implications of a possible shift to scenario 2 or 3.

We argue that, while blends or utilization targets are very effective in creating or expanding the biofuels industry, their inflexibility can generate undesired pressure on agricultural commodities prices and severely reduce the potential contribution of biofuels to global warming stabilization. This policy may have disturbing implications when the mandatory targets are set up at levels that go beyond the actual capacity of the industry to produce biofuels at a reasonable price and to utilize agricultural resources in a sustainable manner. On the other hand, unless there is a clear trend of increasing oil prices and declining feedstock prices, the absence of mandatory blends or utilization targets may require the presence of other mechanisms aimed at stimulating the biofuels industry.

The establishment of a carbon dioxide (CO_2) price is one among the possible measures that can generate increased demand for biofuels by raising the price of burning fossil fuels with which biofuels compete. The next chapter focuses on carbon policies.

Greenhouse gas markets, carbon dioxide credits and biofuels

Chapter II[3] highlights that the establishment of a carbon dioxide (CO_2) price would create incentives for the development of a global biofuels market either directly, through incentives to substitute fossil fuel with biofuels in countries with climate change policies, or indirectly, through the Clean Development Mechanism (CDM) under the Kyoto Protocol.

As biofuels have the potential to reduce GHG emissions, there is a strong interest in understanding how global markets and policy-driven schemes to reduce GHG emissions can impact the expansion of the biofuels sector and improve its environmental performance. Indeed, the effectiveness of biofuels as a lower carbon alternative to fossil fuels depends on how they are produced and how emissions related to land use are managed.

At a high level of biofuels demand, there would be very little incentive to protect carbon in the soils and vegetation. Landowners would instead tend to convert land to biofuels production or to more intense cropping. In an alternative scenario, a "cap and trade" system would cover all land-use emissions. This would create incentives to control both land-use emissions and enhance land-use sinks.

Potential ways of expanding cap and trade systems by including terrestrial carbon sinks and forests are discussed in this chapter. There has been reluctance or a lack of understanding of how to extend a cap and trade system to land-use emissions, but we argue that many of the concerns that analysts and policymakers have expressed can be easily addressed.

Another important development that could play a crucial role in improving the environmental performance of biofuels is the evolution of second generation technologies, the focus of the next chapter's analysis.

[3] Chapter II was prepared by Sergey Paltsev, John Reilly and Angelo Gurgel, Massachusetts Institute of Technology, United States.

The commercial viability of second generation biofuel technology

Chapter III[4] focuses on second generation biofuels, specifically biofuels derived from cellulosic or lignocellulosic conversion. Advocates for the development of cellulosic conversion believe that second generation technologies avoid many of the adverse effects of first generation biofuels. However, for the time being second generation biofuels are not commercially produced anywhere and expectations about future costs and energy output per unit of land vary. Taking those variations into account and using the Massachusetts Institute of Technology (MIT) Emissions Prediction and Policy Analysis (EPPA) model, the chapter analyses the potential role of second generation biofuels as an energy supplier through the current century.

Four scenarios in which second generation biofuels could develop are examined: with and without climate policy, and with and without trade restrictions on biofuels. The chapter provides insights into several issues related to second generation biofuels, such as the limitations of biofuel production in terms of land availability and how the development of the industry would affect land cover and food and land prices.

The model predicts a relatively small price increase for food, agricultural and forestry products, therefore suggesting that it is possible to introduce a large cellulosic biofuels industry without dramatically upsetting agricultural markets. It also projects that, depending on whether international trade in biofuels is restricted or unrestricted, different countries and regions will become relevant biofuel producers.

Indeed, trade regimes play a key role in determining which countries and regions are likely to become leading biofuel producers and exporters. The objective of chapter IV is to analyse trade opportunities for developing countries.

Trade opportunities for developing countries

Developed countries are the major consumers of transportation fuels. Therefore, the potential demand for biofuels and related export opportunities for developing countries are largely influenced by the objectives that developed countries pursue.

Chapter IV[5] analyses the trade potential available to developing countries under two scenarios: one assumes that the main objective pursued by the EU and the United States within their biofuels policies is energy independence. Under this scenario, priority is given to domestic production of biofuels. The second scenario assumes that the main objective pursued by the EU and the United States is the expansion of biofuel production and its use as a means to address global climate change. Under this scenario, preference is given to biofuels with the highest potential to reduce GHG emissions.

While both scenarios offer an opportunity for developing countries to participate in the international biofuels market as producers and exporters, the size of the opportunity implied by each scenario is significantly different. Obviously, the first scenario offers more limited opportunities for exports than a strategy based on pursuing environmental benefits. The second scenario could be particularly beneficial to developing countries if their comparative advantage to produce biomass were fully recognized. Indeed, developing countries have a larger potential to produce biomass than industrialized countries, due to better climate conditions and lower labour costs. Under this scenario, international trade would significantly expand with substantial positive implications for development.

[4] Chapter III was prepared by Sergey Paltsev, John Reilly and Angelo Gurgel, Massachusetts Institute of Technology, United States.
[5] Chapter IV was prepared by Daniel G. De La Torre Ugarte, University of Tennessee, United States.

Besides trade regimes, access to advanced biofuel technologies is an important issue for developing countries. A precondition for the benefits of second generation technologies to come to fruition is the ability of developing countries to have access to them and adapt them to their own needs. Second generation biofuel technologies are being developed in a period of booming patenting activity in the area of renewable energies and increasing interest in strengthening intellectual property rights (IPRs). The following chapter focuses on the intellectual property aspects of second generation biofuels.

Advanced biofuels and developing countries: intellectual property scenarios and policy implications

Chapter V[6] analyses recent patenting and investment trends in advanced, second generation biofuels. Subsequently, it presents three scenarios based on extensive, restricted and limited access to proprietary biofuel technologies. Specific mechanisms that developing countries could use to access technology within the framework of each scenario are presented. Finally, the chapter addresses issues related to innovation systems and presents some policy options for developing countries to fast-track innovation into their national policies.

This chapter argues that a restrictive IPR regime for second generation biofuels will likely prevail. The biofuels industry may follow the trajectory of the agricultural biotechnology industry: through divestitures, mergers and acquisitions, there has been a process of consolidation in the global agribusiness in recent years. The outcome has been a few major integrated companies, each controlling proprietary lines of agricultural chemicals, seeds and biotech traits.

The application of second generation technologies will entail greater systems complexity, integrated engineering design and other technical parameters that may limit the diffusion of such technologies to most developing countries, for two reasons. First, advanced technologies will be proprietary and thus costly to obtain; second, they may be too complex for developing countries to easily absorb and adapt them to local needs. Therefore – as happened in the agricultural biotechnology sector – there is a risk of limited technology transfer to developing host countries. In that sense, it remains important for developing countries to invest in their own innovation systems.

Technological developments also have a role to play in expanding the number of feedstocks available for conversion into biofuels and increasing their energy yield. To continue the expansion of the biofuels sector without provoking undesirable spikes in agricultural commodity prices, significant investments in the production capacity of the agricultural sector are necessary. A first step in this direction is the production of high energy yield feedstocks on land not currently allocated to agricultural production. In the last chapter of this volume a specific feedstock – jatropha – is analysed.

Biodiesel: the potential role of jatropha

Several alternative biofuel feedstocks are currently being produced on a limited basis and explored for potential widespread use, such as sweet sorghum, cassava and jatropha. We focus on jatropha because if it were to emerge as a dominant feedstock due to its positive characteristics, this outcome would significantly change the pattern of production and export of biodiesel.

Several developing countries with thousands of hectares of waste, degraded and semi-arid land suitable for jatropha production could become significant players in the biodiesel market. Moreover, using jatropha as feedstock would mitigate the pressure on agricultural prices, since

[6] Chapter V was prepared by Calestous Juma, Harvard Kennedy School of Government, United States, and Bob Bell Jr., University of California, United States.

jatropha production has the potential to be expanded to land not currently allocated to agricultural production. The present competition for arable land would then decrease.

Even though the environmental and economic potential of jatropha is not yet fully mapped, many national agencies, international organizations and research institutes are currently investigating the feasibility of making jatropha a large-scale feedstock for biodiesel. Therefore, chapter VI[7] presents a scenario in which jatropha is used as a key feedstock for biodiesel production; furthermore, it highlights the possible impacts of such development on the vegetable oils market and on the price of biodiesel.

[7] Chapter VI was prepared by Daniel G. De La Torre Ugarte, University of Tennessee, United States.

I. The role and implications of biofuels blending targets[8]

Mandatory blends and utilization targets have played an essential role in the development and expansion of the biofuels sectors of the two major producers, Brazil and the United States.

In this chapter we assess whether the production capacity of the biofuels industry is able to fulfil the existing mandatory blends and utilization targets. We consider the installed capacity and the actual production of ethanol and biodiesel by individual countries, as well as plants currently being built. For almost all the countries analysed, there is a gap between the potential demand generated by mandatory or voluntary blending targets and their production capacity. We estimate that current and expected blending targets will increase global demand for biodiesel to 88 billion litres (23.2 billion gallons), while total production capacity will be around 34 billion litres (9 billion gallons). Global demand for ethanol will reach around 187 billion litres (49.4 billion gallons) to satisfy existing blending targets, while production capacity will increase only up to 150 billion litres (40 billion gallons).

We also analyse three alternative scenarios related to the role and implications of including blending or utilization targets within domestic biofuels policies: these mechanisms can be used to stimulate the production of biofuels (scenario 1) or to serve as a safeguard for an already established industry (scenario 2). The third scenario assumes the absence of such measures, i.e., biofuels' share in the domestic energy mix is determined by market signals.

We argue that, while mandatory blends or mandatory utilization targets are very effective in expanding the biofuels industry, their inflexibility can generate undesired pressure on agricultural commodities prices and severely reduce the potential contribution of biofuels to global warming stabilization. On the other hand, unless there is a clear increasing trend in the oil price and declining feedstock prices, the absence of mandatory blends may require other incentives to develop a domestic biofuels industry.

This chapter is structured as follows: first we provide an overview of blending targets put in place by some countries, the potential demand it induces and the existing installed capacity, for both ethanol and diesel. We then discuss the linkages between the biofuel, feedstock and transportation markets. Finally, we analyse the alternative roles of mandatory blending and its advantages/disadvantages.

A. Blending and utilization targets

The production and use of biofuels in many countries has been promoted through a variety of policy measures, of which mandatory blends and utilizations targets are examples.

A mandatory blend refers to the percentage of biofuels that a transportation fuel needs to have when it is sold to consumers. The participation of biofuel in the final blended fuel is usually expressed as a percentage of the final blended fuel. Brazil and other developing countries have adopted this system (in Brazil, for example, 20–25 per cent of ethanol is blended with gasoline).

The second type of mandatory mechanism refers to utilization levels of biofuels with respect to overall transportation fuels. In the United States the target is expressed as a specific

[8] This chapter was prepared by Daniel G. De La Torre Ugarte, Professor, Agricultural Policy Analysis Centre, Department of Agricultural Economics, University of Tennessee, United States. Tables 1 and 2 were prepared by Marco Antonio Conejero, USP Ribeirao Preto, Brazil.

volume of biofuels utilization that needs to be achieved (36 billion gallons in 2022, for example), while in the EU the target is a percentage of the transportation fuels demand that needs to be supplied by biofuels (5.75 per cent by 2010). In summary:

Blending target	Utilization target
Percentage of biofuel in transportation fuel Ex: Brazil	1. Percentage of biofuels relative to total fuel demand. Ex: EU 2. Specific volume. Ex: United States

The approach followed by the United States and the EU does not require that a particular blend be made available to the market. The biofuel content can change throughout the year as it responds to short-term changes in the supply and prices of biofuels and fossil fuel products. In practice, Brazil's blend requirements can also change within a set range (20–25 per cent) to accommodate market fluctuations.

The volumetric approach of the United States, however, represents a more inflexible target, as it does not respond to the consumption of transportation fuels. In that sense, whether the use of transportation fuels increases or decreases, the target remains the same: a certain number of litres/gallons of biofuels have to be used in a year. Conversely, in the case of the target defined in terms of percentage, the overall use of biofuels would decrease should the demand of transportation fuels decline.

While mandatory blends or mandatory utilization targets are very effective in expanding the biofuels industry, their inflexibility can generate undesired pressure on agricultural commodities prices.

In order to provide a reference point to the future role of mandates, we assess how the production capacity of the biofuels industry is able to fulfil those mandates. Hereafter we provide an overview of these policies for both ethanol and biodiesel.

Box 1.1. The Brazilian experience

Brazil's Pro-alcohol Programme is often considered an example of renewable energy development (Goldenberg et al., 2004). The programme, initiated in 1975, had three basic components: (a) the state-owned oil producer and distributor of transportation fuels (Petrobras) had the obligation to purchase a guaranteed amount of ethanol; (b) the agribusiness sector received incentives (in the form of low-interest loans) to develop the ethanol production infrastructure; and (c) ethanol was sold at the pump for 59 per cent of the price of gasoline, to make it attractive for consumers. This was possible because the gasoline price was established by the government. By 1990 alcohol replaced one half of the gasoline that would be otherwise consumed in the country (Moreira and Goldenberg, 1999). The first element of the programme guaranteed the demand and the second contributed to create the productive capacity. The importance of the ethanol subsidy at the pump was crucial since ethanol was competing as a separate fuel and not as a component of a mandatory blend applicable to all fuels. Brazil's case is a good example of how investments in technology and the right incentives can bring an industry rapidly through the learning curve and reduce the cost and price of biofuels (Goldenberg et al., 2004). The implication is that biofuels supply expanded and the price of ethanol decreased due to economies of scale. The lower ethanol price also reduced the pressure on the transportation fuels market, since the cost of the blend decreased. This is a strong argument in favour of South–South cooperation in biofuels, especially for countries with a significant potential in sugar production that could benefit from the Brazilian experience.

1. Ethanol blending targets

According to Nastari (2008), world ethanol production has grown, on average, 12 per cent per year between 2000 and 2007. In 2007, world ethanol production for energy reached 49.5 billion litres (13 billion gallons). This amount represents 4.4 per cent of global gasoline consumption (1.117 trillion litres or 295 billion gallons).

Lately, the international market has been especially open to anhydrous ethanol, due to policies that encourage adding ethanol to gasoline. Some countries have already implemented mandatory blending targets, while others are relying on voluntary blending targets (Japan). In the latter case we consider that the target, even if it is voluntary, is fulfilled (i.e., mandatory and voluntary targets are treated the same way).

Table 1.1 contains an overview of ethanol policies in selected countries. It illustrates the actual production and the installed capacity of ethanol production by individual countries (in 2006/2007) as well as plants currently being built. It also shows the potential demand generated by mandatory blends until 2022 (the United States Energy Act sets targets until 2022).

The potential demand was calculated by applying the expected blending target (if implemented before 2022) to the actual consumption of gasoline in 2006. For example, the expected blending target for Canada is 5 per cent in 2010, and gasoline consumption in 2006 was 39 billion litres (19 billion gallons); therefore, the expected demand for ethanol is 2 billion litres (0.5 billion gallons). As Japan is expected to adopt the 20 per cent target only by 2030, the current 3 per cent blend target is used instead, which is equivalent to a demand for ethanol of 1.8 billion litres (0.5 billion gallons). In the case of Brazil, gasoline consumption was 24 billion litres in 2006 (6.3 billion gallons), so the 20–25 per cent blend represented the use of 5 billion litres (1.3 billion gallons) of anhydrous ethanol. Moreover, pure ethanol consumption (hydrated ethanol) by flex-fuel cars was 6.2 billion litres (1.6 billion gallons). Therefore, the total consumption of ethanol is equivalent to 11.2 billion litres (Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP), 2007).

In the case of the European Union,[9] the directive mentions a target for renewable sources in general: 5.75 per cent in 2010 and 10 per cent in 2020.[10] Therefore, the EU can meet the target by using ethanol and biodiesel at the same time. To construct the table, we assumed that 3.2 per cent of the target would be fulfilled by using ethanol, given that around 32 per cent of EU-15 energy consumption in transport is petrol fuel (European Union Road Federation, 2008). Diesel consumption by the transportation sector represents approximately 52 per cent and the remaining 16 per cent represents kerosene, which can also be replaced by biodiesel. Therefore, we split the 10 per cent target by 2020 in two: 3.2 per cent of the total transportation fuels are assumed to be fulfilled by ethanol and 6.8 per cent by biodiesel.

For the United States, from the total of 36 billion gallons (136 billion litres) of renewable fuels required by 2022 under the Energy Independence and Security Act of 2007, ethanol is expected to represent around 31 billion gallons (117.3 billion litres). This amount includes ethanol from corn, cellulosic ethanol and ethanol from other feedstocks such as sugar cane. Biodiesel is expected to represent 5 billion gallons (19 billion litres) of those 36 billion gallons by 2012 (Energy Information Administration (EIA), 2008).

For almost all the countries analysed, there is a gap between the potential demand generated by mandatory or voluntary blending targets and their production capacity.

The table indicates that total demand for ethanol by these countries could reach around 155 billion litres (40.8 billion gallons) to satisfy existing blending targets by 2022. This number is likely to be 40 per cent higher given the expected increase in gasoline consumption (Nastari, 2008) by 2022 with respect to current consumption. Adding existing installed capacity to that currently being built, production would grow to 160 billion litres (42.2 billion gallons).[11]

[9] Data for the EU and the United Kingdom are presented separately because the latter follows an independent policy (targets).

[10] On 17 December 2008 the European Parliament adopted the directive on the promotion of the use of energy from renewable sources that includes the mentioned utilization targets.

[11] These are rough estimates that provide a broad picture of potential demand and production, since we do not have data for the current production, installed capacity and projects under construction for all countries.

These estimates suggest that there is room for growth of ethanol production, assuming that gasoline consumption will rise until 2022. Based on 2006 gasoline consumption, expected installed capacity of ethanol production seems to be enough to supply the expected demand. It is worth mentioning that this result is largely driven by projects under construction in the United States, which are expected to produce additional 66 billion litres of ethanol (17.4 billion litres). In the absence of such projects, demand for ethanol would be significantly larger than supply; i.e., considering only the current installed capacity (65.5 billion litres or 17.3 billion gallons), supply would not be enough to fulfil the expected ethanol blending targets.

The NIPE/Unicamp (Interdisciplinary Centre of Energetic Planning, University of Campinas, Brazil) made a simulation based on a scenario where 10 per cent of gasoline worldwide would be replaced by ethanol: 152 billion litres of ethanol per year (42 billion gallons) would be necessary to replace 10 per cent of gasoline based on the gasoline consumption in 2002. Similarly, 225 billion litres of ethanol per year (59 billion gallons) would be needed to replace 10 per cent of the estimated gasoline consumption in the year 2025 (Leal, 2006).

The largest ethanol importer is the United States (it imported about 2.7 billion litres, or 0.7 billion gallons, in 2006), followed by Japan (which imports basically industrial ethanol), Germany and the Netherlands. The United States' demand has been pulled by the replacement of MTBE (methyl tertiary butyl ether) by ethanol due to the 2005 Renewable Fuels Standard, and more recently, to the 2007 Energy Bill.

The banning of MTBE in California, and later in all states of the United States, can be considered a mandatory utilization target for ethanol, since other oxygenates were not available to the oil refining and distribution industry. Most of the United States' ethanol imports have been supplied by Brazil and China, through Caribbean and Central American countries, taking advantage of the duty-free treatment under the Caribbean Basin Initiative (CBI).[12]

The estimated production of ethanol by 2012 in the United States is between 45.2 and 51.4 billion litres (12–13.5 billion gallons), about two and a half times current production. Brazil is expected to produce between 35.4 and 40.5 billion litres by the same year (9.3–10.7 billion gallons), double the amount of its 2007 production (ICONE, 2007).

[12] CBI is a unilateral concession by the Government of United States for tariff exoneration for a large part of the products of the Caribbean region. As a part of the initiative, duty-free status is granted to fuel ethanol under certain conditions. If produced from at least 50 per cent local feedstock, ethanol may have free access. If the local feedstock share is lower, limitations apply on the quantity of duty-free bioethanol. If no local feedstock is contained in the bioethanol imported to the United States, then only 7 per cent of CBI imports can enter the United States market duty-free (Yacobucci, 2008).

Table 1.1. Potential demand for ethanol – billion litres and billion gallons

Country/Region	*Gasoline Consumption in 2006*	*% of blend*	*Potential Demand until 2022*	*Production/ Capacity 2006/2007*	*Remarks*	*Source*
United States	530 bi L 140 bi G	The new energy bill requires 36 bi G of renewable fuels by 2022 (136.8 bi L) 5 bi G is expected to be biodiesel and the remaining, ethanol	117,8 bi L 31 bi G	Production: 26.5 bi L / 7 bi G Installed capacity: 34 bi L /9 bi G (126 facilities) In projects: 66 bi L / 17.4 bi G(100 facilities)	US needs to replace the MTBE and ethanol is the natural substitute. 6.2 bi G (1.6 bi L) are necessary to substitute the MTBE Feedstock: corn,cellulosic and other feedstocks	Economic Report of the President (2008) Coyle (2007) RFA (2008)
European Union	148 bi L 39 bi G	5,75% (2010) 10% (2020); assuming 3.2% for ethanol	4.7 bi L 1.2 bi G	Production: 2.3 bi L / 0.6 bi G Installed capacity: 3.5 bi L / 0.9 bi G(38 facilities) In projects: 3.8 bi L /1 bi G (30 facilities)	Tax exemption in the Member States; Feedstock: wheat, other grains, sugar beets, wine, ethanol	EIA/DOE (2007) EBIO (2007) Coyle (2007)
China	68 bi L 18 bi G	10% 15% (2010)	10.2 bi L 2.7 bi G	Production: 2 bi L / 0.52 bi G Installed capacity: 2.3 bi L / 0.6 bi G Expected capacity in 2020: 12.7 bi L/3.3 bi G	Mandatory blend targets in 5 provinces, FFV about 16% of the fleet of vehicles. Feedstock: corn, wheat, cassava, sweet sorghum	EIA/DOE (2007), USAD/FAS (2007), Coyle (2007)
Japan	60 bi L 16 bi G	3% authorized 20% (2030)	1.8 bi L 0.5 bi G	0.1 bi L 0.02 bi G		USDA/FAS (2006)
Canada	39 bi L 10 bi G	5% (2010)	2.0 bi L 0.52 bi G	1.2 bi L 0.3 bi G	Feedstock: corn, wheat, straw	USDA/FAS (2007), Coyle (2007),Greenfuels (2007)
United Kingdom	26 bi L 7 bi G	5% (2010)	1.3 bi L 0.3 bi G	0.03 bi L 0.008 bi G		UK Department of Transport (2007) UKTRADEINFO (2008), IEA (2005)
Australia	20 bi L 5 bi G	10%	2.0 bi L 0.52 bi G	Production: 0.07 Installed capacity: 0.15	Feedstock: waste starch and wheat, cane molasses	USDA/FAS (2007) RIRDC (2007)
Brazil	24 bi L 6.3 bi G	20-25%	5 bi L/ 1.3 bi G (mandatory blend targets) and 6.2 bi L/1.6 bi G (hydrated ethanol for flex fuel cars) Total: 11.2 bi L/2.9 bi G	Production: 20.5 bi L (336 facilities) Projects: 15 bi L (76 facilities).	Tax exemption of R$ 0.28/ liter (CIDE). Feedstock: sugarcane Consumption of ethanol:over 50% of fuel demand in light vehicles	Datagro (2008) UNICA (2007) ANP (2008)
South Africa	11.3 bi L 3 bi G	8%	0.9 bi L 0.23 bi G	0.12 bi L 0.03 bi G		USDA/FAS (2007)
India	13.6 bi L 3.6 bi G	5% 10% (2012)	1.3 bi L 0.3 bi G	Production: 0.25 bi L/0.06 bi G Installed capacity: 3.2 bi L/0.8 bi G	Feedstock: molasses, sugarcane	USDA/FAS (2007)
Thailand	7.2 bi L 1.8 bi G	10%	0.72 bi L 0,2 bi G	Production: 0.1 bi L/0.03 bi G Installed Capacity: 0.2 bi L/0,05 bi G	E10 consumption is expected to double by 2011 trough price incentives.	USDA/FAS (2007)
Argentina	5 bi L 1.3 bi G	5% (2010)	0.25 bi L 0.06 bi G	0.3 bi L 0.08 bi G		SAGPYA/MECON (2007) Mathews and Glodstein (2007)
Philippines	4 bi L 1.1 bi G	5% (2009) 10% (2011)	0.4 bi L 0.1 bi G	0.08 bi L 0.02 bi G		USDA/FAS (2007), RFA (2008)
TOTAL	***956.1 bi L*** ***250.2 bi G***		***154.6 bi L*** ***40.8 bi G***	***Production:53.5 bi L / 14.1 bi G*** ***Installed capacity:65.5 bi L/17.3 bi G*** ***In projects: 93.8 bi L/24.8 bi G***		

Source: Table elaborated by Marco Antonio Conejero, USP Ribeirao Preto, Brazil

Table 1.2. Potential demand for biodiesel – billion litres and billion gallons

Country/ Region	Diesel Consumption in 2006	% of blend	Potential Demand until 2022	Production/ Capacity 2006/2007	Remarks	Source
United States	220 bi L 58 bi G	The new energy bill requires 36 bi G of renewable fuels by 2022 (136.8 bi L) EIA (2008) expects that 5 bi G (19 bi L) would represent biodiesel	19 bi L 5 bi G	Production: 1.3 bi L.(0.35 bi G) Installed capacity: 1.9 bi L/0.5 bi G (165 facilities) In projects: 4.5 bi L /1.9 bi G (80 facilities).	The federal law gives a tax credit of US$ 0.50 per gallon for use of transportation and US$ 1.00 for use in agriculture. Feedstock: soybeans, other oilseeds, animal fat, recycled fat and oil.	NBB (2007) EIA (2008)
European Union	354 bi L 93.5 bi G	2% interim target 5,75% (2010) 10% (2020); assuming 6.8% for biodiesel	24 bi L 6.3 bi G	Production: 6.5 bi L / 1.7 bi G Installed capacity: 18 bi L /4.7 bi G distributed in 241 facilities	Feedstock: rapeseed, sunflower, soybeans. Germany is the largest worldwide producer of biodiesel.	EBB (2007), Commission of the European Communities (2007)
China	92 bi L 24.3 bi G	15% (2020)	13.8 bi L 2.1 bi G	0.46 bi L 0.12 bi G Expected capacity in 2020:6.5 bi L/1.7 bi G	Feedstock: used and imported vegetable oils, Jatropha curcas.	USDA/FAS (2007)
Brazil	39 bi L 10.3 bi G	3% (2008) 5% (2012)	1.9 bi L 0.5 bi G	Production:0.7 bi L/0.2 bi G Installed capacity: 1.62 bi L/0.43 bi G (27 facilities) In projects: 1.9 bi L / 0.5 bi G (37 facilities).	Feedstock: soybeans (75%), palm oil, castor seed, Jatropha curcas. Tax exemption (PIS/COFINS) for biodiesel of palm, Jatropha curca and castor bean, produced by small growers in northern and northeastern regions. Duty fleet of 2.3 million trucks.	ANP (2007)
India	37.8 bi L 9.9 bi G	5% 10% (2012)	3.7 bi L 0.9 bi G	0.08 bi L 0.02 bi G	Feedstock: Jatropha curcas, imported palm oil.	USAD/FAS (2007)
Canada	26 bi L 6.9 bi G	2% (2010)	0.5 bi L 0.14 bi G	0.1bi L 0.03 bi G	Tax exemption of 4% for biodiesel production and use. Feedstock: animal fat, vegetable oils.	USDA/FAS (2007)
Indonesia	26 bi L 6.9 bi G	Initial blending of 5%, recently reduced to 2.5%(*) due to high price of raw materials such as methanol	0.6 bi L 0.17 bi G	0.7 bi L / 0.18 bi G In projects: 5.9 bi L / 1.6 bi G (59 new facilities).	Feedstock: palm oil, Jatropha curcas.	USDA/FAS (2007)
United Kingdom	24 bi L 6.3 bi G	2.5% (2008) 3.75% (2009) 5% (2010)	1.2 bi L 0.3 bi G	0.1bi L 0.03 bi G		UK Department of Transport (2007), UK TRADE INFO (2008)
Argentina	14 bi L 3.7 bi G	5% (2010)	0.7 bi L 0.18 bi G	Production: 0.2 bi L/0.05 bi G Installed capacity: 1 bi L/0.26 bi G (8 facilities) In analysis: 4 more bi L/1.05 bi G	Tax exemption for biodiesel industry in a period of 10 years. Feedstock: soybean, canola.	SAGPYA/ MECON (2007) Mathews and Goldsztein (2007) Molina (2007)
Thailand	18.4 bi L 4.9 bi G	5% Expected 10% in 2012.	1 bi L 0.2 bi G	0.33 bi L 0.08 bi G	Feedstock: palm oil, used vegetable oil.	USDA/FAS (2007)
Australia	14.5 bi L 3.8 bi G	No mandatory blending; what is produced is consumed	0.05 bi L 0.01 bi G	Production: 0.05bi L/ 0.01 bi G Installed Capacity: 0.3 bi L/0.08 bi G	Feedstock: waste oil and tallow	RIRDC (2007), BAA (2007), USDA/FAS (2006)
Malaysia	7.5 bi L 2 bi G	5% (2008)	0.38 bi L 0.09 bi G	0.25 bi L/0.06 bi G In projects: 7.5 bi L / 2 bi G(75 new facilities)	Feedstock: palm oil.	Nacarajan (2008), MPOC (2006)
Philippines	7 bi L 1.85 bi G	2% 5% (2008).	0.35 bi L 0.09 bi G	0.16 bi L 0.04 bi G	Feedstock: palm oil.	IEA (2005), EIA/DOE (2007), USDA/FAS (2007)
South Africa	5 bi L 1.32 bi G	2%	0.1bi L 0.03 bi G	0.03 bi L 0.008 bi G		USDA/FAS (2007)
TOTAL	***885.2 bi L*** ***233.9 bi G***		***67.3 bi L*** ***17.8 bi G***	***Production:11 bi L/2.9 bi G*** ***Installed capacity: 25.1 bi L/ 6.6 bi G*** ***In projects:23.8 bi L/6.3 bi G***		

Source: Table elaborated by Marco Antonio Conejero, USP, Ribeirao Preto, Brazil

2. Biodiesel blending targets

Table 1.2 provides the same information for biodiesel: it illustrates the actual production and the installed capacity of biodiesel production by individual countries, as well as plants currently being built (“in projects”) or projects under analysis (“in analysis”). It also shows the potential demand generated by mandatory blends, which was calculated by applying the expected blending target, through 2022, to the consumption of diesel in 2006. For example, the expected blending target for Canada is 2 per cent in 2010 and diesel consumption in 2006 was 26 billion litres (6.9 billion gallons); therefore, the expected demand for biodiesel in Canada is 0.5 billion litres (0.14 billion gallons). Obviously, this potential demand is likely to be higher according to the increase in diesel consumption (since our estimates are based on 2006 diesel consumption).

As already mentioned, in the case of the United States we considered the expected consumption of 19 billion litres (5 billion gallons) of biodiesel to accomplish the target of 36 billion gallons (136 billion litres) of fuels from renewable sources in 2022.

The table indicates that expected blending targets will increase demand for biodiesel to about 67.3 billion litres (17.8 billion gallons) until 2022. However, the world’s installed capacity of biodiesel does not match such demand. Existing producing facilities and those being constructed will be able to produce a maximum of 48.9 billion litres (12.9 billion gallons) of biodiesel. Thus, in the case of biodiesel, production would have to increase by approximately 18.4 billion litres (4.9 billion gallons) to meet the expected blending targets until 2022.

The biodiesel market is currently significantly smaller than the ethanol market: approximately 80 per cent of the biofuels market represents ethanol and 20 per cent biodiesel (Organization for Economic Cooperation and Development (OECD), 2008). There is basically no international trade in biodiesel. However, the growth of biodiesel production may be greater than ethanol, if the objective is to accomplish the expected blending targets through 2022.

Expected blending targets will increase demand for biodiesel to about 62 billion litres (16.3 billion gallons) through 2022.

The estimated consumption of biodiesel by 2012 is 14.9 billion litres (3.9 billion gallons) in the European Union and 5.2 billion in the United States (1.4 billion gallons). Countries such as Argentina, China and Malaysia, which have programmes to stimulate the use of biodiesel, will present a combined demand similar to that of the United States (ICONE, 2007).

Recent research from NIPE/Unicamp (Leal, 2006) indicates that if there was a global biodiesel blend obligation of 10 per cent, production and consumption of biodiesel would reach 136 billion litres per year (36 billion gallons). Producing such an amount of biodiesel would require a total area of 76 Mha. These calculations assume 50 per cent of biodiesel coming from palm oil (with a productivity of 3,000 L/ha) and 50 per cent from castor oil (productivity of 600 L/ha)[13]. Assuming an increase in the agricultural yield, the same 10 per cent would represent 200 billion litres a year (52.9 billion gallons) and an area of 57 Mha in 2025, considering a higher productivity for palm and castor oil (6,000 L/ha and 1,000 L/ha respectively).

B. The impact of mandatory blending targets

For analytical purposes we define a mandatory utilization target in terms of a blend by dividing the total utilization target by the expected or actual consumption of gasoline. Consequently, to simplify the analysis, blending and utilization targets will be treated as being the same.

[13] The Brazilian Biodiesel Programme is based on soybean oil, palm oil and castor oil.

Mandatory blending targets impact simultaneously the feedstock, the biofuels and the transportation fuel markets. Previous analyses by Runge (2002), Althoff et al. (2003) and Gardner (2003) looked at one or two of the markets, while the analysis by De Gorter and Just (2008) is based on an integrated approach of the three markets. These studies focus on ethanol policies in the United States, including both mandatory blending targets and subsidies. Schmitz et al. (2002) analysed the impacts of mandatory blends in the ethanol sector in Brazil.

We performed a hypothetical exercise to illustrate the link between these three markets. Starting from equilibrium in the biofuels market, in which production is relatively small, the establishment of a mandatory blending target results in an expanded demand for biofuels. This results in higher biofuels prices and therefore pushes the industry to higher levels of production.

As a result of the mandatory blending, there is an increase in the demand for the feedstocks necessary to produce biofuels. This results in higher feedstock prices. Regarding the transportation sector, in the absence of any requirement to blend biofuels with fossil fuels, the initial supply represents transportation fuels such as gasoline and diesel. Once the mandatory blend is established, the transportation fuels become a combination of ß per cent of biofuels (ß is the blending rate) and (100-ß) per cent of gasoline or diesel. As biofuels are more expensive than fossil fuel-based transportation fuels, and considering that the price of biofuels has also increased as a result of the mandatory blend, the cost of producing the blended fuel is now higher. Consequently, the price of transportation fuels increases and their demand decreases.[14]

Thus, a mandatory blend will likely: (a) increase the production and price of biofuels; (b) increase the demand for feedstocks and consequently increase the price of agricultural commodities (assuming feedstocks of agricultural origin); and (c) increase the fuel price and decrease the demand for fuel. For an oil-importing country implementing the blending target, the volume of oil imports can decrease.

Therefore, if the blending targets are set too high, the pressure on agricultural markets would be reflected in price increases of agricultural commodities. To manage this pressure, countries can: (a) increase the availability of biofuels or feedstocks by importing them; (b) expand the set of feedstocks used in the production of biofuels; and/or (c) invest in the productive capacity of the agricultural sector, which would result in an expanded supply of feedstock.

In an economic and policy environment in which blending targets are considered necessary elements of a biofuels policy, the opportunity arises for an additional impact. If a large oil-consuming country – i.e., China, India, Japan, the United States or EU member states – or a sizeable group of medium or smaller oil-consuming countries implement mandatory blends, there is a real opportunity of reducing the demand for oil. The volume of oil replaced by biofuels because of the blending targets would generate a significant reduction in the global demand for oil. In this case, oil prices would likely fall. As such, the cost of the blended transportation fuel also decreases. This would reduce the overall price of transportation fuels and affect all countries, whether they are pursuing a biofuels strategy or not. This result is analytically documented by De Gorter and Just (2008). According to their analysis, the final outcome would depend on the elasticities of the biofuels and oil markets.

This is the scenario that bears the largest promise. However, its feasibility at reasonable agricultural prices may imply significant investments to expand the productive capacity of the agricultural sector and/or to make second generation biofuel technologies commercially available.

[14] The sensitivity of gasoline demand to changes in prices and income has been extensively estimated in the literature and it varies greatly by country and period analysed. Hughes et al. (2008), for example, find a relatively small short-run (up to one year) price elasticity for the United States, ranging from -0.034 to -0.077 during 2001 to 2006. Another study (Espey, 1996) finds that, in the United States, the average price elasticity of demand for gasoline is -0.26 in the short run (a 10 per cent increase in the price of gasoline lowers quantity demanded by 2.6 per cent). In the long run, the price elasticity of demand is -0.58.

It is intuitive that, at least initially, consumers bear the costs of mandatory blending targets. The initial impact in all three markets is price increases, which generates a transfer of income from consumers to producers of feedstocks, biofuels and blenders of transportation fuels. The public budget is affected due to the implementation and monitoring costs of the blending targets system. However, through the expansion of the supply of biofuels (with a consequent cost reduction due to economies of scale), and/or through a significant substitution of biofuels for fossil fuels, the price of oil could decrease and finally the overall impact could be positive, even for consumers (De Gorter and Just, 2008).

Countries may feel the pressure to alleviate the impact on the overall economy induced by the higher price of blended transportation fuels. Implementing subsidies schemes for fuels has the drawback of potentially increasing the use of transportation fuels. The analysis of De Gorter and Just (2008) indicates that, in the presence of biofuel subsidies, the cost of the blend may not increase and consequently the expected economic and environmental gains from biofuels may be reduced or not even realized.

C. Alternative scenarios for mandatory blending targets or utilization mandates

The current context surrounding biofuels policies is characterized by high and volatile oil and food prices and by growing concerns about the actual contribution of biofuels to GHG emissions reduction. Thus, countries that have already implemented mandatory blends or utilization targets for biofuels (or that are planning to do so) are questioning how suitable such measures are.

Two of the main aspects to be taken into account when analysing blending targets or utilization mandates are the level at which they can be set and the role that they play in a biofuels strategy.

The first is an issue that has to be addressed on a case-by-case basis, according to the specificities of individual countries. Analysing the alternative role that mandatory blends may play in a biofuel strategy is a less travelled route in the existing literature, and a more promising one.

What follows is a discussion of three possible scenarios for mandatory blends: (a) using mandatory blends to stimulate the expansion of the biofuels industry (which is the current case); (b) using mandatory blends as a way to provide a safety net for the biofuels industry; and (c) eliminating the use of mandatory blends.

Scenario 1: mandatory blends as measures to stimulate the expansion of the biofuels industry

This is the traditional use of the instrument: mandatory blending targets are set keeping in mind the desired size of the biofuels industry. This is perhaps the most effective way to introduce biofuel in the energy mix of a country or to expand its participation. However, as discussed above, this use of blending targets can generate undesirable side effects.

Because demand is guaranteed by the mandate and the mandate requires consumers to adjust to the cost of the blend, this approach provides a secure and predictable environment for investors and leads to the expansion of the biofuels industry. At the same time, the cost of blending biofuels with fossil fuels is totally transferred to consumers, regardless of what happens with the price of biofuel feedstocks. The rapid growth of the biofuels industry in the United States illustrates this phenomenon. Indeed, the expansion in the United States of the maize-based ethanol sector may be a good example of the effects that a guaranteed demand can provoke.

As previously mentioned, the ban on the use of MTBE was de facto translated into a utilization mandate for ethanol, since the ethanol industry rushed in to provide the alternative oxygenate that the oil-refining and distribution sectors were looking for. The subsidies granted to blenders provided a mechanism to reduce the cost of blending and at the same time protected consumers from the increase in the price of transportation fuel. The Renewable Fuel Standards (established for the first time in 2005) allowed for the continued expansion of ethanol use in gasoline: the blending rate moved from 6 to 10 per cent.

Together with the quick expansion of the ethanol productive capacity came a strong pressure on the feedstock market – this may be one of the main results of aggressive mandatory blends or utilization targets. The growth in the utilization of maize for ethanol production may be responsible for a 40 per cent increase in the price of maize (Perrin et al., 2008). Interestingly enough, the adjustment to the new prices did not occur in the export sector, which remained stable, but materialized in the reduced utilization of maize for animal feed and in the expansion of planted acreages of maize at the expense of soybeans.

The Energy Independence and Security Act of 2007 (EISA) represents yet another mandatory use of ethanol (it establishes the use of 36 billion gallons by 2022). It is still unclear how the higher cost of feedstock and ethanol will be handled: whether it will be transferred to consumers, to the fiscal treasury, or shared between the two. At the same time, without a significant growth in the capacity of the agricultural sector to produce feedstock, it is unclear the level of agricultural commodities prices at which the utilization targets will be achieved. One of the means to increase the ability of the agriculture sector to produce feedstocks is to speed up the development and commercial availability of second generation biofuel technologies. In this regard, for the first time the EISA includes provisions supporting the production of cellulosic feedstock.

Another unintended consequence of an aggressive mandatory blending target is the pressure on natural resources. In an effort to comply with the mandate, feedstock production may expand into environmentally sensitive areas, including carbon-rich areas. Feedstock production may be based on unsustainable agricultural practices, exacerbating the already high contribution of the agriculture sector to GHG emissions.

In summary, while mandatory blends or mandatory utilization targets are very effective in expanding the biofuels industry, their inflexibility can generate undesired pressure on agricultural commodities prices and severely reduce the potential contribution of biofuels to global warming stabilization. Because of the sizeable amounts of private and public investments poured into the sector to fulfil the targets, a sudden modification (reduction) of the targets could face stiff opposition from the parties participating in the industry.

Scenario 2: mandatory blends as measures that provide a safety net for an already established biofuels industry

Mandatory blends or utilization targets can also be used to provide the biofuels industry with a guaranteed level of demand. Instead of being used as an instrument to expand the industry, the targets can be used to secure the economic viability of the industry during critical times. The basic premise behind this scheme is that once the ethanol industry has been established, the expansion of the industry should be driven by market signals, technological innovation and investment in infrastructure.

In Brazil, for example, after almost fifteen years of existence of the Pro-alcohol Programme, the conditions for expansion of the bioethanol industry changed dramatically (Koizumi, 2003). The price of oil collapsed from a high of $38 per barrel in 1980 to less than $20 in 1989. At the same time Brazil was experiencing macroeconomic instability and had to significantly restrain fiscal expenditures. Consequently, PETROBRAS was no longer able to subsidize the cost of hydrated ethanol at the pump – the fuel used by the growing fleet of cars running at 100 per cent ethanol.

The consequences of the adjustment process were severe: ethanol supply at the pump became unstable, ethanol price could not compete with gasoline anymore and the country had to import ethanol. Facing increasing sugar prices, producers diverted sugar cane to sugar production for the export market. All of this resulted in a loss of consumer confidence that materialized in the unwillingness to buy cars running at 100 per cent ethanol. Indeed, in practice, these cars disappeared from the market. As a consequence, ethanol production dropped by almost 30 per cent (Walter et al., 2006).

However, during this critical period a 20 per cent mandatory blend continued to be in place and saved the industry from a much larger decline. The existence of the blend mandate provided a safety net for the industry. With the mandatory blend, blenders could transfer the higher cost of ethanol – relative to pure gasoline – to consumers. This is the basic feature of any mandatory blending programme, whenever the price of ethanol is above that of gasoline. Today, gasoline sold in Brazil is a blend of gasoline and ethanol, with ethanol representing between 20 and 25 per cent of the fuel.

The development of the ethanol sector in Brazil indicates that high oil prices, compulsory purchases of ethanol by PETROBRAS, provision of low-cost loans to the ethanol industry and the expansion – especially during the first phase of the Pro-alcohol Programme – of the fleet running on 100 per cent ethanol were important factors in the development of ethanol production.[15] Once these factors disappeared – almost simultaneously – the 20 per cent mandatory blend provided a safety net for the industry and avoided its full decline. When national and global circumstances changed and using ethanol to power vehicles became once again an appealing alternative to fossil fuels, the ethanol industry had the capacity to quickly respond to both domestic and foreign demand of ethanol.

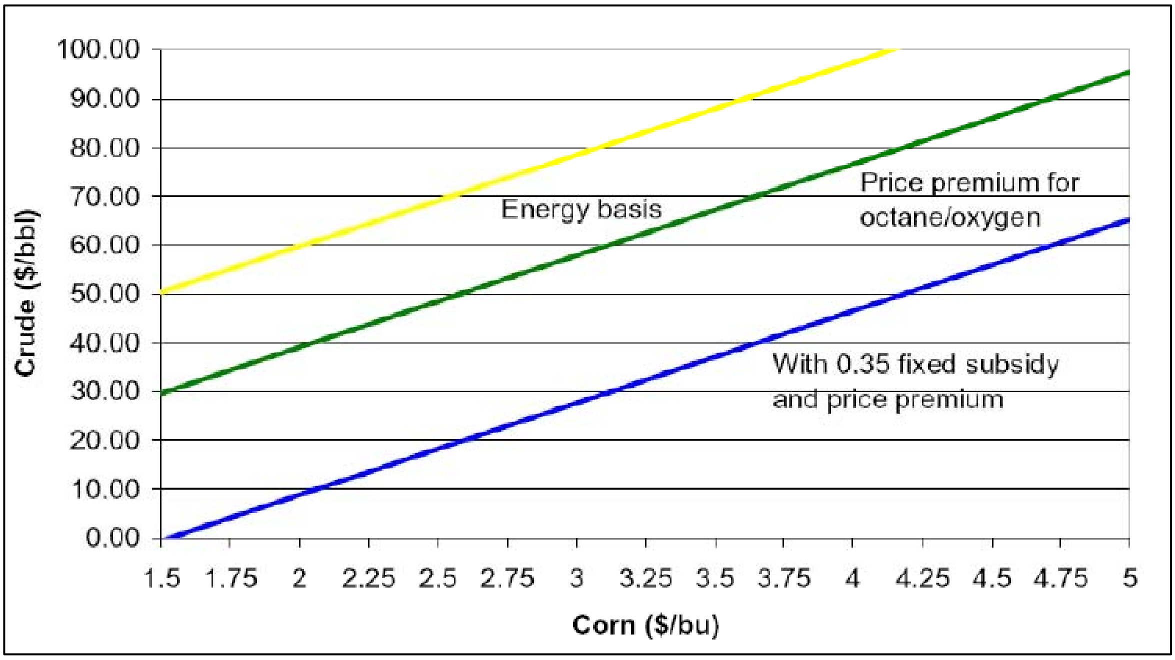
Scenario 3: no use of mandatory blends or mandatory consumption targets

An alternative to the use of mandatory blends is to let the market determine the share of biofuels in the domestic energy mix. Under this scenario, biofuel production and consumption should be driven by market signals, namely oil price, the cost of feedstock and conversion costs.

Figure 1.1 illustrates the relationship between oil and feedstock prices (maize) in the United States. It reveals the ranges in which the ethanol margins are positive and negative, and whether the economic environment points to the expansion or to the contraction of ethanol production. The break-even analysis indicates the level of prices at which all variable costs of production are covered by the firm.

[15] Before flex-fuel cars were introduced in 2003, auto makers in Brazil developed cars that ran on 100 per cent ethanol. Flex-fuel cars are vehicles with an internal combustion engine designed to run on more than one fuel.

Figure 1.1. Relationship between crude oil price and the break-even price of maize in the United States



Source: Tyner and Taheripour (2007).

The top line indicates what would be the break-even combination of oil and corn prices, when ethanol from maize is valued on an energy basis and in the absence of subsidies. Any point above the yellow line indicates that the margin – the difference between ethanol revenues and costs – is positive and any point below indicates negative margins. For example, if the price of maize is $4.50 per bushel, the price of oil should be above $100 per barrel for the margin of ethanol to be positive.

The intermediary line illustrates the case where ethanol is valued as an additive to replace MTBE, and therefore has a premium over ethanol valued on an energy basis. As the price of ethanol is assumed to be a premium price, it takes a lower price of oil per every corresponding price of corn to achieve the break-even level. If the price of maize is $4.50 per bushel, a price of oil above $85 dollars per barrel is enough to guarantee a positive margin for ethanol production.

The bottom line assumes that a $0.35 fixed subsidy per unit of ethanol is added to the revenue obtained by selling a gallon of ethanol as an additive (i.e., ethanol sold at premium price).[16] The results follow the same logic: if revenues increase, the price of oil at which ethanol production has a positive margin is lower than before at every level of corn price. Following the same example used above, oil prices need only to be above $55 per barrel to result in positive returns over variable costs.

Unless there is a clear increasing trend in the oil price and declining feedstock prices, the absence of mandatory blends may require other incentives if the objective is to develop a domestic biofuels industry.

Therefore, in the absence of mandatory blending requirements, the middle line summarizes the market signals that would be necessary for the production of ethanol to expand, assuming that ethanol is used as an additive to replace MTBE. Once ethanol has completely replaced MTBE, the relevant market signals become the ones represented by the top line, where ethanol is used for its energy content. The gap between the top and the bottom lines indicates the additional competitiveness added to ethanol by the subsidy, assuming that ethanol still gets a premium price. This gap is the one that has been driving the expansion of the ethanol industry in the United States since 2006. Considerations

16 For the purpose of this analysis, blending targets and subsidies are treated as equivalents.

about the yields and price of maize are also relevant, but without the tax rebate the growth of the ethanol industry would not have been as aggressive. We believe that the increase in the price of oil and the fixed tax rebate had a significantly more important role in this expansion.

In summary, unless there is a clear increasing trend in the oil price and declining feedstock prices, the absence of mandatory blends may require other incentives if the objective is to develop a domestic biofuels industry. For oil-importing countries with no feedstock potential or no intention to produce biofuels domestically, it is clear that even in the absence of mandatory blends they could include biofuels into their energy mix as a way to improve air quality and reduce GHG emissions. This would only require that the infrastructure for the blending is available when needed.

D. Concluding remarks

In this chapter we analysed the current and expected blending targets for ethanol and biodiesel. Our estimations indicate that the current installed production capacity will not be sufficient to cover the demand induced by these mandates. For almost all the countries analysed, there is a gap between the potential demand generated by mandatory or voluntary blending targets and their production capacity. These results suggest that additional production will be needed to fulfil the mandates and reduce the pressure on biofuel prices. This perception is stronger with respect to biodiesel production.

We looked at the impact of a mandatory blend on the biofuels, feedstock and transportation markets. Initially, the cost of the mandatory blend is transferred to consumers through higher fuel prices. However, the expansion of the biofuels supply is likely to lead to both lower production costs and a significant substitution of biofuels for oil. These developments could take some pressure away from the oil market and lead to a decrease in oil prices, having ultimately an overall positive impact, including for consumers.

Mandatory blends or utilization targets are effective mechanisms to ensure the setting up or expansion of an ethanol industry. However, their inflexibility can generate pressure on agricultural commodities prices and severely reduce the positive contribution of biofuels to GHG emission reductions. Because of the sizeable amounts of private and public investments poured into the sector to fulfil the targets, a sudden modification (reduction) of the targets could face stiff opposition by the parties participating in the industry.

The use of mandatory blends as a safety net or floor for the industry can be an effective tool to deal with changes in the overall economic environment. When direct government support to the Brazilian ethanol industry ended, the mandatory blends played precisely this role with a significant degree of success. Unless there is a clear trend towards increasing oil prices and declining feedstock prices, the absence of mandatory blends may require other type of incentives, if the objective is to develop a domestic biofuels industry. Examples of such complementary incentives are differential tax structures for gasoline and blended ethanol, public investments in conversion technology and development of the carbon market, among others.

The next chapter analyses the potential role of carbon credits.

References

Althoff K et al. (2003). Economic analysis of alternative Indiana state legislation on biodiesel. Center for Food and Agricultural Business, Department of Agricultural Economics, Purdue University. West Lafayette.

ANP (2007). http://www.anp.gov.br. Rio de Janeiro.

De Gorter H and Just D (2008). The law of unintended consequences: how the U.S. biofuel tax credit with a mandate subsidizes oil consumption and has no impact on ethanol consumption. WP 200-20. Department of Applied Economics and Management, Cornell University. Ithaca.

Energy Information Administration (EIA) (2008). http://www.eia.doe.gov. Washington DC.

Espey M (1996). Explaining the variation in elasticity estimates of gasoline demand in the United States: a meta-analysis. 17 (3): 49–60.

European Union Road Federation (2008). *European Road Statistics 2008*. Brussels, European Union Road Federation.

Gardner B (2003). Fuel ethanol subsidies and farm price support: boon or boondoggle? Working paper 03-11. Department of Agricultural and Resource Economics, University of Maryland. College Park.

Hughes JE et al. (2008). Evidence of a shift in the short-run price elasticity of gasoline demand. *Energy Journal*. 29 (1): 113–134.

ICONE, Institute for International Trade Negotiations (2007). http://www.iconebrasil.org.br. São Paulo.

Koizumi T (2003). The Brazilian ethanol programme: impacts on world ethanol and sugar markets. Working paper 1. FAO Commodity and Trade Policy Research.

Leal MRLV (2006). O teor de energia da cana-de-açúcar. NIPE – Núcleo Interdisciplinar de Planejamento Estratégico, UNICAMP – Universidade Estadual de Campinas. Brazil.

Nastari M (2008). Tendências de preços para açucar e alcool no Brasil. Presented at the I Workshop Nacional da Cana-de-Açucar. São Paulo. January.

Perrin R et al. (2008). The maize ethanol boom and food prices. Cornhuskers Economics, University of Nebraska. Lincoln.

Runge C (2002). Minnesota's biodiesel mandate: taking from many, giving to few. Prepared for the MN Trucking Association and the Biodiesel by Choice Coalition. 15 February.

Schmitz T et al. (2002). Brazil's ethanol program: the case of hidden subsidies. *International Sugar Journal*. 105 (1254): 254–265.

Tyner WE and Taheripour F (2007). Future biofuels policy alternatives. Paper presented at Biofuels, Food, & Feed Tradeoffs Conference. St. Louis. 12–13 April.

Walter A et al. (2006). Biomass energy and bio-energy trade: historic developments in brazil and current opportunities, country report: Brazil – EIA/Task 40 – Sustainable bio-energy trade; securing supply and demand.

Yacobucci D (2008). Ethanol imports and the Caribbean Basin Initiative, CRS report for Congress.

II. Greenhouse gas markets, carbon dioxide credits and biofuels[17]

The previous chapter analysed mandatory blends and utilization targets as policy measures that can provide incentives for expanded biofuels production. GHG policies[18] that create a carbon price either through an emissions trading system or directly by taxing GHG emissions also generate increased demand for biofuels. They do so by raising the price of burning the fossil fuels with which biofuels compete. GHG policies thus represent yet another way to stimulate biofuel production.

It is widely believed that the biofuels industry has a unique role in climate policy because it represents a low-carbon alternative to fossil fuels. Nevertheless, the industry may face challenges in taking full advantage of this potential if CO_2 markets do not take into account all emissions related to biofuels production and use. Indeed, the effectiveness of biofuels as a low-carbon alternative depends on how they are produced and how emissions related to land use are managed.

At a high level of demand for biofuels, the overall need for cropland requires significant conversion of land from less intensively managed grass and forestland. This initial disruption leads to significant carbon dioxide release from soils and vegetation. If mature forests are converted, it can take decades of biofuels use to make up for the initial carbon loss. Given the increasing competition for the use of land, which can result in higher agricultural, land and food prices, it becomes relevant to address the potential outcomes from land conversion.

This chapter argues that it is necessary to have a full assessment of the emissions linked to biofuels production and use, including emissions related to direct and indirect land-use changes. Therefore, we discuss potential ways of expanding "cap and trade" systems by including terrestrial carbon sinks and forests, in order to ensure that biofuels are produced in a sustainable manner.

The chapter starts with an analysis of the interactions between the biofuels industry and GHG policies, followed by a discussion on the carbon neutrality of biofuels. Finally, we address the issues related to the inclusion of emissions from land-use change in a cap and trade system.

A. GHG policies as a way to boost biofuel demand

Increased focus on the mitigation of greenhouse gas (GHG) or carbon dioxide (CO_2) emissions can provide incentives for expanded biofuels production through a variety of policy measures, such as the mandatory blends, utilization targets and low-carbon fuels standards analysed in the previous chapter. GHG policies that create an emissions trading system such as the cap and trade mechanism can also stimulate the production of biofuels by imposing a cap on carbon emissions and allowing trade of emissions permits (allowances). In practice, such a

---

[17] This chapter was prepared by Sergey Paltsev, John Reilly and Angelo Gurgel, Joint Programme on the Science and Policy of Global Change, Massachusetts Institute of Technology, Cambridge, United States.

[18] Most GHG proposals focus on carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6) emissions. As CO_2 is the main greenhouse gas related to human activities, the terms "carbon policy", "CO_2 policy" and "GHG policy" are often used as synonyms. We follow this convention, unless otherwise specified.

system creates a price for carbon, similarly to the imposition of a tax on GHG emissions. Box 2.1 defines the cap and trade system in more detail.

Box 2.1. Creating tradable emissions reductions

There are two main approaches to create tradable emissions reductions (Ellerman et al., 2000). The first is a cap and trade system in which a central authority sets a limit or cap on the amount of a pollutant that can be emitted. Companies or other groups are required to hold an equivalent number of allowances (or credits) that represent the right to emit a specific amount. The total amount of allowances and credits cannot exceed the cap. Covered entities may purchase allowances if they need them or sell extras as long as they have enough to match their emissions. The transfer of allowances is referred to as trade. Differences among entities in terms of their costs of abatement determine the demand and supply for allowances and their market price.

An alternative approach is a baseline and credit system. Polluters not under an aggregate cap can create credits by reducing their emissions below a baseline level of emissions. These credits can be purchased by polluters that are under a regulatory limit. The baseline is established on a project-by-project basis. Applying for approval of projects that produce such credits is voluntary. To be effective, a credit system needs to be part of a mandatory system (i.e., cap and trade or tax). Credits have value and entities have an incentive to produce them since they can be used by entities under the mandatory cap and trade (or tax) system instead of issuing allowances (or paying the tax). An entity not covered by the cap has an economic incentive to enter the credit market if its baseline is established in such a way that it can produce credits through abatement at less than the market price of allowances. Interest in the credit system depends thus on the baseline and the allowance price. Non-covered entities that choose not to enter the credit system are not required to make any reductions, and can increase emissions without any penalty. The main concerns with a credit system are the voluntary nature of participation and the bureaucracy of establishing a baseline for each project.

An example of carbon emissions trading system is the European Union Emissions Trading Scheme (EU ETS). In the United States, Senators McCain and Lieberman (Climate Stewardship Act of 2003) and Senators Warner and Lieberman (Climate Security Act of 2007) tried to introduce a similar system, but the legislation was not approved by the United States Congress. Nevertheless, a similar bill is expected to be approved soon.

Policies that create a carbon price either through an emissions trading system or directly by taxing GHG emissions can also stimulate the production of biofuels.

Cap and trade systems may or may not include agriculture in a sectoral coverage, but such CO_2 pricing systems often include a mechanism whereby credits from activities not directly covered by the trading system (or the carbon tax) can be used to offset emissions from covered entities.[19]

The main international agreement currently addressing GHG mitigation is the Kyoto Protocol (United Nations Framework Convention on Climate Change (UNFCCC), 1997).[20] Under this agreement, 37 industrialized countries and the European Community are committed to reduce their overall emissions of greenhouse gases by at least 5 per cent below 1990 levels during the period 2008–2012. Countries under the cap are referred to as “Annex B countries”.

The Kyoto Protocol establishes the use of three market-based mechanisms to facilitate GHG emission-reduction targets: (a) Emissions Trading, which allows the international transfer of national allocations of emission rights between parties with commitments under the Kyoto Protocol (Annex B countries); (b) The Clean Development Mechanism (CDM), which allows Annex B countries to implement emissions reduction projects in developing countries that generate certified emission reduction (CER) credits; and (c) Joint Implementation, which allows

[19] Most of the current American proposals exclude agriculture (both emissions and sinks) from direct coverage of the cap and trade system, but so-called “offsets” from project-type credits from agriculture are allowed. In principle, agricultural emissions and sinks can and should be included into cap and trade, as we argue in this chapter.

[20] The Protocol was adopted in Kyoto, Japan, in December 1997 and entered into force in February 2005; 183 parties of the convention have ratified the protocol to date.

the creation of emissions reduction credits through transnational investment between Annex B countries (and/or companies from those countries).

Emissions reductions generated under any of these mechanisms are referred to as “carbon credits”. One carbon credit represents one ton of CO2-e (carbon equivalent) non-emitted or reduced. The Kyoto Protocol, along with the EU ETS, created the largest market in the world for trading carbon credits. Therefore, countries under the Kyoto Protocol or other cap and trade systems that allow credit creation by non-covered entities have incentives to finance credit-generating projects elsewhere or to purchase approved credits.

Biofuel is considered a low-carbon emissions fuel, and therefore a biofuel production project is a potential candidate for eligibility under the CDM or Joint Implementation mechanisms.[21] CDM projects are approved on a case-by-case basis; the CDM Executive Board avoids approving projects that would have happened despite the carbon policy and seeks to ensure that projects reduce emissions more than would have occurred in the absence of the projects. So far, none of the existing biofuels projects in developing countries has been approved for CDM, but there are several biofuels CDM projects at the validation stage, including biodiesel projects in China, Indonesia and Thailand.

The Kyoto Protocol paved the way for a GHG credit market by establishing the CDM and Joint Implementation mechanisms. The demand for credits depends, however, on the establishment of binding limits within each country, but not all Annex B countries have allocated caps to individual emitters, who could in turn acquire allowances or CDM/Joint Implementation credits to meet their targets. To the extent that these credits are fully fungible in different countries, a de facto international emissions trading system would be created, equalizing the price of CO_2 credits in all markets.[22]

Europe implemented its emissions trading scheme in January 2005, as part of the Kyoto Protocol. The EU ETS works on a cap and trade basis, forcing companies either to emit less CO_2 than their determined cap of emissions for all installations or to buy EU Emission Allowances (EUA) from elsewhere.[23]

Apart from European countries that are under a cap and trade system, countries that have not attributed a cap to individual firms but face commitments under the Kyoto Protocol also represent a potential source of demand for credits. For example, Canada and Japan have not moved yet to set up a market trading system but face their commitments under Kyoto, and entering the carbon credit market is one likely avenue for them to meet their reduction targets.

Even without explicit GHG markets that allow for CO_2 credits, demand for biofuels is likely to expand unless another low-carbon alternative in the transportation sector emerges.

Nevertheless, we believe that, even without explicit GHG markets that allow for CO_2 credits, the demand for biofuels is likely to expand unless another low-carbon alternative in the transportation sector emerges. Moreover, bioenergy production will likely increase even in the

[21] On the other hand, projects that encourage land use as a carbon sink are also eligible for CDM and can thereby limit the amount of land available for biofuels production.

[22] An exception would be a country with a cap and trade system that generated a price below the international price, if its allowances could not be traded internationally. There would be no incentive for firms within that region to purchase the more expensive credits elsewhere.

[23] The European ETS (EC, 2003; EC, 2005) was in its test phase during the years 2005–2007; when CO_2 prices reached over 30 euros per ton, great interest was generated in Kyoto’s Clean Development Mechanism. After a collapse to under 1 euro per ton in 2007 (discussed in Reilly and Paltsev, 2006), the price of the ETS during the Kyoto period (2008–2012) remains in the range of 20–25 euros. For a detailed analysis of the ETS, see Ellerman and Joskow (2008).

absence of climate policy due to higher oil prices.[24] The last seven years have been characterized by an unprecedented, sharp and volatile rise in oil prices. Prices have risen for seven consecutive years from $26 per barrel in 2001 to over $140 per barrel in July 2008. After the price spike in July, oil prices declined in September and went down to below $50 in December 2008, as growth of demand weakened. However, prices remain very volatile, with daily swings.

Under a scenario of increased biofuels production, key issues remain to be addressed: the long-term impact on food prices and land use and the extent to which it translates into deforestation and ecosystem disruption. In the present analysis we focus on this second issue, which is closely linked to the discussion of whether biofuels are indeed carbon neutral.

Box 2.2. The competitiveness of biofuels

Apart from GHG policy, recent movements in the crude oil price have changed the competitive picture for biofuels. The IMF (2007) provides cost estimates for ethanol and biodiesel production, compared to gasoline and diesel. Assuming a $65 per barrel crude oil price and 2006 agricultural prices, only sugar cane-based ethanol has a lower production cost (about $0.25/litre versus $0.30/litre for gasoline). If free trade is allowed, these cost estimates suggest that Brazil, India and Malaysia would be major biofuels exporters. Asian (Indonesia, Philippines and others) and African countries (Benin, Burkina Faso, Ghana, Kenya, Madagascar, Nigeria, the United Republic of Tanzania and others) with a similar climate and available land may also become important biofuel exporters. With a crude oil price of $120/barrel (May 2008), the production cost of gasoline and diesel is around $0.90/litre (IEA, 2006). At that level, biofuels from any of the feedstocks available (maize, wheat, sugar beets, palm oil, soybean oil, rapeseed oil and others) become competitive, even without mandates or a further CO_2 price on fossil fuels. On the other hand, the level of oil prices has already returned to about $45/barrel (December 2008) and is likely to remain so, or decline even further, given the recent financial crisis and consequent global slowdown.

B. Is biofuel carbon neutral? The importance of land-use change and deforestation

When biofuels are burned, there is CO_2 emission; however, when vegetation re-grows, it again takes CO_2 out of the atmosphere. A cycle of growth, harvest, and re-growth can thereby be carbon neutral (i.e., zero net emissions over the harvest and re-growth cycle).

Since GHGs have a long life, a cropping cycle of a year or less (or even a decade in the case of a fast rotation woody crop), would not lead to significant changes in GHG concentrations. On this basis, an emissions trading system might exempt biofuel use from the cap and thereby not require allowances to cover CO_2 emissions from biofuels. A GHG credit could be created through the CDM or Joint Implementation to the extent that the production of biofuels replaces fossil fuel use (outside of capped countries). Thus, the amount of CO_2 emissions avoided would determine the number of GHG credits generated by the project.

But are biofuels indeed carbon neutral? Some biofuels use significant amounts of fossil fuel in production and the correct offset ratio may be as small as 0.3 unit of credit for every unit of fossil fuel CO_2 avoided. Moreover, the issue of land-use change and deforestation needs to be considered. A mature “old growth” forest or one that has been undisturbed for decades contains a large stock of carbon in the woody parts of the plant and in the soil. Deforestation leads to the release of much of this carbon and depletion of the stock of carbon.

A short rotation biofuel crop would get credit for offsetting fossil fuel use, but should be debited for the depletion of carbon that occurred with land-use change. The carbon loss from initial conversion is essentially a one-time loss which, through annual harvests of biofuels that are credited for offsetting fossil fuel use, eventually makes biofuels a net positive contributor to

[24] Box 2.3 illustrates recent climate policy developments in Europe and the United States that are likely to increase demand for biofuels. Box 2.2 briefly discusses the relation between oil prices and biofuels production.

reducing carbon emissions. How long it takes to pay off the carbon debt depends on the quantity of carbon previously stored in the disturbed ecosystem and on the net fossil fuel use offset. Regarding the latter, we need to take into account any fossil fuel used in growing, transporting or processing the biomass/biofuel. If biofuel crops are established on degraded or nutrient-limited land, it is possible that intensive management of the crops could actually increase the carbon stock by adding to the soil the unharvested stubble/roots of the crop.

However, establishing the extent to which land-use change emissions are attributable to biofuels is complicated by the fact that agricultural and potential biofuels markets are global in nature. In that sense, the presence of biofuels crops on degraded pasture and grazing land might have a neutral or positive effect on soil carbon on that parcel of land. However, if the displaced grazing activity leads to deforestation elsewhere, the emissions from that land-use conversion should be indirectly attributable to biofuels.

We argue that if emissions derived from biofuels productions are included in the trading systems, the issue of carbon neutrality of biofuels is mitigated.

1. A "comprehensive" CO_2 cap and trade or tax system would solve the issue of the carbon neutrality of biofuels

Questions related to the degree of carbon neutrality arise for biofuels in a CO_2 cap and trade or tax system when the system does not take full account of all emissions derived from biofuels production and use, as is currently the case. If biofuels production was itself under the cap, allowances would be required for any fossil fuel used. If land sinks and sources were under the cap, allowances would be required to offset emissions related to deforestation. Requiring allowances for biofuel production and land-use change would thus ensure the carbon neutrality of biofuels even if fossil fuels were used and land-use change occurred. Producers and landowners would have to procure CO_2 allowances that led to emissions reductions elsewhere to offset their own emissions.

Cap and trade systems like the ETS have so far not been extended to land-use emissions and do not cover production facilities of any kind, including biofuels, outside of the region with a cap and trade. In fact, the ETS does not include the transportation sector and therefore does not provide incentives for ethanol or biodiesel use in Europe. Nevertheless, the EU directive sets a target for the use of biofuels in transportation, and that requirement has already led to the perception that such incentives for expanded biofuel use can lead to non-sustainable production, i.e., deforestation that emits carbon and destroys unique ecosystems.

Below we discuss the issues related to the inclusion of land-use emissions in a trading system.

C. Expanding the carbon market to enhance the sustainability of biofuels

We argue that, for environmental effectiveness, it is important to bring all carbon-related activities into carbon markets. In addition to fuel-burning activities, land-use change affects emissions. Full protection of soils and vegetation (and fossil fuels used in processing biofuels) would allow biofuels to be credited for 100 per cent offset of the fossil fuel they displace. While full inclusion of land-use emissions and sinks under a cap and trade system would seem to be ideal, a number of practical issues and objections have arisen. In the following sections we consider how these emissions can be included in carbon markets. For a more complete discussion see Reilly and Asadoorian (2007).

Many analysts and policymakers argue that land's unique characteristics make it impossible or difficult to include it in a cap and trade system. Land, unlike other fossil fuel emissions, can be a source of emissions similar to coal combustion in a power plant, but it can also be a sink for carbon. However, we argue that this particularity (negative emissions or sinks) does not impede the inclusion of land in a trading system. Emissions are normally counted from zero to some positive amount, requiring allowances for all emissions above zero. For fossil emissions, the usual perception is that one could abate all of its emissions. However, nothing about a trading system inherently prevents abatement of more than 100 per cent of emissions. Thus, land can emit or capture carbon, and both land emissions and sinks can be included in a trading system.

Land can be included in a cap and trade system to fully account for biofuels' sustainability and carbon neutrality. However, agreeing on baseline land emissions can be challenging.

There is, however, an important distributional issue related to what is expected of a landowner or a country with large stock of land-based carbon. The natural approach is to establish a baseline at zero net flux of carbon to the atmosphere. Landowners (or countries) with a positive net flux would need to acquire allowances, while those with a negative net flux would be able to sell allowances. Nevertheless, other criteria can be used to establish a baseline for land-use emissions. If the objective is to not reward actions already taken, the landowners/countries could be required to meet an estimated path of uptake and only be permitted to sell allowances if they exceeded that uptake. Countries subject to deforestation could be given a baseline that allowed further deforestation but would then be allowed to sell allowances if that deforestation (or some part of it) was avoided.

One important aspect is that if a great parcel of the existing uptake is allowed to be credited (e.g., the baseline is implicitly zero net flux), this will relax an overall carbon emissions target. However, that can be offset by further cutting the number of allowances allocated to other emitters. At this point it is important to outline the definition and distribution of property rights. At one extreme, landowners have the right to convert all land they own (and release the carbon associated with it) unless they get paid for avoided emissions. At the other extreme, they are responsible for maintaining (or restoring) carbon in land and vegetation at its natural level and must purchase allowances if the stock is below this level. What matters for efficiency (and for the incentive to preserve carbon) is the value of carbon at the margin. In either of these extreme cases (or others in between) the landowner values carbon at the going price, either because (s)he faces the opportunity cost of not being able to sell allowances or must acquire allowances for maintaining the natural level of carbon in land and vegetation

If land use is completely within a carbon cap and trade system, the most direct implication for biofuels is that landowners would balance the market price for biofuels (reflecting its value in terms of offsetting fossil fuel use) with the cost of acquiring allowances to cover emissions from land-use conversion for biofuels production. On the other hand, by producing biomass in a manner that increases the stock of carbon on degraded or poor quality land, landowners would benefit from both the price of biomass and the ability to sell carbon credits. However, if pasture or grazing land was converted to biofuels, livestock producers would need to consider the carbon implications of converting other natural lands to pasture or grazing since this would imply the need to acquire carbon allowances to cover carbon emissions.

Many policy and science discussions about biofuels posit that substantial amounts could or should be produced on degraded or poor quality land, and therefore would not result in significant land-use conversion. When land-use decisions are market-driven and the pricing of carbon emissions from land includes the cost of converting land with large stocks of carbon, there are incentives to use degraded or poor land for biofuels production.

D. Issues of sinks in policy discussions

Analysts have raised a number of issues related to the incorporation of sinks[25] into a cap and trade system. These issues are often used as justifications for the impossibility or difficulty of including them in the carbon market. Nevertheless, we believe that none of the issues pose insurmountable challenges for including land use fully under a cap and trade system and that the claim that land use is different from fossil emissions is often exaggerated. Below we summarize each of these issues.

1. Payment for land-use emissions

How much to pay for an additional ton of sequestration, compared to an avoided ton of emissions? Among the various approaches proposed to determine the payment for land-use emissions, many focus on establishing the value of a temporary storage of carbon (Herzog et al., 2003). Landowners are paid a rental value (an annual amount for each ton). However, since the landowners' responsibility for future changes in the stock of carbon is not well defined, the rental rate is often based on some presumption of how long the carbon will remain in the land, and requires that the public agency establishing the rental price determine the time path of the carbon price. Like a credit system, landowners must be perpetually bid into the system. McCarl et al. (2005) and Lewandrowski et al. (2004) provide a comprehensive review of different approaches.

We propose that, to ensure consistency with a cap and trade system, landowners should instead pay the full price, or receive the full credit for each ton emitted or taken up over a period. They are permanently under the cap so that future changes in the carbon stock are subject to the cap, and landowners bear permanent responsibility for the carbon. Decisions about what to do with a parcel of land are reversible at any time but must take into account the carbon implications of the change and the market price of carbon at that time, as well as expectations about future changes in the price. If this becomes the principle for managing land carbon, then private intermediaries can devise payment schedules or contracts that remove risk from unexpected changes in the carbon price (Reilly and Asadoorian, 2007).

Without this type of provision, there are concerns about the permanence of carbon sinks, with attempts to penalize landowners for not maintaining the carbon, as discussed further below. Such provisions could be important given the growing biofuels industry. Biofuels production ought to be responsible for land-use emissions but if the demand for biofuels is strong, conversion of land may be warranted, and if allowances for carbon are purchased to offset such emissions then the net impact on the atmosphere is neutral. Without this flexibility to convert land when demand for biofuels (or food) is unexpectedly high, the price of land and of food could rise unnecessarily.

2. High variability in carbon uptake and release on land

The quantity of carbon taken up by plants varies dramatically from year to year depending on the weather (e.g., Felzer et al., 2004; Sarmiento and Gruber, 2002). Events such as wildfires can lead to sudden release of much of the carbon stored in the area subjected to the fire (Zhuang et al., 2003). However, we argue that natural phenomena that generate variability are not different from the average situation landowners face: inclement weather that leads to relatively little carbon uptake, and possibly net emissions, is not different from inclement weather leading to crop failure and financial loss.

[25] A carbon sink is a reservoir of carbon that accumulates and stores carbon for an indefinite period. Oceans and plants (through photosynthesis) are the main natural sinks.

This variability does not suggest per se that land use cannot come under a cap and trade system. Rather, we suggest that the squaring up period (how often a landowner is required to measure the carbon stock) should be relatively long, in the order of 10 or 20 years. As such, the issue of high variability would be attenuated, since landowners would be able to bank and borrow emission allowances against the future (Reilly and Asadoorian, 2007).

3. Direct human responsibility for sequestration

One of the most problematic aspects of the Kyoto Protocol is that it limits the generation of carbon credits to "direct human-induced change" (article 3). However, there are several natural or indirectly human-induced changes that can cause an increase/decrease of GHG emissions in the atmosphere. For example, nitrogen deposition, along with increased ambient levels of CO_2, enhances forest growth and carbon uptake (Felzer et al., 2004); tropospheric ozone and other pollutants damage vegetation and reduce uptake (Felzer et al., 2005). Climate change itself affects plant growth – these are examples of "indirect effects" that the Kyoto Protocol excludes. We believe that article 3 creates considerable difficulties in defining what constitutes direct human-induced changes versus natural changes or those indirectly caused by human action. The problem is very similar to the issue of carbon emissions directly or indirectly related to biofuels expansion. Therefore, a cap and trade system should include rules that require responsibility for carbon on the landowner's parcel of land, regardless of the cause (direct or indirect). These rules would minimize endless challenges and controversy.

4. Permanence and leakage

Another issue is the presence of leakage in the context of a cap and trade system. Physical leakage happens when, in a specific project or land parcel, parts of the carbon originally stored returns to the atmosphere. This phenomenon is also often referred to as an issue of the "permanence of the sink". A particular form of leakage is what has come to be known as "indirect" emission. These occur in a cap and trade system when more emissions enter the atmosphere due to an increase in emissions by entities that are not under the cap, which offset reductions made by regulated entities.

We believe that physical leakage can be addressed if landowners have permanent responsibility for carbon stocks. As discussed above, physical permanence is not necessarily desirable because there may be good reasons to reverse decisions to build up carbon stocks. That is not a problem if allowances are required to offset losses whenever conversion occurs. However, spatial and temporal leakage from a policy regime occurs when the policy is incomplete in the sense that it covers some sources but not all, or provides incentives for a period of time but not indefinitely (Reilly and Asadoorian, 2007).

Policy-induced leakage is a particular problem for biofuels. This is a fairly homogenous product for which one would expect there to be an international market. As a result, a country that includes land use in a cap and trade system might discourage unsustainable biofuels production within its borders, but that could result in imports of biofuels (or of food and forest products) from countries without such controls. Therefore, an efficient carbon control system needs to discriminate among sources of biofuels. Indeed, policies prescribing biofuels or low-carbon fuels usually include criteria related to biofuels' production method or origin. As long as land-use emissions are incompletely controlled such discrimination remains necessary. However, discriminating against a country or a particular production technology does not create direct incentives for producers to improve their processes, whereas a complete carbon management system including land-use emissions would.

5. Pre-existing distortions

Due to the presence of taxes, subsidies and other unregulated externalities, prices do not exactly reflect the real marginal cost of goods. Therefore, a policy that results in equating marginal costs of carbon reduction among countries or across sectors may not be the most effective policy (Babiker et al., 2004). Some countries impose heavy taxes on fuels, for example, which affect the cost-effectiveness of carbon policy (Paltsev et al., 2007). Likewise, agricultural subsidies affect the efficiency of carbon pricing (currently there is no study on this effect). There are also positive externalities (ancillary benefits) from carbon sequestration and emissions reductions: for example, emissions reductions by fuel switching may reduce the emissions of other air pollutants (Matus et al., 2008) and carbon sequestration may reduce soil erosion and leaching agricultural chemicals, thereby reducing water pollution (Marland et al., 2001).

Biofuels production presents its own set of positive and negative externalities that depend, in part, on what it is replacing. If biofuels replace row crops or severely degraded grazing land, this could result in benefits in terms of reduced soil erosion or reduced use of chemicals pesticides. However, sustained production of biofuels would likely require fertilizer inputs, generating the negative externality of N_2O emissions from nitrogen fertilizer. It seems possible to provide a single price signal to cover major greenhouse gases (CO_2, CH_4, N_2O) by using Global Warming Potentials (GWPs) to convert non-CO_2 GHGs to CO_2-equivalent emissions. Thus, a cap that covers land-use emissions should also include N_2O and CH_4 emissions, powerful greenhouse gases that, if not included, could undermine biofuels' value in offsetting fossil fuel emissions. In summary, we believe that pre-existing distortions should be treated on a case-by-case basis, depending on the nature of the distortion.

6. Measurement, monitoring and enforcement

Concern exists regarding the feasibility of monitoring and enforcing changes in land-use emissions. Despite progress in the development of methods to measure soil and vegetation carbon, there is an ongoing debate on whether direct measurements are needed or whether a list of practices associated with specific carbon levels is enough. Given the high carbon variation associated with different practices, we believe that some form of direct observation and assessment is needed. Nevertheless, it is necessary to evaluate the trade-off between the cost of monitoring and the accuracy required. The value of good monitoring and measuring instruments and protocols increases with the presence of higher quantities of carbon in vegetation and soils, and with increasing biofuel production.

7. Carbon stored in products

Harvested material from forests and farms compounds a variety of product streams. Some are relatively short-lived such as food or pulp and paper. Others may remain "stored" for decades or hundreds of years (e.g., lumber used in buildings or furniture). The lifetime of carbon in biofuels is very short (weeks or months), from the time the biomass leaves the field to the moment it is finally used in a vehicle. For this reason, biofuel is often considered neutral with respect to atmospheric carbon: carbon taken up by plants is released when biofuels are combusted and recaptured when plants re-grow. Therefore, over a period of a year there is no net change in atmospheric carbon. Schlamadinger and Marland (1999) provide estimates and discuss issues related to carbon in the product stream.

This raises a key question: should the harvested product be tracked until it decomposes, and only then counted as an emission of carbon requiring an allowance? In principle, the answer is yes: this would provide an incentive to not finally dispose of the product, if it can be reused. In doing so, it would accurately account for the time between harvest and decomposition, during which the carbon remained out of the atmosphere. However, this would require a complex tracking system both of the product and its owners. Such a system would presumably favour products with longer-term storage of carbon (which is not the case of biofuels).

A simpler approach would be to ignore the storage and assume that the carbon will ultimately return to the atmosphere. Yet another approach is to apply an average discounted ton factor as an offset to the total harvest.[26] Both approaches do not create incentives to prolong the life of carbon stored by not destroying structures or by recycling used lumber. Crediting via a discounted ton approach brings the problem of estimating this discount factor, which is not a trivial task (Herzog et al., 2003).

Schlamadinger and Marland (1999) find that, in cases of massive cutting of forests with large amounts of biomass, the level of carbon may never return to the pre-disturbance level. Similarly, disturbed cropland often has significantly less carbon than in its pre-disturbed state. To correctly account for such land conversion losses of carbon or non-sustainable management of land, land used to produce biomass would need to come under a cap. In that way, correct incentives to maintain carbon stocks in soils or in standing vegetation would be provided. Because the bioenergy would be combusted relatively quickly after production (e.g., weeks, months or a few years at most), one could then exempt emissions from fuel combustion (e.g., at power plant or by vehicles using a liquid fuel). This approach could be applied to other product streams that are short-lived, reducing the monitoring problem to the land parcel without the need to follow the product stream.

And what happens if biomass is not finally converted to fuels? If a large portion of biomass not converted to biofuels is instead used as process energy, then the carbon would be released to the atmosphere. To the extent that some portion of the biomass ends up in animal feed, it too would end up mostly emitted as carbon dioxide with relatively fast turnaround. One exception to this would be process facilities that include carbon capture and storage (CCS), similar to that envisioned with power generation. Under this circumstance, biofuels could create a net sink: the fuel produced would offset fossil fuels and the carbon emitted in the production process would be stored (for example, in deep aquifers). Moreover, biofuels production processes that utilize gasification can benefit from the same carbon capture and storage technologies as those applied for coal gasification. For fermentation/distillation conversion processes, “end of pipe” capture methods would be needed.

The issue of carbon contained in products presents a further measurement and monitoring issue that could add considerable complexity to any system. The lifetime of the product matters, and further investigation is needed as to whether a monitoring system for long-lived products, tracking their fate until their eventual decomposition, would improve efficiency or present a costly burden with little benefit.

Box 2.3. Recent developments in climate policies in the United States and Europe

United States. While the United States did not ratify the Kyoto Protocol, its Congress has introduced legislation (the McCain and Lieberman Climate Stewardship Act of 2003 and the Warner and Lieberman Climate Security Act of 2007) that, if passed into law, would create a nationwide cap and trade system. This legislation did not gain enough support in Congress, but as the newly elected United States President is in favour of a cap and trade system, it is expected that similar legislation will be introduced again soon. The United States Administration also announced a significant goal for the utilization of alternative fuels for transportation (Renewable Fuel Standards, 2005), driven by climate and energy security purposes. More importantly in terms of actual market dynamics, the ban on the use of MTBE (methyl tertiary butyl ether) generated additional demand for biofuels, as refineries in the United States decided to switch to ethanol as an oxygenate substitute. Ethanol use as a direct gasoline replacement is still limited but is increasing, since it requires the penetration of flexible fuel vehicles and the development of infrastructure to deliver E85 and biodiesel to consumers. This, in turn, is likely to involve a major change in capital investment plans for refineries, car manufactures and gas stations.

[26] Concerned that the carbon may not remain stored, the concept of “discounted” tons was created, whereby a fractional discount factor would be applied to account for possible return of carbon in the future (i.e., physical leakage).

In December 2007, President Bush signed into law the Energy Independence and Security Act. A major feature of the legislation is the requirement to produce 9 billion gallons of ethanol by 2008 and 36 billion by 2022. The act distinguishes between conventional corn-based ethanol, biomass-based diesel, cellulosic ethanol and advanced biofuels from other sources (such as sugar starch, waste materials and biogas). The CO2 emissions associated with production are a concern and must meet a minimum improvement of 20 per cent for life cycle greenhouse gas emissions compared with gasoline. Biomass-based diesel and advanced biofuels should have at least 50 per cent less of life cycle greenhouse gas emissions compared to the fuel they replace, and for cellulosic biofuels the requirement is at least 60 per cent less life cycle emissions. Biofuels that achieve 80 per cent or more reduction in life cycle greenhouse gas emissions are eligible for further subsidies (section 207(b)(2)). The legislation also has specific carve-outs for cellulosic biofuels and other non-conventional biofuels (e.g., biodiesel). However, recent reports indicate that the United States Department of Energy believes that the long-term target may not be fully achievable and some members of the United States Senate would like to see the short-term requirements relaxed to take pressure off of food prices.

Finally, in April 2007 the Supreme Court ruled (Massachusetts v. EPA) that carbon dioxide and other heat-trapping emissions are “air pollutants” under the Clean Air Act, and that the United States Government has the authority to curb them. Various states have already proposed to limit CO2 emissions through fuel standards or cap and trade systems.

Europe. Europe’s 20/20/20 proposal for 20 per cent reduction in greenhouse gases, 20 per cent improvement in efficiency and 20 per cent generation of energy from renewables (10 per cent from renewables in the transport sector) by 2020 is also expected to spur demand for biofuels. On 17 December 2008 the European Parliament adopted the directive on the promotion of the use of energy from renewable sources, which includes the above-mentioned targets.

E. Concluding remarks

The establishment of a carbon dioxide (CO_2) price creates incentives for the development of a global biofuels market either directly through enticements to substitute biofuels for fossil fuel use in countries with greenhouse gas (GHG) policy or indirectly through the Clean Development Mechanism (CDM). Nevertheless, it is reasonable to assume that bioenergy production will increase even in the absence of climate policy.

However, efforts to promote biofuels amid concerns about climate change have led to the perception that the efficacy of biofuels as a low-carbon alternative to fossil fuels depends on how they are produced and how land-use emissions are managed. At high levels of biofuels demand, there would be no incentive to protect carbon in the soils and vegetation through a credit system. Landowners would instead tend to convert land to biofuels or more intense cropping. Therefore, the provision of carbon credits to biofuels producers would increase biofuels production even more. This disruption would lead to significant carbon dioxide release from soils and vegetation.

We believe that the inclusion of land-use change emissions in emission trading systems (such as the EU ETS cap and trade system) would create incentives to control both direct and indirect land-use emissions and enhance land sinks. No allowances would be required when biofuels are used; however, they would be necessary to cover fossil fuel emissions related to biofuels production and any direct or indirect carbon losses associated with land conversion. There has been reluctance or a lack of understanding of how to extend a cap and trade system to land-use emissions, but we argue that many of the concerns that analysts and policymakers have expressed are easily addressed.

Another important factor that could play a crucial role in improving the environmental performance of biofuels is the development of second-generation technologies, which will be the focus of analysis of the next chapter.

References

Babiker M et al. (2004). Is emissions trading always beneficial. *Energy Journal.* 25 (2): 33–56.

Ellerman AD and Joskow PL (2008). The European Union's Emissions Trading System in perspective. The Pew Center on Global Climate Change.

Ellerman AD et al. (2000). *Markets for Clean Air: The U.S. Acid Rain Program.* Cambridge, Cambridge University Press.

European Commission (2003). *Directive 2003/87/EC Establishing a Scheme for Greenhouse Emission Allowance Trading within the Community and Amending Council Directive 96/61/EC.* Brussels, European Commission.

European Commission (2005). *EU Emission Trading. An Open Scheme Promoting Global Innovation to Combat Climate Change.* Brussels, European Commission.

Felzer B et al. (2004). Effects of ozone on net primary production and carbon sequestration in the conterminous United States using a biogeochemistry model. *Tellus B.* 56 (3): 230–248.

Felzer B et al. (2005). Future effects of ozone on carbon sequestration and climate change policy using a global biogeochemical model. *Climatic Change.* 73 (3): 345–373.

Herzog H et al. (2003). An issue of permanence: assessing the effectiveness of ocean carbon sequestration. *Climatic Change.* 59: 293–310.

Lewandrowski J et al. (2004). Economics of sequestering carbon in the U.S. agricultural sector. *Economic Research Service Technical Bulletin.* TB1909 (March): 1–69.

Marland G et al. (2001). Soil carbon: policy and economics. *Climatic Change.* 51 (1): 101–117.

Matus K et al. (2008). Toward integrated assessment of environmental change: air pollution health effects in USA. *Climatic Change.* 88 (1): 59–92.

McCarl BA et al. (2005). *The Comparative Value of Biological Carbon Sequestration.* http://agecon2.tamu.edu/people/faculty/mccarl-bruce/papers/915.pdf.

Paltsev S et al. (2007). How (and why) do climate policy costs differ among countries? In: Schlesinger M et al., eds. *Human-Induced Climate Change: An Interdisciplinary Assessment.* Cambridge, Cambridge University Press: 282–293.

Reilly J and Asadoorian M (2007). Mitigation of greenhouse gas emissions from land use: creating incentives within greenhouse gas emissions trading systems. *Climatic Change.* 80 (1–2): 173–197.

Reilly J and Paltsev S (2006). European greenhouse gas emissions trading: a system in transition. In: De Miguel C et al., eds. *Economic Modeling of Climate Change and Energy Policies.* Cheltenham, Edward Elgar Publishing: 45–64.

Reilly J and Paltsev S (2007). Biomass energy and competition for land. Report 145. MIT Joint Programme on the Science and Policy of Global Change. Cambridge.

Sarmiento JL and Gruber N (2002). Sinks for anthropogenic carbon. *Physics Today.* 55 (8): 30–36.

Schlamadinger B and Marland G (1999). Net effect of forest harvest on CO_2 emissions to the atmosphere: a sensitivity analysis on the influence of time. *Tellus.* 51B: 314–325.

UNFCCC (1997). *The Kyoto Protocol*. Bonn, Climate Change Secretariat.

Zhuang Q et al. (2003). A process-based analysis of methane exchanges between Alaskan terrestrial ecosystems and the atmosphere. Report 104. MIT Joint Programme on the Science and Policy of Global Change. Cambridge.

III. Commercial viability of second generation biofuel technology[27]

The previous chapters focused on first generation biofuels. In this chapter we focus on second generation biofuels, specifically biofuels derived from cellulosic or lignocellulosic conversion. Advocates for the development of cellulosic conversion believe that second generation technology avoids many of the adverse consequences of first generation biofuels: it does not directly compete for food (since it is based on crops such as switchgrass or waste like maize stover), it causes less environmental impact than row crop agriculture, and the energy yield per hectare (ha) is generally higher (it has the potential to be five times higher than that of maize, since the entire plant can be converted to fuel).

Yet second generation biofuels are currently not competitive and expectations about future costs and energy output per unit of land vary. Taking those variations into account and using MIT's Emissions Prediction and Policy Analysis (EPPA) model, we estimate the potential role of biomass as an energy supplier until 2100. We construct four scenarios in which second generation biofuels could develop: with and without climate policy, and with and without trade restrictions on biofuels. We provide global results and specific results for the United States. Our aim is to provide insights into the following issues:

(a) What is the potential size of a cellulosic biofuels industry?

(b) What are the limitations of biofuels production in terms of land availability?

(c) How would the development of the industry affect land cover and food and land prices?

(d) If this technology matures, where and when will biomass production occur?

We estimate that second generation biomass has the potential to generate 30–40 EJ/year (exajoules per year) by 2050 and 180–260 EJ/year by 2100. As a comparison, global bioenergy[28] production in 2005 was less that 1 EJ and global oil consumption in 2005 was 190 EJ.

Under a scenario with climate policy in place, global prices for food, agriculture and forestry products would increase by 5 to 10 per cent. This relatively small price increase seems to suggest that it is possible to introduce a large cellulosic biofuels industry without dramatically disturbing agricultural markets.

If unrestricted bioenergy trade is allowed, we project that the main biofuels producers would be Africa, Latin America and the United States. Conversely, if trade restrictions are set up, China, Europe and India also become relevant producers. In this scenario, the level of global bioenergy production is lower by 3–6 EJ/year in 2050 and by 70–110 EJ/year in 2100 in comparison to the unrestricted trade scenario.

The chapter is organized as follows: the next section provides estimates of cost and yield energy output for second generation biofuels. Subsequently, we present four scenarios for bioenergy production, where the level of climate stabilization and the trade regime are taken into account. Finally, we discuss land-use implications and impacts on agricultural and land prices.

---

[27] This chapter was prepared by Sergey Paltsev, John Reilly and Angelo Gurgel, Joint Programme on the Science and Policy of Global Change, Massachusetts Institute of Technology, Cambridge, United States.

[28] We use the terms "bioenergy", "biomass energy" and "biofuels" interchangeably in this chapter. Unless specified otherwise, we measure them in terms of energy in liquid biofuels.

A. Cost and energy yield estimates

In order to understand the potential of second generation biofuels we provide an overview of their cost and energy output. We consider early estimates of global resource potential and economics (Edmonds and Reilly, 1985) and more recent reviews (Moreira, 2004), as well as the economics of liquid fuels (Hamelinck et al., 2005) and bioelectricity (International Energy Agency, 1997).

Hamelinck et al. (2005) estimate costs of €9–13/Gigajoule (GJ) for lignocellulosic conversion of ethanol, compared with €8–12/GJ and eventually €5–7/GJ for methanol production from biomass. Before tax, costs of gasoline production are €4–6/GJ. The IMF (2007) reports that the current cost of ethanol from cellulosic waste is $0.71 per litre, which is 2.1 times higher than the cost for gasoline production.[29] The International Energy Agency (IEA, 2006) estimates that lignocellulosic production costs for ethanol could fall to $0.40 per litre of gasoline equivalent, and for biodiesel to $0.70–$0.80 per litre using the Fischer-Tropsch synthesis.[30]

Regarding energy yield estimates, different biomass sources must be considered. Vegetable oil crops have a relatively low energy yield (40–80 GJ/ha/year) compared with crops containing cellulose or starch/sugar (200–300 GJ/ha/year). According to the Intergovernmental Panel on Climate Change (IPCC, 2001), high yielding short rotation forest crops or C4 plants (e.g., sugar cane or sorghum) can give stored energy equivalent of over 400 GJ/ha/year.

Woody crops are another alternative. The IPCC (2001) reports a commercial plot in Sweden with a yield of 4.2 oven-dry tons[31] (odt)/ha/year, and anticipates that with better technologies, management and experience, the yield can be up to 10 odt/ha/year. Using a higher heating value (20 GJ/odt)[32] similar to that used by Smeets and Faaij (2007) in their study of bioenergy potential from forestry, we estimate a potential of 84–200 GJ/ha/year yield for woody biomass.

Hybrid poplar, willow and bamboo are some of the quick growing trees and grasses that may serve as fuel source for a biomass power plant. They contain high amounts of lignin, a glue-like binder that is largely composed of cellulose. These so-called "lignocellulose" biomass sources can potentially be converted into ethanol via fermentation or into a liquid fuel via a high temperature process.

Table 3.1 provides a summary of recent estimates of energy output per unit of land, of energy content of dry biomass and conversion efficiency of dry biomass into liquid fuels. Current energy output per unit of land varies from 6.5 oven-dry ton/hectare (odt/ha) for corn to 30 odt/ha for sugar cane. The most optimistic estimates about the future potential energy output per hectare of land double the amount to around 60 odt/ha for sugar cane. Expected efficiency of converting biomass into liquid fuels also varies, with most estimates ranging around 30–45 per cent.

Table 3.1 also reports the corresponding numbers for 2020, 2050 and 2100 for second generation biomass, following the analysis from MIT's Emissions Prediction and Policy Analysis

[29] Different studies report costs in different units. An important metric is cost of biofuels production relative to gasoline production.
[30] The Fischer-Tropsch synthesis is a catalyzed chemical reaction in which synthesis gas (syngas), a mixture of carbon monoxide and hydrogen, is converted into liquid hydrocarbons of various forms.
[31] One oven-dry ton (odt) is the amount of wood that weighs one ton at 0 per cent moisture content.
[32] Higher heating value (HHV) of a fuel is defined as the amount of heat released by a specified quantity (initially at 25° C) once it is combusted and the products have returned to a temperature of 25° C.

(EPPA) model. The EPPA model is less optimistic than the maximum potential numbers as it represents an average for land of different quality in different regions.[33]

Table 3.1. Estimates of the potential for energy from biomass

Biomass source	Odt/ha	GJ/odt	Dry biomass energy yield (GJ/ha)	Conversion efficiency	Liquid biomass energy yield (GJ/ha)
Grain corn[(a)]	6.5	21	136.5	16%	21.8
Grain corn *(future)*	6.5[(a)]	21	136.5	45%[(b)]	61.4
Sugar cane[(c)]	30	21.5	650	40%	260
Sugar cane *(future)*	63	21.5	1350[(c)]	45%[(d)]	607.5
Eucalyptus[(c)]	23	20	450	43%[(f)]	193.5
Eucalyptus *(future)*	50	20	1000[(c)]	68%[(g)]	680
Poplar	20[(h)]	20	400	51%[(e)]	204
Switch-grass fuel pellets[(a)]	10	18.5	185	88%	162.8
Switch-grass			430[(c)]	51%[(e)]	219.3
EPPA Model estimates (2020)[(i)]	6 – 16	20	120 – 320	40%	48 – 128
EPPA Model estimates (2050)[(i)]	11 – 18	20	210 – 360	40%	84 – 144
EPPA Model estimates (2100)[(i)]	18 – 30	20	358 – 600	40%	144 – 240

[(a)] Samson et al. (2000). [(b)] Novem/ADL (1999), cited by Fulton and Howes (2004). [(c)] Moreira (2006).[(d)] Assumption based on Moreira (2006) considering all solid biomass primary energy will be converted into final energy through cogeneration plants and 40 per cent of the sugar cane residues are left in the field to protect the soil. [(e)] Assumption based on Novem/ADL (1999), cited by Fulton and Howes (2004) for ethanol production from poplar through enzymatic hydrolysis. [(f)] Assumption based on Novem/ADL (1999), cited by Fulton and Howes (2004) for diesel production from gasification / Fischer-Tropsch. [(g)] Assumption based on Novem/ADL (1999), cited by Fulton and Howes (2004) for diesel production from hydrothermal upgrading (HTU) biocrude. [(h)] Luger (2007). [(i)] Values are region-specific.

Despite all the advantages of second generation biofuels with respect to the current technology, some of the shortcomings of the latter remain valid even for second generation biofuels. Box 4.1 below summarizes this point.

B. Land area and potential for energy from biomass

Land needed to grow energy crops competes with land used for food and wood production. For example, Smeets and Faaij (2007) estimate a global theoretical potential of biomass from forestry in 2050 at 112 EJ/year. This number is reduced to 71 EJ/year after considering demand for wood production for other uses. And the number is further decreased to 15 EJ/year when economic considerations, such as profitability, are taken into account.

In a study about biodiesel use in Europe, Frondel and Peters (2007) found that 11.2 million hectares (Mha) of land would be required to meet the EU target for biofuels (5.75 per cent of transport fuels from renewable sources by 2010). This represents 13.6 per cent of total arable land in the EU-25. Similarly, an IEA (2004) study estimates that replacing 10 per cent of fossil fuels by bioenergy in 2020 would require 38 per cent of the total acreage in the EU-15. These analyses, while providing useful benchmarks, take market conditions as given and do not consider future changes in prices and markets. These will depend, for example, on the existence of greenhouse gas mitigation policies that could create additional incentives for biofuels production, as discussed in chapters I and II.

Table 3.2 provides estimates of the global potential for energy from biomass based on the world land area.[34] IPCC (2001) estimates an average energy yield of 300 GJ/ha/year from biomass by 2050. The area not suitable for cultivation is about half of the total Earth land area of

[33] Second generation biomass technology in the EPPA model is not crop-specific as it can use sugar cane, switchgrass, corn stover, willow, bamboo, etc. as a source. For more information on the model and cost estimates used, see Reilly and Paltsev (2007) and Gurgel et al. (2007).
[34] This table refers to productivity of second generation biomass, but sugar cane presents similar productivity.

15.12 Gha and includes tropical savannas, deserts and semi-deserts, tundra and wetlands. Converting area in hectares into energy yield, we estimate the global potential for biomass at around 2100 EJ/year. This estimate could increase/decrease if different land types are included/excluded from the calculation. Assuming a conversion efficiency of 40 per cent from biomass to the final liquid energy product, we estimate a potential of 840 EJ/year of liquid energy product from biomass.

Table 3.2. World land area and potential for energy from biomass

	Area (Gha)	*max dry bioenergy (EJ)*	*max liquid bioenergy (EJ)*
Tropical Forests	1.76	528	211
Temperate Forests	1.04	312	125
Boreal forests	1.37	411	164
Tropical Savannas	2.25	0	0
Temperate grassland	1.25	375	150
Deserts and Semideserts	4.55	0	0
Tundra	0.95	0	0
Wetlands	0.35	0	0
Croplands	1.6	480	192
Total	**15.12**	**2106**	**842**

Source: area (IPCC, 2000); assumptions about area to energy conversion: 15 odt/ha/year and 20 GJ/odt (IPCC, 2001); assumption for conversion efficiency from biomass to liquid energy product: 40 per cent.

Table 3.3 presents similar calculations for the United States, where potential for dry bioenergy is 200 EJ/year and for liquid fuel from biomass is 80 EJ/year. Note that these are maximum potential estimates that assume that all land that currently is used for food, livestock and wood production would be used for biomass production.

Table 3.3. United States land area and potential for energy from biomass

	Area (Gha)	*max dry bioenergy (EJ)*	*max liquid bioenergy (EJ)*
Cropland	0.177	53	21.2
Grassland	0.235	70.4	28.2
Forest	0.26	78.1	31.2
Parks, etc	0.119	0	0
Urban	0.024	0	0
Deserts, Wetland, etc	0.091	0	0
Total	**0.906**	**201.6**	**80.6**

Source: area (United States Department of Agriculture, 2006); assumptions about area to energy conversion: 15 odt/ha/year and 20 GJ/odt (IPCC, 2001); assumption for conversion efficiency from biomass to liquid energy product: 40 per cent.

A recent study by the United States Government (CCSP, 2007) estimates an increase in the global energy use from 400 EJ/year in 2000 to 700–1000 EJ/year in 2050 and to 1275–1500 EJ/year in 2100. The corresponding numbers for the United States are 100 EJ/year in 2000, 120–170 EJ/year in 2050 and 110–220 EJ/year in 2100. These numbers indicate that energy from biomass alone will not be able to satisfy global needs even if all land is used for biomass production, unless a major breakthrough in technology occurs.

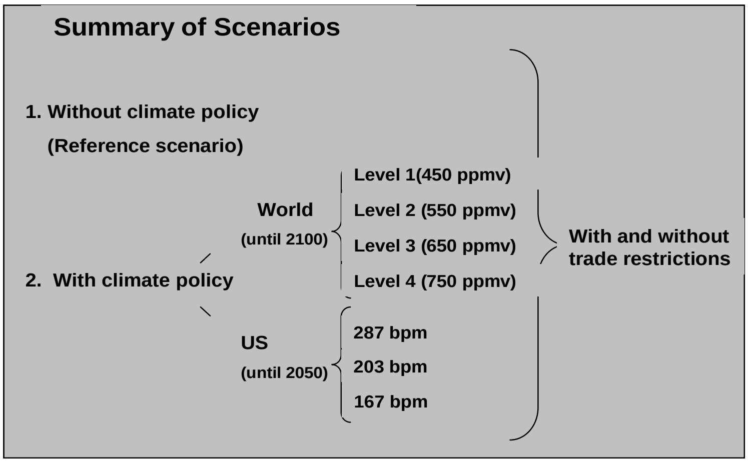
Indeed, a recent cost/benefit study (Hill et al., 2006) found that even if all American production of maize and soybean were dedicated to biofuels production, this supply would meet only 12 per cent and 6 per cent of the United States' demand for gasoline and diesel, respectively.

Another study shows that the climate benefit of biofuels (using current production techniques) is limited because of the fossil fuel used in the production of the crop and processing of biomass (Brinkman et al., 2006). However, advanced synfuel hydrocarbons or cellulosic ethanol produced from biomass could provide greater supplies of fuel and environmental benefits compared to current technologies. In this chapter we consider a second generation biofuel with production costs based on a "cellulosic" or "lingocellulosic" conversion. Examples are grasses and fast-growing trees, which are widespread and abundant.[35]

To illustrate the potential role of biomass as an energy supplier, we draw on recent applications of the Emissions Prediction and Policy Analysis (EPPA) model developed by the Massachusetts Institute of Technology's Joint Programme on the Science and Policy of Global Change (Paltsev et al., 2005).

The first of these applications involves scenarios of atmospheric stabilization of greenhouse gases. The second study involves investigation of GHG mitigation policies in the United States that have been proposed in recent Congressional legislation (for an assessment of the Congressional proposals, see Paltsev et al., 2007) and additional assumptions about developed countries' reduction of greenhouse gases, by 2050, from present levels to 50 per cent below 1990 levels. These applications allow us to focus both on the global bioenergy potential and on specific issues related to the United States.

We present below different scenarios: a reference scenario that assumes no climate policy and a scenario with a climate policy. It is expected that, in the latter case, biofuels production will develop earlier and faster. Under each of these two scenarios, two other options are presented, one based on restricted trade in biofuels and the other on unrestricted trade.



C. Scenarios for climate policy

1. Reference scenario: no climate policy

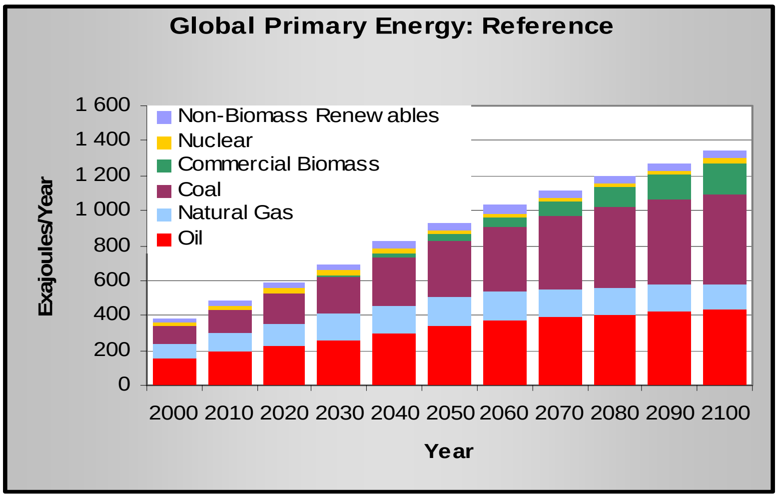
The reference scenario is one in which no climate policy is introduced. It allows us to compare the economic costs and performance of the biomass industry when a climate policy is in place, as opposed to a situation without climate policy. Obviously, the world is already

[35] Some analysts also consider that genetically modified micro-organisms could be an efficient way to produce biofuels. While this is an important topic for future research, we do not attempt to include in our current analysis considerations on possible consumer reaction against genetically modified products and trade restrictions that may affect the expansion of the biofuels industry.

committed to climate-related actions through instruments such as the Kyoto Protocol or the EU Emissions Trading Scheme, as discussed in chapter II. However, we expect those commitments to have broader coverage in terms of participating countries and the degree of emissions reduction.

Figure 3.1 shows the composition of global primary energy in the reference scenario as developed for the recent United States Climate Change Science Programme study (CCSP, 2007). The reference scenario exhibits a growing production of biofuels from the year 2020 on. Deployment is driven primarily by a 2100 world oil price that is over 4.5 times the price in 2000. Dwindling supplies of high grade crude oil drive up the oil price to make cellulosic ethanol competitive.

Figure 3.1. Global primary energy consumption in the reference scenario



Source: CCSP (2007).

By 2040, the total global biofuels production (in terms of liquid fuel output) reaches 30 EJ/year, which is a drastic increase compared with the 2005 output of 0.8 EJ/year. By 2100 bioenergy production reaches 180 EJ/year,[36] which is approximately the same amount of energy related to global oil consumption in 2000. Even with these substantial increases in bioenergy production, it would still account for only 5 per cent of global primary energy use in 2040 and 15 per cent in 2100. This result is mainly driven by the absence of climate policies that encourage or mandate the use of renewable fuel sources.

2. Scenario with climate policy: atmospheric stabilization of greenhouse gases

We illustrate how bioenergy technologies perform when climate-related constraints are introduced by using four stabilization scenarios employed in the CCSP study (CCSP, 2007). The stabilization levels are defined in terms of the total long-term effect of GHGs on the Earth's heat balance. The stabilization scenarios are defined in terms of associated CO_2 concentrations; nevertheless, the study formulates the targets as radiative forcing levels that allow for the increase in other greenhouse gases as well. Box 3.1 below discusses the measurement of atmospheric stabilization and defines radiative forcing.

[36] A recent study with the EPPA model (Gurgel et al., 2007) tests the sensitivity of biomass production estimates with respect to different land supply representations. An explicit representation of land conversion costs slows the initial penetration of bioenergy but increases the amount of biofuels production by 2100 in the range of 220–270 EJ/year in the reference scenario, with a strong growth in biofuels production starting in 2040.

Box 3.1. Defining atmospheric stabilization

The multigas suite of substances with different radiative potency and different lifetimes in the atmosphere presents a challenge to defining what is meant by atmospheric "stabilization". Specification in terms of quantities of the gases themselves is problematic because there is no simple way to add them in their natural units such as tons or parts per million by volume. One alternative would be to define stabilization in terms of an ultimate climate measure, such as the change in global average temperature. Unfortunately, a measure of actual climate change would necessarily introduce uncertainties into the analysis given that the climate system response to added GHGs is uncertain. Complex and uncertain interactions and feedbacks include increasing levels of water vapour, changes in reflective Arctic ice, cloud effects of aerosols and changes in ocean circulation that determine the ocean's uptake of CO_2 and heat. Given these problems, scientists have instead used an intermediate, less uncertain measure of climate effect: the direct heat trapping (or light reflecting, in the case of cooling aerosols) impact of a change in the concentration of such substances. It is constructed to represent the change in the net energy balance of the Earth and the sun ("energy in" versus "energy out") where the units are watts per square meter of the Earth's shell (W/m^2). A positive value means a warming influence and is referred to as radiative "forcing".

Specifically, these radiative forcing levels were chosen so that the associated CO_2 concentrations (measured in ppvm – parts per million by volume) would be roughly 450 ppmv (level 1), 550 ppmv (level 2), 650 ppmv (level 3) and 750 ppmv (level 4). Obviously, the CO_2-equivalent (CO_2-e) concentration considering radiative forcing from other greenhouse gases is higher than the CO_2 concentration itself.[37]

The four stabilization scenarios were developed so that the increased radiative forcing from greenhouse gases was constrained to no more than 3.4 W/m^2 for level 1, 4.7 W/m^2 for level 2, 5.8 W/m^2 for level 3 and 6.7 W/m^2 for level 4 (see box 3.1 for the definition of this measure). These levels are defined as increases above the pre-industrial level, i.e., they include the 2.2 W/m^2 increase that has already occurred as of the year 2000.

To meet these radiating forcing levels, an idealized worldwide cap and trade system is set to begin in 2015. The price path of the emissions constraint over the whole period (2015–2100) is implemented to rise at a 4 per cent rate to simulate cost-effective allocation of abatement over time. Thus, banking and borrowing of allowances over time is allowed.

The numbers for biomass represent only the production of biomass energy from the advanced technologies represented in the EPPA model and do not include, for example, the own-use of wood wastes for energy in the forest products industry. Those are implicit in the underlying data to the extent that the forest industry uses its own waste for energy (thus it purchases less commercial energy). Similarly, to the extent that traditional biomass energy is a substantial source of energy in developing countries, it implies less purchase of commercial energy.[38]

Figure 3.2 presents global "advanced" biomass production across the four stabilization scenarios and in the reference one. Tighter emissions constraints (represented by level 1) lead to an earlier increase in bioenergy production. Global biomass production reaches nearly 250 EJ/year in the climate policies scenarios, against 180 EJ/year in the reference scenario (in the year 2100).

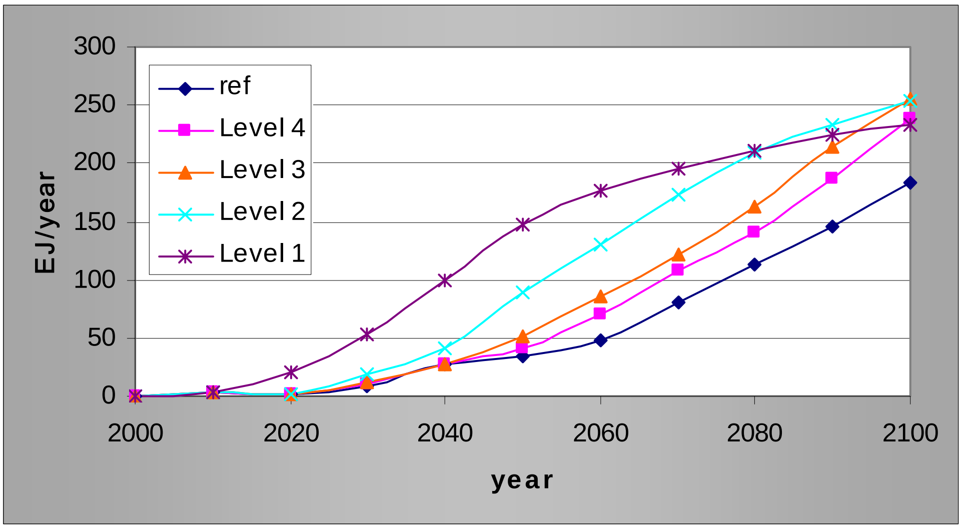
The maximum potential of bioenergy is not very different in the stabilization scenarios by 2100 due to limited land availability. The types of land are not modelled explicitly in the version

[37] A correspondence between CO_2 and CO_2-equivalent targets for these scenarios is provided in Paltsev et al. (2007).

[38] Developing countries are likely to transition away from this non-commercial biomass use as they become richer and this is likely one reason why we do not observe the rates of energy intensity of GDP improvements in developing countries that we observe in developed countries. EPPA accommodates this transition by including lower rates of Autonomous Energy Efficiency Improvement in poorer countries, thus capturing the tendency this would have to increase commercial fuel use without explicitly accounting for non-traditional biomass use.

of the EPPA model used for the CCSP exercise, but, as discussed before, it is possible to estimate the amount of physical land that would be required. Estimates for the world are provided in table 3.4 and in table 3.5 for the United States: the land area requirement is substantial even with the assumed significant improvement in land productivity. Globally, land area required for bioenergy production in 2100 is over 700 Mha (million hectares) in the reference case, and approximately 1,000 Mha in the stabilization scenarios.

Figure 3.2. Global biomass production across CCSP scenarios



Source: Reilly and Paltsev (2007).

For the United States, estimated land use for bioenergy reaches about 150 to 190 Mha in 2100, across all scenarios. This level of land use is close to the 177 Mha of current cropland (from table 3.5). Similarly, at the global level, the requirement of 1,000 Mha is close to the total current cultivated land reported by IPCC (2001) at 897 Mha.[39] Improved land productivity leads to reduction in land required for biofuels after 2050.

Table 3.4. Global land area (Mha) required for biomass production in CCSP scenarios

	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Ref	46	27	88	261	281	346	496	601	672	728
Level 4	46	27	115	267	341	501	663	752	857	942
Level 3	46	29	134	271	422	619	753	868	987	1011
Level 2	46	30	209	391	739	933	1070	1117	1071	1002
Level 1	46	268	589	958	1229	1264	1208	1122	1032	921

Table 3.5. United States land area (Mha) required for biomass production in CCSP scenarios

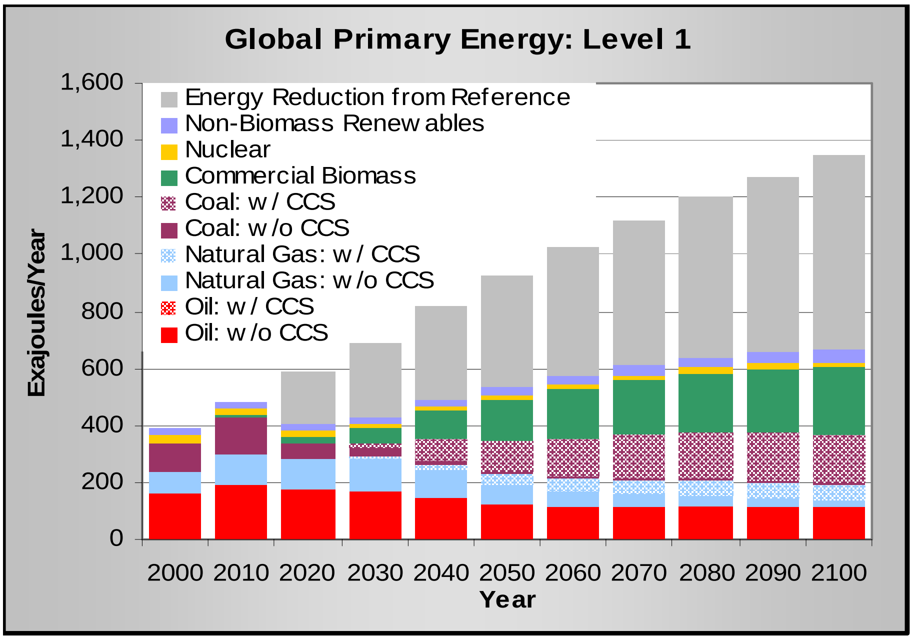
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Ref	11	5	16	48	50	61	91	114	131	147
Level 4	11	5	21	49	63	96	132	155	175	158
Level 3	11	5	25	51	82	128	166	191	179	170
Level 2	11	6	41	79	175	238	237	200	198	187
Level 1	11	56	144	253	272	261	251	226	202	174

[39] IPCC (2001) reports 0.897 Gha for global cultivated land in 1990 and 2.495 Gha for total land with crop production potential.

Figures 3.3 and 3.4 show the composition of global primary energy for the level 1 and level 3 scenarios, respectively.[40] Across the stabilization scenarios, the energy system relies more heavily on non-fossil energy sources and biomass energy plays a major role. Total energy consumption, while still higher than current levels, is lower in the stabilization scenarios than in the reference scenarios.

In the stabilization scenarios, there is a variety of low-carbon and carbon-free generation technologies that outperform bioelectricity.[41] An important reason for this is that the demand for liquid biofuels from biomass (which we loosely refer to as bio-oil) is high since there are no other good low-carbon substitutes for petroleum products used in the transportation sector. As a result, this demand drives up the land price and raises the cost of bioelectricity. We expect increasing utilization of carbon capture and storage technologies (CCS) associated with natural gas and coal, especially after 2040.[42]

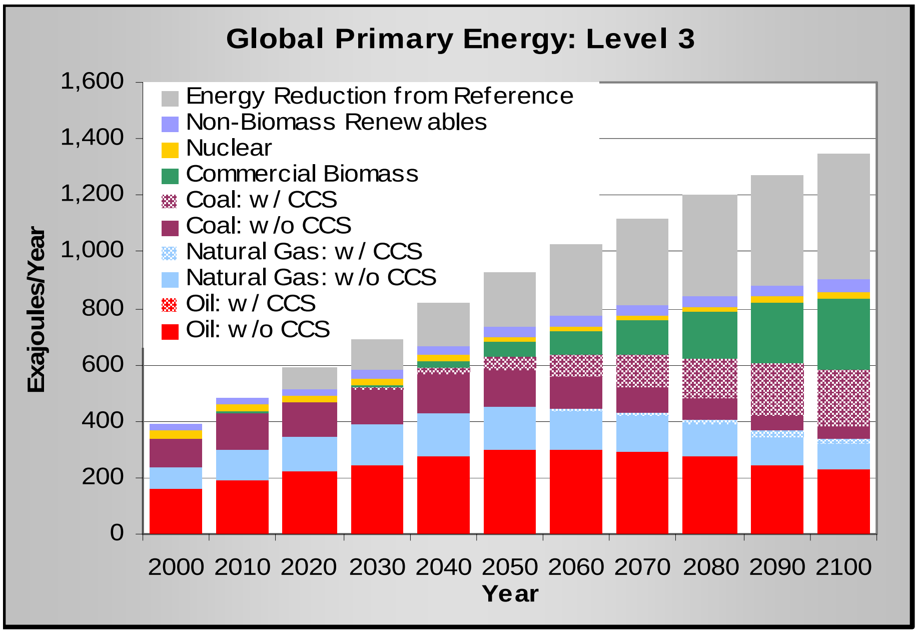
Figure 3.3. Global primary energy in the level 1 scenario (with and without carbon capture and storage technologies, or CCS)



Source: CCSP (2007).

[40] The level 1 scenario is the 450 ppmv scenario, which is often used in climate policy discussions. The level 3 scenario is provided for a comparison here. See CCSP (2007) for the corresponding numbers for the other scenarios.
[41] Bioelectricity is bagasse and biomass used in co-firing in coal electric plants. Coal continues to be an inexpensive source of energy for power generation in the reference case and therefore bioelectricity is not a competitive source of energy.
[42] CCS is used mostly for electricity. Oil is not widely used in electricity production, so researchers mostly envision CCS on coal (as coal is cheap) and gas. Biofuels with CCS is another possibility, but so far there are no reliable estimates on this technology. We have not considered biomass with CCS in the current analysis.

Figure 3.4. Global primary energy in the level 3 scenario (with and without CCS technologies)



Source: CCSP (2007).

We now turn to the role of bioenergy under mitigation scenarios in the United States. We refer to Congressional GHG scenarios based on the level of GHG emissions allowed in the atmosphere between 2012 and 2050 and the implications of a restricted or unrestricted trade framework.

D. Bioenergy under a GHG mitigation scenario in the United States, with and without trade restrictions

Interest in GHG mitigation legislation in the United States Congress has grown substantially and by the end of 2007 there were several proposals to establish a nationwide cap and trade system.[43] Some of the proposed bills envision emissions reductions of 80 per cent below the 1990 level by 2050. Such a steep reduction would entail significant cuts of CO_2 emissions from transportation, which currently account for 33 per cent of American CO_2 emissions related to fossil fuel combustion (Energy Information Administration (EIA), 2006).

The initial allowance level is set to the estimated GHG emissions in the United States in 2008. We distinguish three scenarios for the path followed by annual allowance allocations until 2050:

(a) 2008 emissions levels;

(b) 50 per cent below 1990; and

(c) 80 per cent below 1990.

Over the 2012–2050 period, the cumulative allowance allocations under these three scenarios are 287, 203 and 167 billion metric tons (bmt), or gigatons, of carbon dioxide equivalent (CO_2-e) emissions. The GHG scenarios are designated with the shorthand labels 287

[43] A more complete discussion and analysis of current Congressional proposals is provided in Paltsev et al. (2007).

bmt, 203 bmt and 167 bmt. The last is thus the most stringent scenario for the United States' climate policy.

The banking of GHG allowances (for use in later periods) in the United States is allowed by meeting the target with a CO_2-e price path that rises at a rate of interest assumed to be 4 per cent.[44] Other developed countries are assumed to pursue a policy whereby their emissions also fall to 50 per cent below 1990 levels by 2050. Moreover, all other regions are assumed to return to the projected 2015 level of emissions in 2025, holding at that level until 2035, when the emissions cap drops to the year 2000 level of GHG emissions.

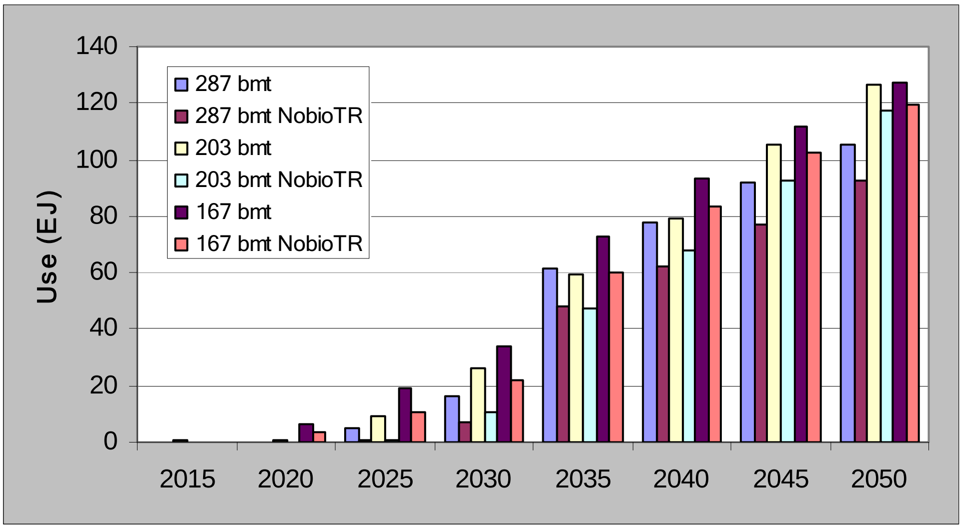
The economywide trading among greenhouse gases at their Global Warming Potential (GWP)[45] value is simulated. All prices are thus CO_2-e. The carbon dioxide prices required to meet these policy targets in the initial projection year (2015) are \$18/t, \$41/t and \$53/t CO_2-e for the 287, 203 and 167 bmt cases, respectively.

These three scenarios are evaluated under two different assumptions: with and without restrictions in biofuels trade. Under free trade, significant amounts of biofuel are used in the United States and nearly all of it is imported. Under trade restriction (denoted here by the extension NobioTR), all biofuels used in the United States (and in other regions of the world) must be produced domestically. Figure 3.5 presents an estimate of global liquid biofuels use in the three scenarios and including the two sets of trade scenarios.

Biofuels use in the United States is substantial in the 203 bmt and 167 bmt cases, rising to 30–35 EJ in 2050 (figure 3.5, panel b). The 287 bmt case results in limited biofuels consumption (less than 1 EJ/year). Global liquid biofuels use is substantial in all three cases, reaching 100–120 EJ in 2050, since the rest of the world is pursuing aggressive GHG policies.

Figure 3.5. Liquid biofuels use, with and without international trade in biofuels

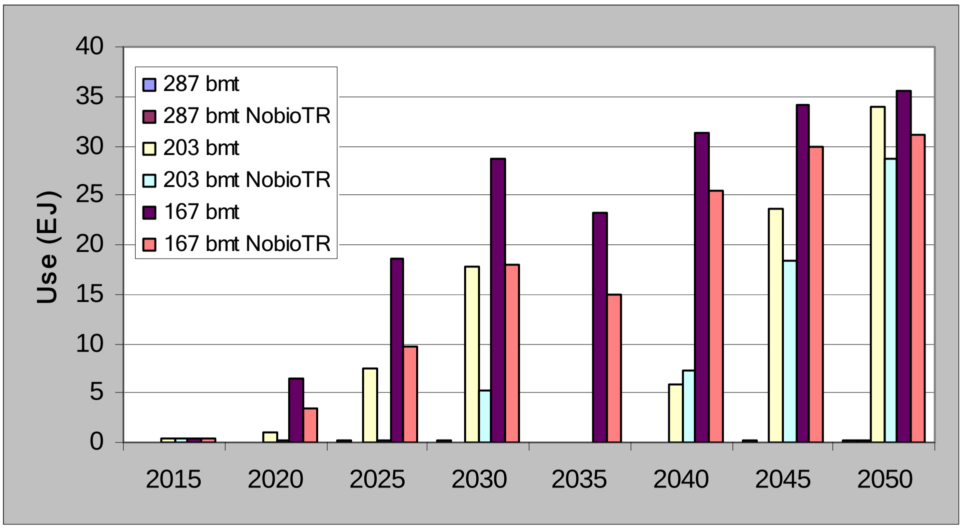
a. World total



[44] This refers to banking and borrowing of emission allowances over time. For example, an entity can buy an allowance and use it only after 10 years.

[45] The Global Warming Potential (GWP) of a greenhouse gas is a measure of the contribution of a particular gas to global warming over a specific time interval (relative to carbon dioxide). Commonly, a time interval of 100 years is used.

b. United States



Source: The EPPA model (Paltsev et al., 2007).

When biofuels trade is restricted, we project lower biofuels use in the United States and in the total for the world (figure 3.5, panels a and b). However, biofuels use and hence production in the United States remain substantial, falling in the 25–30 EJ range rather than 30–35 EJ by 2050. Biofuels would substantially displace petroleum products, accounting for nearly 55 per cent of all liquid fuels in the United States.

When biofuels trade is restricted, we project lower biofuels use in the United States and in the total for the world.

As discussed above, the amount of land required for biofuels production in these scenarios can be calculated. Estimates for the United States are reported in table 3.6. In the policy scenarios the land required in 2050 approaches or exceeds that in the CCSP scenarios in 2100. The reason is that these policy scenarios for the United States require a much more rapid reduction in greenhouse gas emissions, particularly in developed countries with large transportation fuel demand. Thus, the demand for carbon-free fuel rises faster. The slower growth in the CCSP scenarios after 2050 takes advantage of further land productivity improvements.

Table 3.6. United States land area (Mha) required for biomass production considering Congressional analysis scenarios

	2015	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*	*2050*
287 bmt	0	0	0	0	0	0	0	0
287 bmt NobioTR	0	0	0	0	0	0	0	1
203 bmt	0	0	0	0	0	0	0	4
203 bmt NobioTR	5	3	2	60	1	71	165	239
167 bmt	0	0	0	0	0	0	0	6
167 bmt NobioTR	5	44	116	202	155	246	268	260

1. Implications for the agricultural sector in the United States

Figure 3.6 illustrates an important implication of biofuels production for the broader agricultural sector, focusing on the 167 bmt case (the strictest one in terms of allowed CO_2 emissions). The United States is currently a substantial net agricultural exporter, and under the EPPA reference scenario (without GHG policy) this is projected to continue. In the 167 bmt case, American net agricultural exports are projected to double in comparison with the reference case.

As other regions expand ethanol production, they import more agricultural goods and thus the United States' net exports grow.[46]

However, in the 167 bmt Nobio TR case (i.e., with trade restrictions on biofuels) the implications for net biofuels flows are quite different. Forcing biofuels to be produced domestically under a stringent climate policy translates into a significant reduction in American agricultural production. Instead of being a net exporter of agricultural commodities, the United States becomes a large net importer. Whereas net exports today are in the order of $20 billion, by 2050 in the 167 bmt NobioTR case, the United States becomes a net importer of nearly $80 billion in agricultural commodities.

It is worth mentioning that the agricultural sector in the EPPA model is highly aggregated. As a result, the absolute value of net exports in the reference scenario is just a rough estimate; it could be higher or lower depending on how agricultural productivity advances in the United States relative to other regions of the world.

Therefore, if approximately 25 EJ of ethanol must be produced in the United States (requiring around 500 million acres, or 200 Mha, of land), it is almost inevitable that this would transform the United States into a substantial agricultural importer.

Figure 3.6. Net agricultural exports in the 167 bmt case, with and without biofuels trading

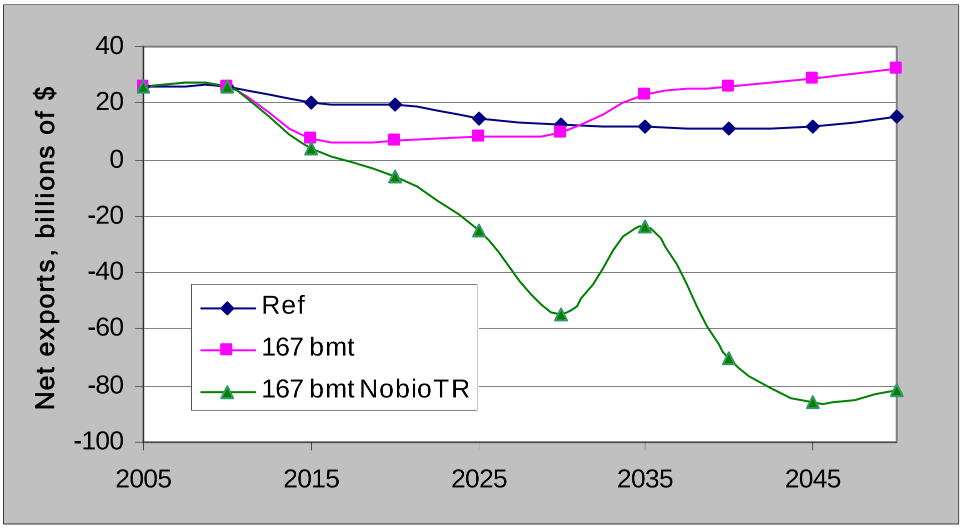


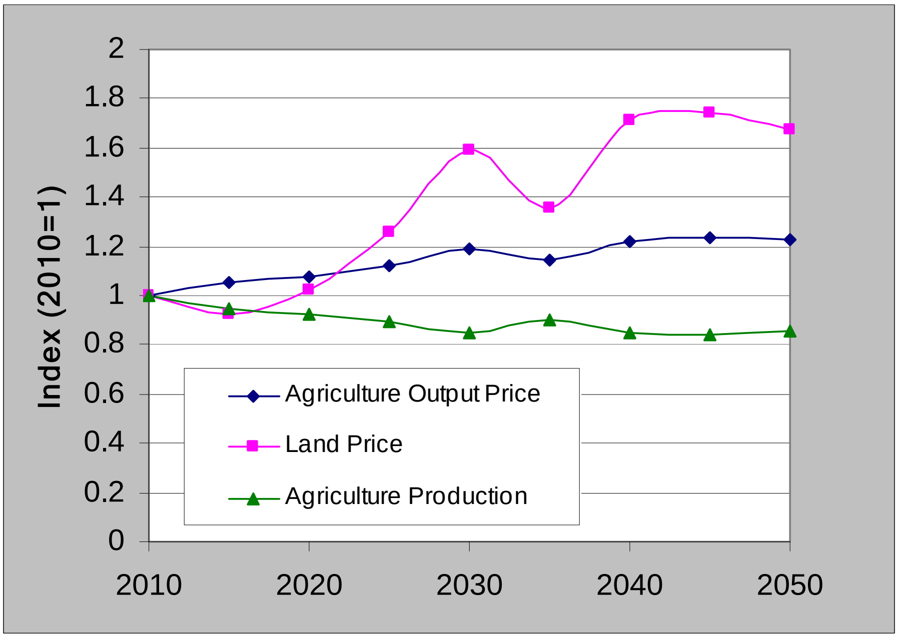
Figure 3.7 shows an index of the land and agricultural commodity prices and agricultural production in the United States in the 167 bmt NobioTR case, relative to the reference scenario. Agricultural land prices fall in 2015 relative to the reference case, while agricultural product prices rise. This reflects greenhouse gas mitigation costs in agriculture that slightly depress land prices and agricultural production while leading to overall higher production costs and agricultural prices.

Agriculture uses a significant amount of energy that emits CO_2, and is also a significant source of N2O and CH_4. The CO_2-e price in 2015 in the 167 bmt NobioTR case is $67, and this added cost is reflected in a combination of lower land prices and higher commodity prices determined by underlying demand and supply elasticities.[47]

[46] As a result from the model, tropical countries would specialize in biofuels production and import agricultural goods from other countries, including the United States.
[47] The values for elasticities are provided in Reilly and Paltsev (2007).

Once biofuels production increases, land prices recover relative to the reference case, agricultural commodity prices rise further and agricultural production falls. The large shock in 2035 reflects the significant tightening of the carbon constraint in developing countries in that year. The United States reduces biofuels production and imports petroleum. As a result, land prices decrease temporarily but remain above the reference.

Figure 3.7. Indexes of agriculture output price, land price and agriculture production in the United States in the no biofuels trading (167 bmtnb) scenario relative to the reference (2010=1.00)



E. Where will biomass production occur?

In order to estimate regional biofuels production and how biofuels policies and the trade regime affect world production, we make some changes to the above assumptions. First, to consider similar reductions in developed countries, we focus on the 203 bmt scenario discussed above.[48] Second, the scenario is extended to 2100 in order to limit global cumulative GHG emissions to 1,490 billion metric tons (bmt) from 2012 to 2050 and 2,834 bmt from 2012 to 2100.

These numbers are equivalent to 60 per cent of the emissions in the reference scenario (no climate policy) in the 2012–2050 period, and 40 per cent over the full period. The cumulative level of GHG emissions is consistent with the 550 ppmv CO_2 stabilization goal discussed before (level 2). The policy is implemented as a cap and trade system in each region. This system limits the amount of fossil fuels that can be used and thus provides an economic incentive for biofuels production and other low-carbon energy sources.

Table 3.7 presents the bioenergy production in selected world regions, with other regions aggregated.[49] Africa and Latin America are the two most important producing regions. In both regions land availability is crucial to achieving high production levels. The greater land productivity in biomass crops allows Latin America to supply between 45 per cent and 60 per cent of world production for most of the model horizon. Africa would supply about 30 per cent.

[48] For a global analysis we focus on the 203 bmt scenario as it corresponds to a 50 per cent reduction relative to 1990, which is similar to the latest Group of Eight (G8) proposal of a 50 per cent reduction by 2050.

[49] These results are from the EPPA model with observed land supply response. For more information about modelling land transformation, see Gurgel et al. (2007).

The United States is the third largest world producer, supplying between 33 and 36 EJ (10 per cent of total production) of biomass in 2100 in the policy case. Australia, Mexico and New Zealand are also able to produce large amounts of biomass. The contribution to biomass production from others is very small (approximately 1 per cent of world production). This reflects the presence of large areas of natural forest and pasture in those countries and regions and the fact that biomass is more productive in tropical areas. China and India are exceptions to this pattern. Growth of food demand and modelling of trade in biofuels and agricultural goods are key aspects of the model that drive this result. Both China and India have increasing demand for food and relatively lower biomass land productivity than other regions and therefore priority is given to land use for agricultural production.

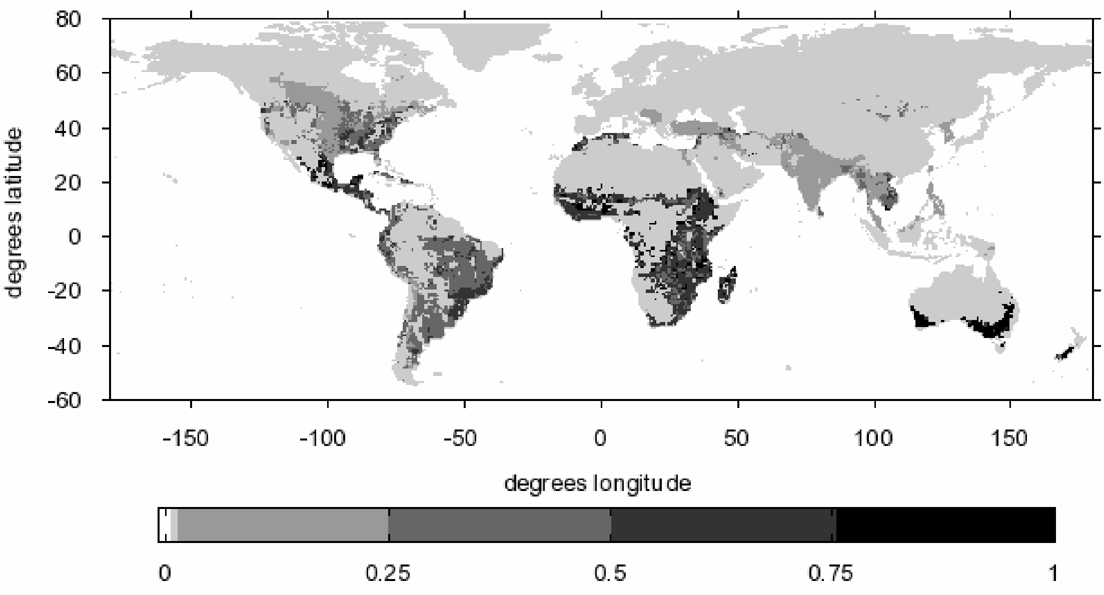
Table 3.7. Regional second generation biomass production in the policy case (EJ/year)

	USA	*Mexico*	*Australia and New Zealand*	*Latin America*	*Africa*	*Other regions*	*Global*
2010	0	0	0	0	0	0	0
2020	0	0	0	0	2	0	2
2030	1	0	1	4	19	0	25
2040	4	2	2	26	30	5	69
2050	13	4	4	54	41	6	122
2060	17	4	6	71	48	6	152
2070	20	5	8	87	58	7	185
2080	24	6	11	107	71	10	229
2090	28	7	13	127	85	13	273
2100	33	8	16	147	98	18	320

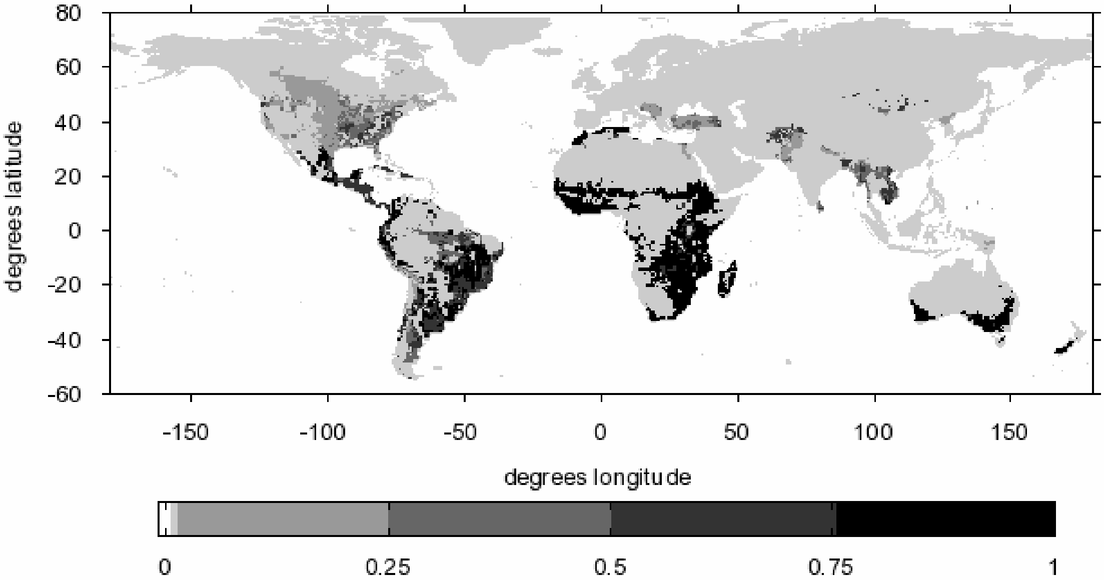
Figure 3.8 presents the share of land devoted to biomass production in a policy scenario in 2050 and 2100 (assuming that second generation biomass is not yet economic in 2010). The red colour represents regions with 80–100 per cent shares (Africa, Australia, Latin America, New Zealand and the United States).

Figure 3.8. Share of land devoted to biomass production in a policy case – OLSR model

Panel a. 2050



Panel b. 2100



An important factor driving these results is the assumption of unrestricted trade in biofuels. Free trade leads to the specialization of production in Africa and Latin America, where land is cheaper. This low cost results from a combination of low land prices and high biomass productivity per hectare. This implies that regional production of biofuels is insensitive to the location of demand: global demand is supplied by those regions with the lowest cost of production. Only an increase in land prices (caused by a rise in biofuels production) in a low-cost region could lead to increased biofuels production elsewhere. The amount of bioenergy exports would be about 80 EJ/year by 2050 and 200 EJ/year by 2100.

However, if trade barriers are in place, the geographical location of production will change. Almost all regions of the world would produce bioenergy, with the main producers being Africa, Europe, Latin America and the United States. The level of global bioenergy production would be lower: 30–40 EJ/year in 2050 and 70–110 EJ/year in 2100.

Thus, we project that energy from biomass will be an important component of world energy consumption. Nevertheless, even in the policy case with unrestricted trade, biofuels would account for around 30 per cent of global energy consumption. The larger share of biomass in the policy case is due to the replacement of oil production, since biofuels are a low-carbon alternative in the transportation sector.

Now we turn to the following question: how would increased biofuels production affect global land cover and food and land prices?

F. Land-use implications

As discussed in chapter II, biofuels production has significant impact on global land use. Figure 3.9 illustrates the competition among land uses, using different approaches for land conversion modelling.

Gurgel et al. (2007) discuss two possibilities for land supply representation in the EPPA model: one approach allows unrestricted conversion of natural forest and grasslands (as long as conversion costs are covered by returns), which is labelled as the Pure Conversion Cost Response (PCCR) model.

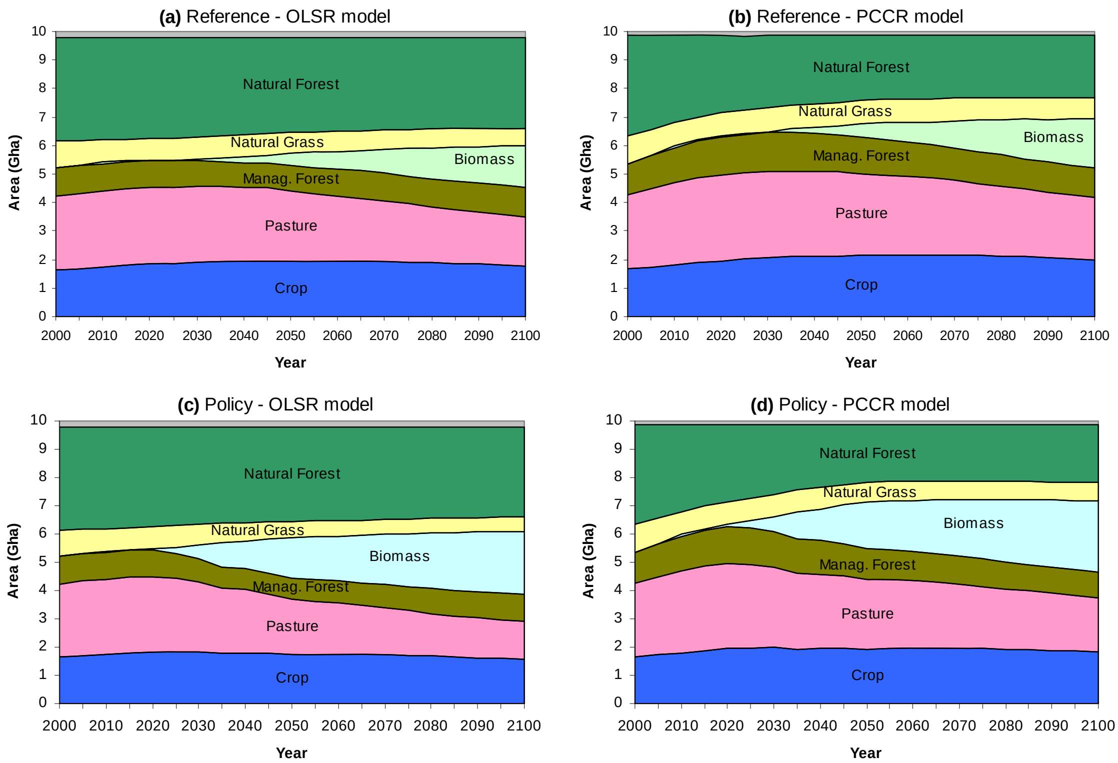
Another approach is to parameterize the model to represent land conversion that occurred in recent years. This version of the EPPA model is labelled as the Observed Land Supply Response (OLSR) model. Land conversion in the latter model is less common than in the PCCR model.

If trade barriers are in place, the geographical location of production will change. Almost all regions of the world would produce bioenergy, with the main producers being Africa, Europe, Latin America and the United States.

These versions capture two extremes: the OLSR version assumes that the response we have witnessed in recent years in land conversion is representative of the long-term response. The PCCR version assumes that conversion will proceed unhindered as long as the value of converting land is greater than the cost.

The two approaches for land conversion are applied both to the reference and policy case described before.

Figure 3.9. Global land use: (a) reference case – OLSR model, (b) reference case – PCCR model, (c) policy case – OLSR model, (d) policy case – PCCR model



Total land area is 9.8 Gha, but the use of this land changes considerably from 2000 to 2100.[50] The area covered by biomass in 2050 ranges from 0.42 to 0.47 Gha in the reference scenario, and from 1.46 Gha to 1.67 Gha under the policy case. In 2100 biomass production covers between 1.44 and 1.74 Gha in the reference case, and from 2.24 to 2.52 Gha in the policy case. Currently, cropland occupies 1.6 Gha.

Natural forests are affected in all scenarios and under both model assumptions, but, as expected, much more conversion occurs under the PCCR model. In this case, natural forests are reduced from the original 3.7 Gha to 2.2 Gha in the reference scenario, and to only 2.0 Gha in the policy case (a 40 per cent reduction in natural forest area).

In contrast, the OLSR model shows less reduction in natural forest area, with a substantial reduction in pasture land. This version of the model makes room for biofuels production by

[50] Figure 3.9 does not include the 3.2 Gha of land not available to agriculture, which by assumption remains unchanged.

greatly intensifying production on existing agricultural land, especially pasture land. In both models natural forest and pasture land are the main land types converted to biofuels production; land dedicated to crops, managed forest and natural grassland show little net changes.

Indeed, crop areas present low sensitivity to the biomass expansion. The original 1.6 Gha covered by crops increase to 1.8 Gha at the end of the century in the reference scenario under the OLSR model, and to almost 2 Gha under PCCR model. In the policy scenario the area covered by crops is reduced slightly to 1.57 Gha under the OLSR model, but still increases to 1.8 Gha under PCCR model assumptions.

This result indicates that crop production and crop area are not greatly affected by biomass expansion, stemming from the relatively inelastic demand for food.

G. Long-term effects on agricultural prices and land rents

The impact of biofuels production on global agricultural and industrialized food prices is shown in figure 3.10. To show the average effect on world prices we compute global price indices using the Walsh index as described by the IMF (2004). The simulated price levels reflect the combination of increasing demand for food, fibre and forestry products as gross domestic product (GDP) and population grow, given our assumption of increasing land productivity.

In the reference scenario we observe price increases in forestry and livestock products, while crop prices remain stable through the century. Forestry and livestock price increases reflect the competition for land from biofuels and higher demand growth for these products than for crops. In the climate policy scenario we see an increase in crops, food and livestock prices of around 5 per cent, which is likely attributable to biofuels' competition for land. The OLSR version of the model shows price increases of 2 to 3 percentage points more than the PCCR model, as a consequence of the lower flexibility in terms of land conversion (from natural areas to agricultural use).

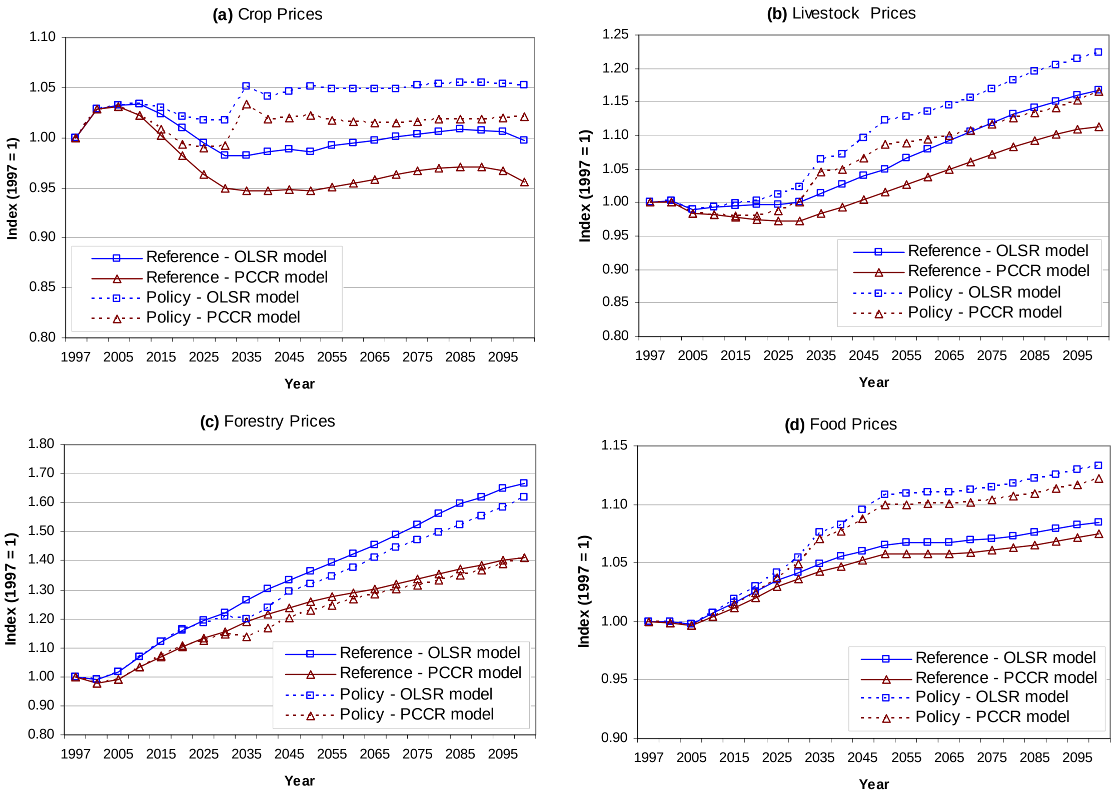
The impact of the biofuels industry on food and commodity prices is projected to be relatively small compared to recent price increases of maize.

The relative changes in prices of crops, livestock and forestry reflect the share of land in the production of each group. They also reflect the fact that livestock production is affected both by the increase in the pasture land rent and the increase in crop prices.

The impact of the biofuels industry on food and commodity prices is projected to be relatively small compared to recent price increases of corn (corn prices rose by nearly 70 per cent from September 2005 to September 2007).

One aspect that should be considered is that the EPPA model projection involves all crops, thus the average price increase does not reflect prices for only one crop. The modelling also reflects long-run elasticities that give time for the sector to adjust, and over the longer term agriculture has proved to very responsive to increasing demand. In fact, the current run-up in corn prices has led to a rapid response by farmers, who have been planting more corn, and with more supply the price may retreat. We also expect less direct effects on crop prices because corn-based ethanol directly affects the corn market whereas cellulosic crops would only indirectly affect crops though the land rent effect.

Figure 3.10. World agricultural and food price indexes



In this regard, the EPPA model simulations suggest that it is possible to integrate a relatively large ethanol industry into the agricultural system over time without causing dramatic effects on food and crop prices.

H. Concluding remarks

Second generation biofuels are expected to have great potential in terms of energy output per unit of land area and cost of production. Technology is expected to be of “cellulosic” or “lignocellulosic” conversion due to the great availability of cellulosic resources. Nevertheless, second generation technology is not yet competitive: most studies report that the current cost is 2.1 times higher than the cost of gasoline production (IEA, 2006; IMF, 2007; Reilly and Paltsev, 2007). Expectations about future costs vary: the IEA estimates that the cost will be similar to ethanol from sugar cane by 2030 while other researchers are not so optimistic. Expectations about energy output per unit of land also vary, with most optimistic estimates being twice as high as current figures of around 30 oven-dry ton/hectares for sugar cane.

Competition for land (which would lead to an increase in agriculture, land and food prices) would still exist, but it is expected to have less impact on prices than the current “first generation” technology. This would be so especially if there is time for the agriculture system to adjust to increased demand. While climate policy can spur bioenergy production, rising oil prices could be enough to bring along second generation technology even if production costs do not fall. For example, Reilly and Paltsev (2007) and Gurgel et al., (2007), using versions of the MIT Emissions Prediction and Policy Analysis (EPPA), project that second generation biomass may produce around 30–40 EJ/year by 2050 and around 180–260 EJ/year by 2100. As a comparison, in 2005 global bioenergy production was less than 1 EJ.

The EPPA projections suggest that, under an unrestricted trade scenario, the largest producers would be Africa, Latin America and the United States, where there is a relative abundance of land with significant biomass productivity per hectare. As a general rule, availability of land, land prices, improvements in agricultural management, seed quality and use of better soils are needed for a country to become a large feedstock producer. Therefore, due to relatively low land prices, African countries seem better placed than Asian countries to become large feedstock producers, given conditions of political stability and improvements in agricultural management and seed quality. The amount of bioenergy trade among EPPA regions reaches about 18 EJ/year in 2050 and around 125 EJ/year in 2100.

Under a restricted trade scenario, Africa, Latin America and the United States would still be the largest producers, but other regions and countries, namely Europe, India and China would play a major role. The level of global bioenergy production would be lower by 3–6 EJ/year in 2050 and by 70–110 EJ/year in 2100 in comparison to the unrestricted trade scenario. Thus, trade restrictions limit biofuels' potential.

The existence of a CO_2 policy, such as a cap and trade system, would result in an increase in fossil fuel prices and in the demand for carbon-free fuels. Therefore, bioenergy would become competitive earlier, if compared to a scenario without a climate policy in place (the exact year depending on the relative price of fossil fuels and biofuels). A climate policy targeting 550 ppmv stabilization of CO_2 concentrations could lead to bioenergy production of 90–130 EJ/year by 2050 and 250–370 EJ/year by 2100 according to studies by Paltsev et al. (2007) and Gurgel et al. (2007). This amounts to approximately 30 per cent of global energy use derived from bioenergy.

If climate policies are in place and trade is unrestricted, trade in bioenergy among EPPA regions reaches 80 EJ/year by 2050 and around 200 EJ/year by 2100. Restricting trade in bioenergy in the presence of climate policy leads to production in almost all regions of the world with the main producers being Africa, Europe, Latin America and the United States. The level of global bioenergy production is lower by 30–40 EJ/year in 2050 and again by 70–110 EJ/year in 2100 in comparison to unrestricted trade.

Regarding the projected results for the United States, we found that the country would be an importer of biofuels under two conditions, namely the existence of a stringent domestic mitigation policy and of unrestricted trade. Rather than for energy feedstock production, American farmland would be used to produce food for export, while regions abroad would devote more of their agricultural land to feedstock production and import food products from the United States. If the United States' biofuels use is restricted to domestically produced feedstock (i.e., under a situation of restricted trade), about 500 million acres (200 Mha) of American land would be required for production. This is more than the total current cropland in the United States. In this case, the country would become a large importer of food, fibre and forest products, rather than the net exporter of these products that it is now.

The global area required to grow biomass crops by the end of the century in the reference scenario is about 1.5 to 1.7 Gha, similar to the amount of land area used for crops today. Under the policy scenario, the land required for biomass production reaches 2.2 to 2.5 Gha in 2100. Global prices for food, agriculture and forestry products increase relative to the reference case as a result of a more rapid expansion of biofuels when there is a strong climate policy. That said, these price increases are relatively modest. Thus, it appears to be possible to introduce a large cellulosic biofuels industry without dramatically upsetting agricultural markets if there is time for the agricultural sector to respond to this increased demand. However, the expansion of the industry could result in substantial deforestation and the unintended release of carbon emissions.

Since trade regimes play a key role in determining which countries and regions are likely to become leading biofuel producers and exporters, the next chapter analyses trade opportunities for developing countries.

References

Brinkman N et al. (2006). Well to wheels analysis of transportation fuel alternatives. *http://www.transportation.anl.gov/pdfs/TA/339.pdf*

Climate Change Science Programme (CCSP) (2007). *CCSP Synthesis and Assessment Product 2.1, Part A: Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations*. Washington DC, United States Department of Energy.

Edmonds JA and Reilly J (1985). *Global Energy: Assessing the Future*. New York, Oxford University Press.

Energy Information Administration (EIA) (2006). *Emissions of Greenhouse Gases in the United States 2005*. Washington DC, United States Department of Energy.

Fulton L and Howes T (2004). *Biofuels for Transport: An International Perspective.* IEA/EET.

Frondel M and Peters J (2007). Biodiesel: a new oildorado? *Energy Policy.* 35: 1675–1684.

Gurgel A et al. (2007). Potential land use implications of a global biofuels industry. Report 155. MIT Joint Programme on the Science and Policy of Global Change. Cambridge.

Hamelinck C et al. (2005). Ethanol from lignocellulosic biomass: techno-economic performance in short-, middle-, and long-term. *Biomass and Bioenergy.* 28 (4): 384–410.

Hill J et al. (2006). Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. *Proceedings of the National Academy of Sciences.* 103: 11206–11210.

International Energy Agency (IEA) (1997). *Renewable Energy Policy in IEA Countries, Volume II: Country Reports.* Paris, OECD/IEA.

IEA (2004). *Biofuels for Transport: An International Perspective*. Paris, OECD/IEA.

IEA (2006). *World Energy Outlook 2006.* Paris, OECD/IEA.

International Monetary Fund (IMF) (2004). *Producer Price Index Manual: Theory and Practice*. Washington DC, IMF.

IMF (2007). *World Economic Outlook 2007*. Washington DC, IMF.

IPCC (2000). *Land-Use, Land-Use Change, and Forestry, Special Report of the Intergovernmental Panel on Climate Change*. Cambridge, Cambridge University Press.

IPCC (2001). *Climate Change 2001: Mitigation, Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, Cambridge University Press.

Luger E (2007). *Energy Crop Species in Europe*. Wieselburg, BLT.

Moreira JR (2004). Global biomass energy potential. Paper prepared for the Expert Workshop on Greenhouse Gas Emissions and Abrupt Climate Change. Paris. 30 September–1 October.

Moreira JR (2006). Global biomass energy potential. *Mitigation and Adaptation Strategies for Global Change.* 11: 313–342.

Novem/ADL (1999). *Analysis and Evaluation of GAVE Chains, Vol. 1-3*. GAVE Analysis Programme.

Paltsev S et al. (2005). The MIT Emissions Prediction and Policy Analysis (EPPA) Model: version 4. Report 125. Cambridge, MIT Joint Programme on the Science and Policy of Global Change.

Paltsev S et al. (2007). Assessment of US cap and trade proposals. Report 146. Cambridge, MIT Joint Programme on the Science and Policy of Global Change.

Reilly J and Paltsev S (2007). Biomass energy and competition for land. Report 145. Cambridge, MIT Joint Programme on the Science and Policy of Global Change.

Samson R et al. (2000). The use of switchgrass biofuel pellets as a greenhouse gas offset strategy. Resource Efficient Agricultural Production (REAP) – Canada, REAP Report. http://www.reap-canada.com/online_library/Reportspercent20andpercent20Newsletters/Bioenergy/14percent20Theper cent20Use.PDF.

Smeets E and Faaij A. (2007). Bioenergy potentials from forestry in 2050: an assessment of the drivers that determine the potentials. *Climatic Change.* 81: 353–390.

United States Department of Agriculture (USDA) (2006). Major uses of land in the United States, 2002. *Economic Information Bulletin.* 14.

IV. Trade opportunities for developing countries[51]

Until recently, biofuels use was limited to local markets and they played a marginal role in the global energy mix. Currently biofuels are acquiring a global dimension with the potential to grow even more.

In general, developing countries have a larger potential to produce biomass than industrialized countries due to better climate conditions and lower labour costs. Under this assumption, international trade in biofuels and/or feedstocks from developing to developed countries is expected to increase with significant positive implications for development. The objective of this chapter is to analyse the trade opportunities for developing countries.

Whether the European Union and the United States will adhere or not to a protectionist policy will determine the size of these trade opportunities. Two scenarios are considered in this chapter:

Scenario 1: the EU's and the United States' objective is to expand the biofuels sector to increase energy independence. This implies that the highest priority will be given to the domestic production of biofuels.

Scenario 2: the EU's and the United States' objective is to expand the biofuels sector to fight global warming. This implies that biofuels with the highest potential to reduce GHG emissions will be preferred.

We estimate that the value of biofuels trade (ethanol and biodiesel) under scenario 1 could be as much as $200 billion by the year 2020. Under scenario 2, the value of imports from developing countries could reach over $520 billion by 2020. These numbers indicate that under scenario 2 the volume of developing country exports to the EU and the United States would be two and a half times larger than under scenario 1.

Developed countries can also choose to import feedstock instead of biofuels. We estimate that the forgone income for developing countries of exporting feedstock rather than biodiesel would range from $14.3 billion for scenario 1 in 2010 to as much as $294.2 billion for scenario 2 in the same year.

The chapter starts with a discussion of the determinants of agriculture's productive capacity and the global potential of bioenergy production. Subsequently, we develop two alternative trade scenarios based on possible policy strategies that the EU and the United States may pursue in the biofuels sector.

A. Agriculture's productive capacity: a result of natural endowments, technology and infrastructure

The productive capacity of the agriculture sector, while largely dependent on natural endowments, can be enhanced by investments in technology and infrastructure. Many developing countries hold a comparative advantage in the production of energy feedstock given their natural

[51] This chapter was prepared by Daniel G. de la Torre Ugarte, Professor, Agricultural Policy Analysis Centre, Department of Agricultural Economics, University of Tennessee, United States.

endowment. Nevertheless, without a significant investment in agricultural productive capacity, these countries may not be able to take full advantage of their potential.

Because agriculture is an ecosystem-based activity, the major factor determining agriculture's productive capacity is the natural endowment (De La Torre Ugarte, 2007). Natural factors define the basic way in which agriculture can be integrated into the natural environment: soil type and abundance, water availability and seasonality, ambient temperatures and sunlight are just a few of the elements that farmers consider when making planting and management decisions in their fields.

These factors influence which crops can be grown and also where and when they can be grown. Sugar cane's productive potential is naturally located in the tropics; conversely, sugar beets' productive potential is located in temperate zones. This productive capacity is more linked to natural endowments than to free trade or any form of economic intervention.

Of the approximately 200 countries and territories in the world for which the Food and Agriculture Organization (FAO) has statistics available (FAO, 2006), 20 account for 84 per cent of the world's arable land (De La Torre Ugarte and Dellachiesa, 2007). Among these are included all countries with extensive and modern agricultural sectors, like Argentina, Australia, Brazil, Canada, some countries of the European Union and the United States; countries like China and India, heavily investing in agriculture; and countries like the Russian Federation and Ukraine, where agriculture is still transitioning from the Soviet era.

Developing countries have a larger potential to produce biomass than industrialized countries due to better climate conditions and lower labor costs.

While natural endowment is an important factor in the formation of agricultural productive capacity, human activity through technology and investment can enhance or overcome the advantages or obstacles of the natural endowment.

Technology can effectively modify crop varieties to adapt to non-native ecosystems and provide yields above natural production capacity. Technology is also important because it results in new agricultural dynamics – practices, implements, machinery, fertilizers, pesticides, herbicides – that have an impact on the physical yield as well as the economic return of the crops and the environmental performance of agricultural production. Therefore, extensive research and development has the potential to enhance the productivity of the endowed natural resources.

Another important factor is the distribution and transportation infrastructure. The ability to move agricultural products to the market and then to the place of consumption greatly influences the economic value of agricultural production. Investment in distribution and transportation networks can enhance the advantages or overcome the disadvantages given by the natural topography and the location of the production areas (Hamilton, 2000).

According to De La Torre Ugarte (2007), investments in agricultural research and distribution infrastructure have occurred in the same countries that already have a comparative advantage in producing cereals and oilseeds due to natural endowments. Investment in developing countries, mostly located in the tropical areas, has lagged behind and consequently their comparative (and even absolute) advantage has been limited to tropical crops, where climate remains the key determinant of productive capacity. By investing in agricultural productive capacity, developing countries could fully exploit their endowed comparative advantage in the production of energy feedstocks.

B. Developing countries will likely be the major bioenergy suppliers

Global biomass supply estimates from plantations range from 47 to 238 EJ/year, with over 80 per cent coming from developing nations (Berndes et al., 2003). But although the vast majority of the studies show developing countries as the greatest potential source of biomass production, there is a great deal of uncertainty about the geographic location and productivity of biomass. The divergence in total estimated biomass production is mainly due to model assumptions made about the future availability of land for biomass plantations and yield of energy dedicated crops.

Fischer and Schrattenhozer (2001) estimate that 34 per cent of global bioenergy could come from developing nation plantations, with 687 Mha in Africa, 400 Mha in Asia and 307 Mha in Latin America. Developing countries are also a significant source of forest biomass, with Fischer and Schrattenholzer (2001) and Sorensen (1999) indicating that Latin American and sub-Saharan Africa are the greatest potential sources.

There are two major challenges to realizing the potential biomass quantities estimated in biomass studies, namely connecting biomass supply with biofuels demand and growing biomass in developing nations while meeting local food demand.

The largest demand for energy is in developed countries: "substantial volumes of biomass can be made available for energy in developing countries, but large-scale export of biofuels to industrialized countries may be required for this potential to be realized since the bioenergy demand in (most) developing countries will be too low (at least during the coming decades)" (Berndes et al., 2003).

Additionally, most biomass studies assume that land classified as "degraded" would be available for plantation agriculture. In reality, local poor subsistence populations still depend upon such land. Any system of biomass production must take their needs into consideration, possibly through a more complex agroforestry system of production. Yet "the suggested bioenergy yield levels [in the biomass studies] appear to refer to large-scale plantations rather than agroforestry systems for integrated food/bioenergy production" (Berndes et al., 2003).

Reviewing a series of studies, Hoogwijk et al. (2003) explored the global potential of biomass for energy. They focused on establishing supply ranges through the year 2050, taking into account the land-use needs for food, feed, urban expansion and recreation. The feedstocks reviewed include energy crops (produced on cropland and on degraded land), agricultural residues, forest residues, animal residues and organic waste. The energy crop estimates include both the production of first and second generation feedstocks. Their work indicates that energy crops and agricultural residues are the most abundant feedstocks.

C. Biofuels trade opportunities for developing countries: selected scenarios

As mentioned above, the level of biofuels demand will determine the amount of feedstocks needed in the market. Developed countries, together with China and India, are the main consumers of transportation fuels. Consequently, the potential demand for biofuels and opportunities for trade for developing countries are largely influenced by the objectives pursued by these countries.

The European Union and the United States' policies have been shaping the recent evolution of the sector regarding production, use and international trade. Brazil is already a key player in the biofuels market; other developing countries are expected to consolidate their position and expand biofuels exports to the EU, the United States and other countries.

Whether the EU and the United States will adhere or not to a protectionist policy will substantially influence the trade opportunities for developing countries. For simplicity, we assume that the EU and the United States pursue the same objectives regarding the biofuels sector. The scenarios consider the potential role of first and second generation biofuels. The eventual commercial availability of second generation biofuels will not necessarily imply the disappearance of first generation biofuels, especially ethanol from sugar cane and biodiesel from palm oil. Moreover, in the case of sugar cane, the availability of second generation technologies would imply an increase of its energy potential, as the conversion of bagasse into ethanol can more than double the ethanol yield of a hectare of sugar cane.

The two scenarios considered are the following:

Scenario 1: the EU's and the United States' objective is to expand the biofuels sector to increase energy independence. This implies that the highest priority will be given to the domestic production of biofuels.

Scenario 2: the EU's and the United States' objective is to expand the biofuels sector to fight global warming. This implies that biofuels with the highest potential to reduce GHG emissions will be preferred.

Scenarios 1 and 2 are considered under the assumption that biofuels use and production will continue to expand in the EU and in the United States at the pace of the directive on the promotion of the use of energy from renewable sources and the 2007 Energy Independence and Security Act (EISA) legislation respectively.

The EU directive includes a mandatory target of a 20 per cent share of renewable energies in overall community energy consumption by 2020 and a mandatory 10 per cent minimum target for renewable energy consumption in the transport sector by 2020.[52] Among many other provisions, the EISA establishes a Renewable Fuel Standard (RFS) that requires minimum annual levels of renewable fuel. The new standard starts at 9 billion gallons in 2008 (34 billion litres) and rises to 36 billion gallons in 2022 (136 billion litres).

Based on those two documents, we have estimated the potential demand for biofuels in 2010, 2015 and 2020, presented in table 4.1. For example, United States legislation establishes a target of 30 billion gallons of ethanol by 2020, including first and second generation ethanol as well as biodiesel. In the case of the EU, the starting point is the 2020 projection contained in the EU memo (2007). From those numbers it is assumed that second generation biofuels would be commercially available at a significant level after 2015. At the same time local production of first generation feedstock reaches a maximum by 2020.

D. Assessment of the trade scenarios

To asses the impact of each scenario, we estimate the volume and characteristics of trade implied by each. This estimation is based on the information related to the contribution of each feedstock to GHG emissions and on the assessment that the United States and the European Union have made on their own ability to produce feedstock domestically to satisfy their targets.

Scenario 1

Under this scenario – where the objective is to maximize local production of biofuels in order to enhance energy independence – we assume that the United States will be able to meet its biofuels objective with domestic production only. This scenario is consistent with the current policy in which imports of biofuels do not play a strategic role, notwithstanding that ethanol imports are allowed duty-free under the Caribbean Basin Initiative and the CAFTA-DR and NAFTA trade agreements. Hence, for simplicity, the volume of imports not being significant, it is

[52] On 17 December 2008 the European Parliament adopted the directive on the promotion of the use of energy from renewable sources, which includes the mentioned utilization targets.

set to zero. This includes ethanol and biodiesel, as well as the first and second generation technological paths.

In the case of the EU, there is widespread acceptance that the domestic productive capacity of the agricultural sector will not be sufficient to supply the biofuels required to fulfil the targets set for the year 2020.[53] For earlier years, we assume that most of the EU's imports would be of biodiesel, as the ethanol demand would be met by an increase in the production of local feedstock.

For scenario 1, the level of imports is taken from the European Commission's estimates for imports of ethanol and biodiesel (DR Agriculture and Rural Development) in the year 2020. For example, the estimated ethanol demand in 2010 is 4.9 million tons of oil equivalent (mtoe), which is equivalent to 2.5 billion litres, and the biodiesel demand is 8.8 mtoe or 11 billion litres. According to these levels, the previous assumption and the information contained in the memo referenced earlier, the estimated imports for ethanol are 0 and for biodiesel 113 million litres. These amounts increase as the demand for biofuels expands and as shown in table 4.1.

Scenario 2

For this scenario the assumed policy objective of the EU and the United States is to expand the biofuels sector to fight global warming. This implies that biofuels with the highest potential to reduce GHG emissions will be preferred.

In the case of the United States, we consider that ethanol from sugar cane would replace ethanol from maize and consequently would have to be imported. On the other hand, the target for second generation ethanol could be fulfilled by locally produced ethanol, based mainly on energy-dedicated crops and agricultural and forest residues. We assume that to achieve this, the required amounts of biodiesel will be imported; although it is assumed that the imported biodiesel is made from palm oil, it could eventually be made using other feedstocks such as jatropha or soybeans.

Whether the EU and the United States will adhere or not to a protectionist policy will substantially influence the trade opportunities for developing countries.

For the EU, the assumption is similar: second generation ethanol could be produced locally, while the remaining biofuels needed to fulfil the target would be imported. The most significant second generation feedstocks likely to be used in the EU for ethanol production would be agriculture and forest residues.

Biofuel imports needed to fulfil the targets established in the legislations of the EU and of the United States (based on the above-mentioned assumptions) are presented in table 4.2. As expected, the volume of imports is significantly larger under scenario 2 than under scenario 1. For example, by the year 2020, the import demand for ethanol is fifty times larger in scenario 2 than in scenario 1; similarly, the import demand for biodiesel is almost three and a half times larger in scenario 2 compared to scenario 1.

The largest increase in imports is due to imports of first generation ethanol and second generation biodiesel. It is presumed that given the relatively small level of demand or requirement for second generation ethanol, both would be able to meet their second generation targets using locally available cellulosic feedstock. In the case of biodiesel, both first and second generation fuels would be mostly imported from developing countries.

[53] The European Commission's analysis of the issue is available at http://ec.europa.eu/agriculture/analysis/markets/biofuel/impact042007/text_en.pdf

Box 4.1. The environmental footprint of biofuels and life cycle analysis

Agriculture and forestry accounted for about 31 per cent of global anthropogenic GHG emissions in 2004 (IPCC, 2007). Biofuels' contribution to this environmental footprint is not intrinsically an addition or a subtraction. As in any agricultural production, the environmental performance of biofuels is determined by the feedstock used, the method of production, soil and climate conditions, water use, the agricultural practices utilized, the amount and type of inputs applied and the agricultural or forest activities that have been replaced (if any). Beyond the agriculture phase, biofuels' environmental footprint is also related to the type of liquid fuel produced, the conversion method, the energy source used in the conversion and the final use of the fuel. The specifics of all of these elements determine the contribution of biofuels to the environmental footprint of agriculture and forestry.

Life cycle analysis (LCA) often captures the impacts of these variables. Some of the LCA impacts for different feedstocks are presented in figure 4.1. These estimates provide an indication of the environmental ranking among different feedstocks: ethanol from sugar cane, lignocellulose, sugar beets and biogas wastes, for example, have lower greenhouse gas emissions than fossil fuels. If the environmental performance of a particular feedstock is better than that of another feedstock used to produce the same biofuels (for example, sugar cane versus maize), increasing the use of sugar cane ethanol would decrease the environmental footprint of biofuels.

In a scenario where the environmental footprint is priority, trade advantages would then go to countries able to produce a biofuel with a smaller footprint. However, until now LCA studies have not been widely used to compare the performance of current agricultural activities with biofuel-related activities potentially replacing them. The estimates presented in figure 1 represent one of the most transparent sets available in the scientific literature (Larson, 2006) and provide enough information to rank the contribution of different biofuels paths to the reduction of GHG emissions. These indicators are applied regardless of the geographic area where feedstock production and conversion occur. However, the ideal indicators should reflect the agricultural methods and the type of energy used in the conversion process in a much more specific manner.

Table 4.1. Potential demand for biofuels (based on EU-27 and United States targets) – billion gallons and billion litres

		2010						2015						2020					
		Ethanol			*Biodiesel*			*Ethanol*			*Biodiesel*			*Ethanol*			*Biodiesel*		
		1st Gen	*2nd Gen*	*Total*	*1st Gen*	*2nd Gen*	*Total*	*1st Gen*	*2nd Gen*	*Total*	*1st Gen*	*2nd Gen*	*Total*	*1st Gen*	*2nd Gen*	*Total*	*1st Gen*	*2nd Gen*	*Total*
USA	mi L	45,425	1,136	46,561	2,461	0	2,461	56,781	11,356	68,137	9,464	0	9,464	56,781	39,747	96,528	17,024	0	17,024
	mi G	11,992	300	12,292	650	0	650	14,990	2,998	17,988	2,498	0	2,498	14,990	10,493	25,483	4,494	0	4,494
EU-27	mi L	4,902	0	4,902	11,000	0	11,000	17,647	0	17,647	13,750	0	13,750	25,666	6,765	32,431	17,238	6,563	23,800
	mi G	1,294	0	1,294	2,904	0	2,904	4,659	0	4,659	3,630	0	3,630	6,776	1,786	8,562	4,551	1,733	6,283
TOTAL	mi L	50,327	1,136	51,463	13,461	0	13,461	74,428	11,356	85,784	23,214	0	23,214	82,447	46,512	128,959	34,262	6,563	40,824
	mi G	13,286	300	13,586	3,554	0	3,554	19,649	2,998	22,647	6,128	0	6,128	21,766	12,279	34,045	9,045	1,733	10,778

Table 4.2. Hypothetical imports of biofuels by the EU and the United States, from developing countries – billion gallons and billion litres

		2010						2015						2020					
		Ethanol			*Biodiesel*			*Ethanol*			*Biodiesel*			*Ethanol*			*Biodiesel*		
		1st Gen	*2nd Gen*	*Total*	*1st Gen*	*2nd Gen*	*Total*	*1st Gen*	*2nd Gen*	*Total*	*1st Gen*	*2nd Gen*	*Total*	*1st Gen*	*2nd Gen*	*Total*	*1st Gen*	*2nd Gen*	*Total*
Scenario A																			
USA	mi L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	mi G																		
EU-27	mi L	-	-	-	113	-	113	-	-	-	2,863	-	2,863	2,549	-	2,549	6,350	6,350	12,700
	mi G				30	-	30	-	-	-	756	-	756	673	-	673	1,676	1,676	3,353
TOTAL	mi L	-	-	-	113	-	113	-	-	-	2,863	-	2,863	2,549	-	2,549	6,350	6,350	12,700
	mi G				30	-	30	-	-	-	756	-	756	673	-	673	1,676	1,676	3,353
Scenario B																			
USA	mi L	45,425	-	46,561	2,461	-	2,461	56,781	-	68,137	9,464	-	9,464	56,781	-	96,528	-	-	17,024
	mi G	11,992	-	12,292	650	-	650	14,990	-	17,988	2,498	-	2,498	14,990	-	25,483	-	-	4,494
EU-27	mi L	4,902	-	4,902	11,000	-	11,000	17,647	-	17,647	13,750	-	13,750	25,667	6,765	32,431	17,238	6,563	23,800
	mi G	1,294	-	1,294	2,904	-	2,904	4,659	-	4,659	3,630	-	3,630	6,776	1,786	8,562	4,551	1,733	6,283
TOTAL	mi L	50,327	-	51,463	13,461	-	13,461	74,428	-	85,784	23,214	-	23,214	82,448	6,765	128,959	17,238	6,563	40,824
	mi G	13,286	-	13,586	3,554	-	3,554	19,649	-	22,647	6,128	-	6,128	21,766	1,786	34,045	4,551	1,733	10,778

E. The potential value of biofuel imports

The volume of biofuels imports provides a clear indication of the potential market for developing countries. It is possible to provide a quick estimation of the monetary value of this potential.

As reference prices for ethanol, we consider the average FOB (free on board) prices of sugar cane ethanol in Santos (Brazil) and of maize ethanol in Chicago (United States), the two main ethanol producers. For biodiesel, the producer prices in Germany and reference price in Thailand are considered. These reference prices are \$2.32 per gallon of ethanol and \$5.55 per gallon of biodiesel (F.O Licht's, 2008).[54]

Using these reference prices and the hypothetical import volumes in table 4.2, we obtain a rough estimate of the value of biofuels trade. Under scenario 1, this value could be as much as \$18 billion by the year 2020 and could reach over \$130 billion under scenario 2 by the same year.

These numbers indicate that under scenario 2 – i.e., an environment-driven scenario – the value of developing country exports to the EU and the United States would be more than seven times larger than under scenario 1 – an energy independence-driven scenario – where the priority is to produce biofuels domestically in the EU and the United States.

For this trade potential to materialize, not only would the EU and the United States targets have to be maintained and achieved, but also the productive capacity of the potential exporting developing countries would have to be expanded. In terms of first generation biofuels, such as sugar cane ethanol, there is already substantial productive capacity in many developing countries, and in several of them efforts are underway to develop biofuel conversion facilities. The same would apply for biodiesel productive capacity.

F. Imports of feedstock instead of biodiesel

Another possible trade scenario is that developed countries may choose to import the raw or pre-processed feedstocks and transform them into biodiesel domestically. Exports of raw sugar cane to be processed into ethanol in the consuming countries are unlikely given the perishable nature of sugar cane. The same could be expected from second generation cellulosic ethanol (the low density of the feedstock may be a significant obstacle to trading it internationally).[55] In the case of biodiesel, there is an already established trade of raw oilseeds, crude vegetable oil and refined vegetable oil.

Importing raw materials and processing them into value added products domestically is a well-known practice in the agrifood sector.[56] This practice is often accompanied by tariff escalation. Indeed, if a country wants to protect its processing or manufacturing industry, it can set low tariffs on imported inputs used by the industry and set higher tariffs on finished products to protect the goods produced by the industry. When importing countries escalate their tariffs, they make it more difficult for countries producing raw materials to process and manufacture value added products for export.

A widespread practice of importing raw materials and processing them into value added products domestically would support a scenario in which feedstocks – raw or pre-processed – would be imported from developing countries and transformed into biodiesel in the EU or in the

[54] Germany and Thailand are the only countries whose biodiesel prices in tracked by F.O. Licht's *World Ethanol Report*. The prices are for the week of 2 June 2008 to 6 June 2008, F.O. Licht's (2008).
[55] Wood chips, on the other hand, are tradable.
[56] Examples of this are the cacao and chocolate complex, the rubber industry, the vegetable oil industry and the candy and sugar industry.

United States. This scenario would imply a significant forgone opportunity for developing countries to manufacture value added products.

Considering the Rotterdam price of palm oil of $ 1,165 per ton (F.O. Licht's, 2008), and the yield of biodiesel from crude palm oil to be at 80 per cent of crude oil, it is possible to estimate that the feedstock cost is approximately $5.31 per gallon of biodiesel produced with imported palm oil.[57] Therefore, given the biodiesel price used before ($5.55 per gallon), for each gallon of biodiesel that is produced in the EU or in the United States with imported palm oil – or possibly jatropha oil – exporting developing countries would see their export value reduced by an estimated $0.24 per gallon.

Thus, the forgone income for developing countries of exporting feedstock rather than biodiesel would range from $8 million for scenario 1 in 2010 to as much as $80 million for scenario 2 in the same year.

So far emphasis has been placed on the volume and value of biofuels that developing countries could potentially export to the EU and the United States. However, the environmental performance of biofuels is closely related to feedstock production. If, for example, most of the expansion of palm or jatropha production occurs at the expense of tropical forests or in environmentally sensitive areas, the environmental cost of producing feedstock and/or biofuels for export would be extremely high.

On the other hand, if most of the land used for feedstock production is recovered cropland in which soil productivity has been enhanced, the environmental and economic benefits of such effort are clear. The same could be said for the production of sugar cane, maize and even cellulosic crops where there is a need to compare, inter alia, production methods, irrigation needs as well as the land-use changes triggered directly or indirectly by biofuels production.

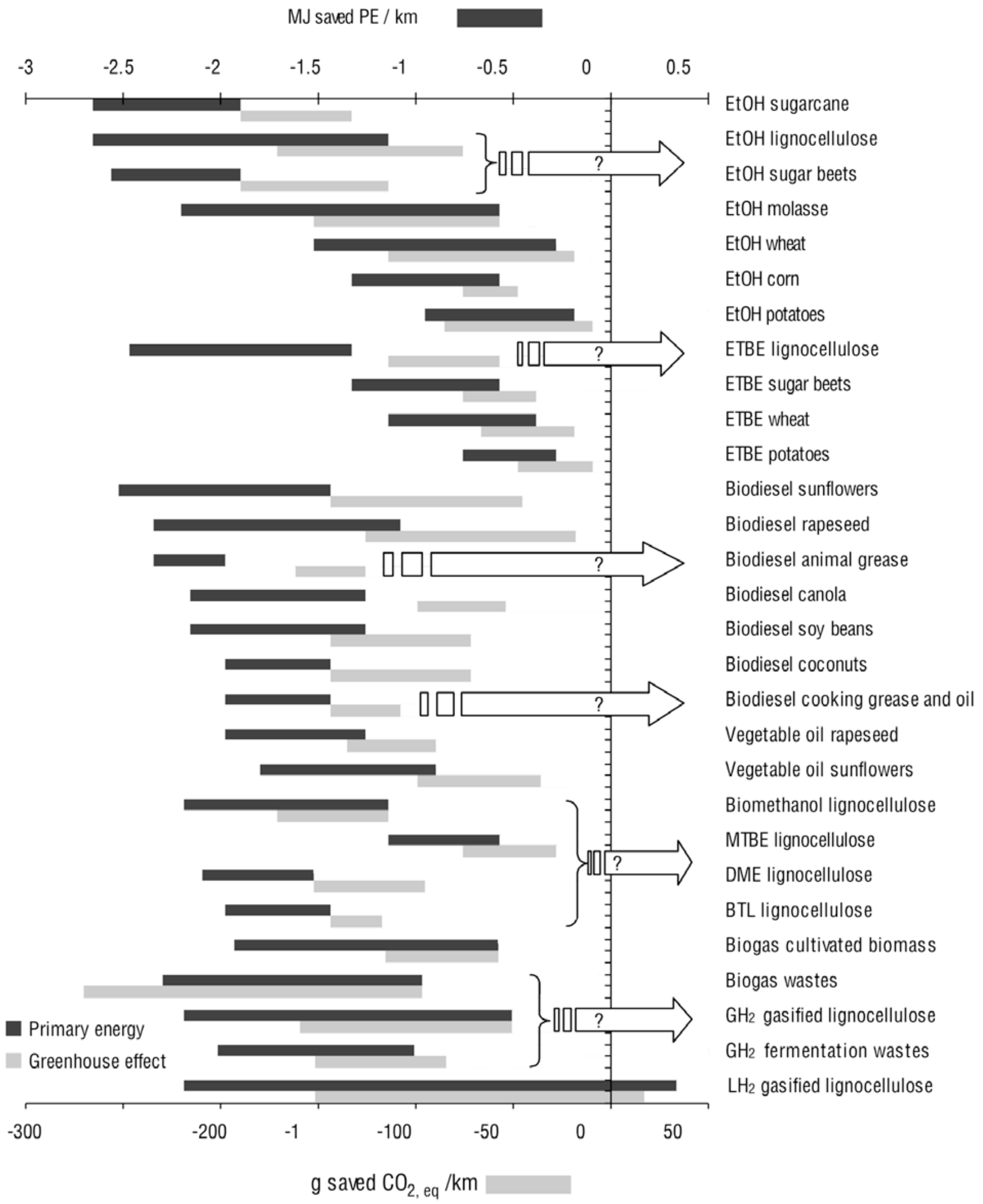
Considering that a significant portion of the overall environmental impact of using biofuels occurs during the feedstock production phase, the lack of mechanisms that ensure the use of best agricultural practices, avoid displacement of tropical forests or the utilization of environmentally sensitive areas could jeopardize the whole effort. In other words, the risk is the "mining" of soil productivity and of environmental resources. This mining would occur in the developing countries, while developed countries, such as the United States or the EU, would reap most of the environmental benefits of biofuels.

The reduction of GHG emissions is used as an indicator of the environmental performance of the different biofuel paths. The indicators used are from life cycle estimates published in the literature (Larson, 2006), discussed in more detail in box 4.1. Notwithstanding that these estimates may contain different assumptions and system boundaries, and reflect mostly production and conversion technologies from Brazil, the EU and the United States, they are used to rank the different biofuels paths.

In a situation where environmental damage could have a global impact, any benefit from biofuels could actually turn into costs, especially if adequate attention is not paid to the feedstock production phase. Consequently, there is an urgent need to put in place environmental accountability mechanisms, in the form of certification or sustainability standards, to ensure the positive environmental performance of biofuels.

[57] 1 metric ton (1,000 kg) of palm oil is equal to 273 gallons.

Figure 4.1. Savings per km in primary fossil energy and in greenhouse gas emissions for a range of biofuel pathways



Source: Quirin et al. (2004). The savings are relative to gasoline (for bioethanol pathways), MTBE (for bioETBE pathways) and diesel (for biodiesel, BTL (Fischer-Tropsch) and DME pathways). The ranges shown reflect the range of results given in the large number of LCA studies that were reviewed by the authors who prepared the chart. The cases marked with broad arrows pointing right are for biomass residue feedstocks. Other cases are for dedicated energy crops. MTBE = methyltetrabutyl ether; ETBE = ethyl tetrabutyl ether; BTL = biomass-to-liquids; GH_2 = gaseous hydrogen; LH_2 = liquid hydrogen; PE = primary energy.

G. Concluding remarks

The increase in the use of biofuels responds to rising and highly volatile oil prices, concerns about global warming and the pursuit of energy independence goals. It is the combination of these objectives that has led the EU and the United States, among others, to implement domestic policies to encourage domestic production and use of biofuels as a source of transportation fuel.

The expansion of biofuels is closely linked to the productive capacity of the agricultural sector and to its ability to provide food, feed, fibre and energy feedstocks simultaneously. A crucial determinant of the agricultural productive capacity of a country is given by its endowment of natural resources, while investment in research and development and in infrastructure has the ability to enhance this potential.

Developing countries are endowed with an abundant mass of agricultural and forest resources that could potentially be used as feedstock for the production of transportation fuels. This puts them in an ideal position to fully benefit from a new and dynamic sector of the world economy.

However, whether biofuels can actually become an opportunity for developing countries depends to a great extent on the policy decisions of the major consuming countries (the EU and the United States), since the expansion of the biofuels sector is mainly the result of the policy strategies put in place by these governments. These strategies could range from an elimination of biofuel support policies, and consequently the virtual reduction of the industry to a boutique-type of fuel, to the implementation of the most ambitious goals.

To analyse the trade potential available for developing countries two policy scenarios were considered: scenario 1, where the main objective pursued by the EU and the United States is energy independence and the priority is the domestic production of biofuels, and the alternative scenario (scenario 2), where the objective is to expand biofuels production and use it as a means to address global climate change.

The size of the opportunity implied by each scenario is significantly different: a strategy of energy independence would offer smaller opportunities than a strategy based on pursuing environmental benefits. The latter could be particularly beneficial to developing countries if their natural endowment to produce biomass were fully recognized.

Furthermore, the EU and the United States could choose to import feedstocks and process them domestically. This situation would imply a significant forgone opportunity for developing countries to manufacture value added products. Our estimation indicates that they would see their export value reduced by an estimated $0.24 per gallon of biodiesel.

Finally, it is important to mention that export opportunities cannot be the only criterion used to assess the contribution of biofuels to development. The analysis of the export potential needs to be accompanied by an evaluation of the environmental performance of the biofuels sector.

Besides trade regimes, access to advanced biofuel technologies is an important issue for developing countries. The following chapter focuses on the intellectual property aspects of second generation biofuels.

References

Berndes G et al. (2003). The contribution of biomass in the future global energy supply: a review of 17 studies. *Biomass and Bioenergy*. 25: 1–28.

De La Torre Ugarte D (2007). The contributions and challenges of supply management in a new institutional agricultural trade framework. Discussion paper 6. ECOFAIR TRADE Dialogue.

De La Torre Ugarte D and Dellachiesa A (2007). Advancing the agricultural trade agenda: beyond subsidies. *The Georgetown International Environmental Law Review*. XIX (4).

FAO (2006). *FAOSTAT Statistical Database*. Rome, FAO.

Fischer G and Schrattenholzer L (2001). Global bioenergy potentials through 2050. *Biomass and Bioenergy*. 20: 151–159.

F.O. Licht's (2008). *World Ethanol and Biofuels Report, Vol. 6, No.22*.

Gollin D., S. Parente, and R. Rogerson (2002), "The Role of Agriculture in Development", *American Economic Review*, 92(2).

Hamilton R (2000). Is geography a destiny? *IDB America, Magazine of the Inter-American Development Bank*. March–April.

Hoogwijk M et al. (2003). Exploration of the ranges of the global potential of biomass for energy. *Biomass and Bioenergy*. 25: 119–133.

Intergovernmental Panel on Climate Change (IPCC) (2007). *4th Assessment Report*. IPCC.

Larson E (2006). A review of life-cycle analysis studies on liquid biofuel systems for the transport sector. *Energy for Sustainable Development*, X (2).

Quirin M et al. (2004). CO_2 mitigation through biofuels in the transport sector: status and perspectives. Main report. Institute for Energy and Environmental Research (IFEU). Heidelberg.

Sorensen B (1999). Long-term scenarios for global energy demand and supply: four global greenhouse mitigation scenarios. Roskilde University, Institute 2, Energy and Environment Group.

United States Congress (2007). *Energy Independence and Security Act of 2007 (EISA)*. Washington DC, United States Government.

V. Advanced biofuels and developing countries: intellectual property scenarios and policy implications[58]

Chapter III analysed the commercial viability of second generation biofuels. This chapter focuses on related intellectual property rights (IPRs) aspects. Three hypothetical scenarios in the context of the intellectual property protection of second generation biofuels are developed, with each scenario representing a different level of strictness of protection. Therefore, each scenario translates into a different level of potential access to advanced biofuel technologies by developing countries.

Second generation biofuels can be classified in terms of the process used to convert biomass into fuel: biochemical or thermochemical. Second generation ethanol or butanol would be made via biochemical processing. Second generation thermochemical biofuels may be less familiar to readers, but many represent fuels that are already being made commercially from fossil fuels using processing steps that in some cases are identical to those that would be used for biofuel production. These fuels include methanol, Fischer-Tropsch liquids (FTL) and dimethyl ether (DME) (Larson, 2007).

Second generation biofuels are currently not being produced commercially anywhere. Many efforts are going on worldwide to commercialize second generation biofuels made by both processes. In the case of biochemical fuels, breakthroughs are needed in the research and engineering of micro-organisms designed to process specific feedstocks, followed by demonstrations preceding commercial implementation. It is expected that 10 to 20 years may be needed before commercial production could begin on a substantial basis. In the case of thermochemical fuels, relatively modest additional development and demonstration efforts would enable commercial production, expected to begin in 5 to 10 years (Larson, 2007). Many of the equipment components needed for biofuels production through the thermochemical process are already commercially established for applications in fossil fuel conversion and processing is relatively indifferent to the specific input feedstock.

A possible trajectory that the biofuels industry may follow is that of the agricultural biotechnology industry. Through divestitures, mergers and acquisitions, there has been a process of consolidation in the global agribusiness in recent years. The outcome is a few major integrated companies, each controlling proprietary lines of agricultural chemicals, seeds and biotech traits. Beginning in the late 1990s, intellectual property ownership has increasingly consolidated in this dwindling number of large multinational corporations.

The application of second generation technologies will entail greater systems complexity, integrated engineering design and other technical parameters (especially in the case of biochemical technology) that may limit the diffusion of such technologies to most developing countries, and this for two reasons: advanced technologies will be proprietary and consequently costly to obtain; they may also be too complex for developing countries to easily absorb and adapt to local needs. Therefore – as happened in the agricultural biotechnology sector – the risk

[58] This chapter was prepared by Calestous Juma, Professor of the Practice of International Development and Director of the Science, Technology and Globalization Project at the Harvard Kennedy School of Government, and by Bob Bell, Jr, Ph.D. student in Information Management and Systems at the University of California, Berkeley, United States.

exists that there would be limited technology transfer to developing host countries. In that sense, it remains important for developing countries to invest in their own innovation systems.

In this chapter we argue that a restrictive IPR regime for advanced biofuel technology will likely prevail. The chapter first analyses recent patenting and investment trends in advanced, second generation biofuels. Subsequently, it presents three hypothetical scenarios based on extensive access, restricted access and limited access to proprietary biofuel technologies. Specific mechanisms that developing countries could use to access technology within the framework of each scenario are presented. Finally, the chapter addresses issues related to innovation systems and presents policy options for developing countries to fast-track innovation into their national policies.

It is worth noticing that the analysis here presented is limited both by the lack of empirical literature on the specific topic and by the difficulties inherent in considering a diversity of hypothetical scenarios. In particular, evidence regarding biotechnology-related intellectual property issues in the developing country context is almost entirely lacking, with almost no empirical work on patenting in the industrial biotechnology sector (Herder and Gold, 2007).

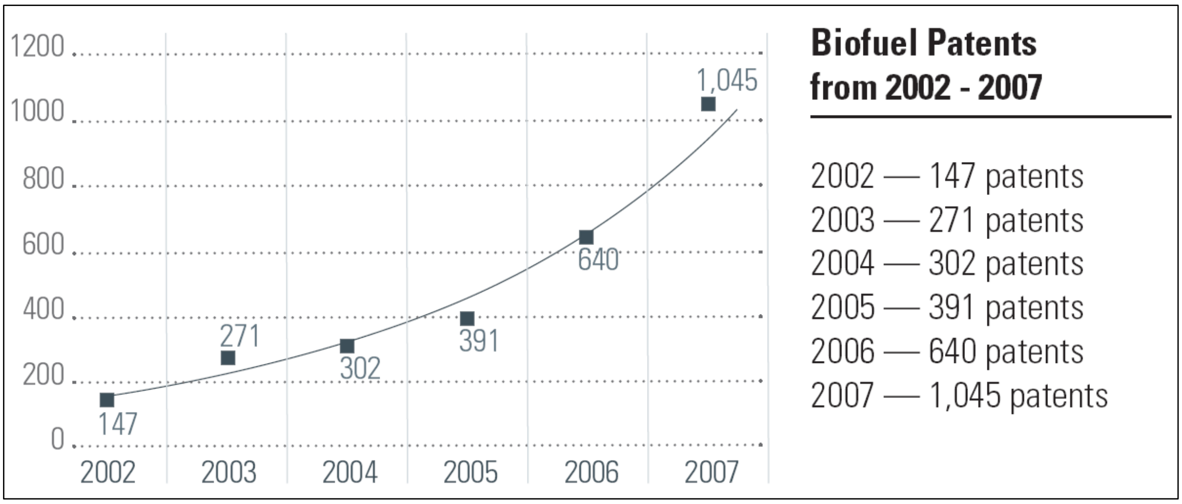
A. Trends in biofuels patenting

Though first generation biofuels are long off-patent, there is increasing patenting activity in second generation technologies (UNCTAD, 2007; Barton, 2007). This section analyses the patenting trends with respect to developing countries' accessibility to advanced biofuel technologies.

1. The United States

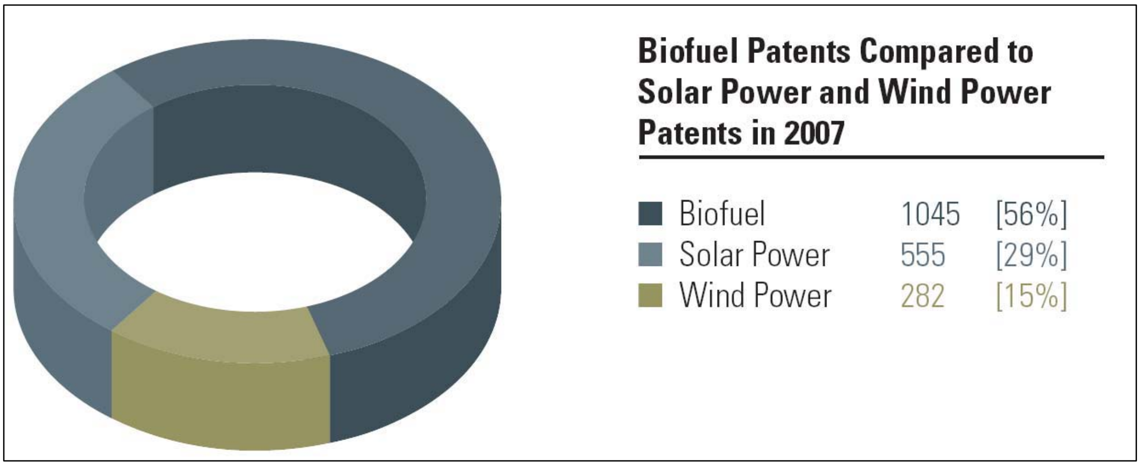
In the United States, biofuel patenting activity is booming. In the 2002–2007 period, 2,796 biofuel-related patents were published, with an increase of 610 per cent from 2002 to 2007 (figure 5.1). In 2007, the number of biofuel patents exceeded the combined total of solar power and wind power patents published (figure 5.2).

Figure 5.1. United States biofuel patents 2002–2007



Source: Kamis and Joshi (2008).

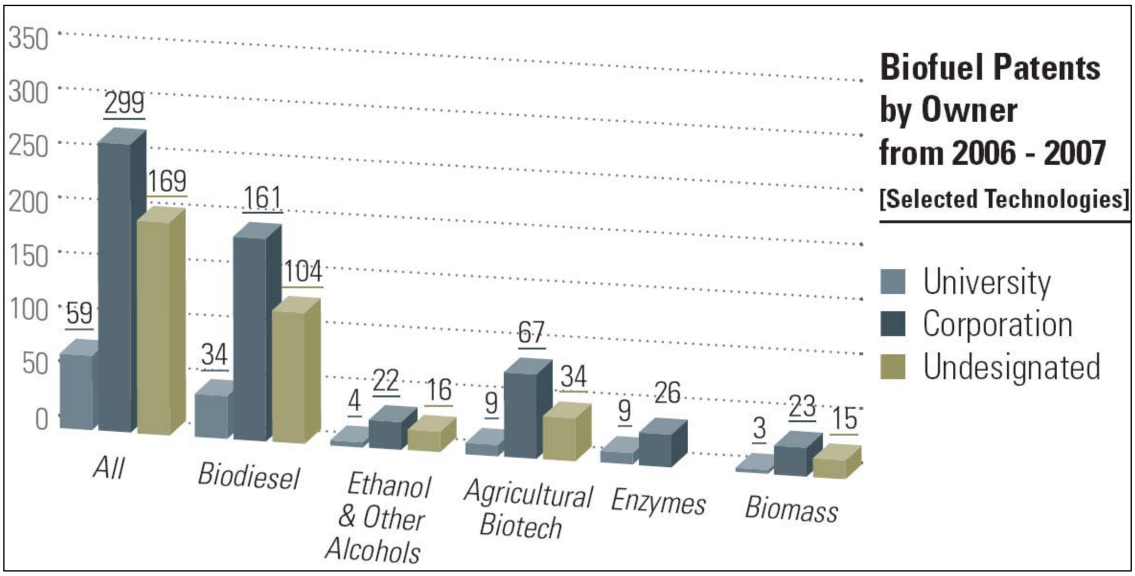
Figure 5.2. United States biofuel patents as compared to other renewable energy patents in 2007



Source: Kamis and Joshi (2008).

Categorized by ownership entity, the patents published in selected technologies in 2006–2007 were 57 per cent owned by corporate entities, 11 per cent owned by universities or other academic institutions and 32 per cent undesignated[59] (figure 5.3) (Kamis and Joshi, 2008). A similar distribution exists for biodiesel or ethanol patents only.

Figure 5.3. United States biofuel patents by ownership categories, 2006–2007



Source: Kamis and Joshi (2008).

Many of the changes in patent policy in the United States during the past two decades have been a result of court decisions, especially those of the Court of Appeals of the Federal Circuit, and to a lesser extent to the Supreme Court (Hall, 2007). *KSR International v. Teleflex Inc*. (No. 04-1350) 119 Fed. Appx 282, on non-obviousness, and *eBay Inc, et al. v. MercExchange, L.L.C.* (No. 05-130) 401 F. 3d 1323, on the four-factor test for injunctions, have raised the bar for obtaining patents on new products that rely on new combinations of existing, publicly known elements (Hall, 2007). In the recent case of *KSR International, Co. v. Teleflex, Inc*., 127 S. Ct. 1727 (2007), the most important patent ruling in years, the Supreme Court of the United States stated:

[59] A significant number of patents are listed as undesignated because the United States' published patent applications often do not list the patent owner.

> We build and create by bringing to the tangible and palpable reality around us new works based on instinct, simple logic, ordinary inferences, extraordinary ideas, and sometimes even genius. These advances, once part of our shared knowledge, define a new threshold from which innovation starts once more. And as progress beginning from higher levels of achievement is expected in the normal course, the results of ordinary innovation are not the subject of exclusive rights under the patent laws. *(as quoted by Herder and Gold, 2007).*

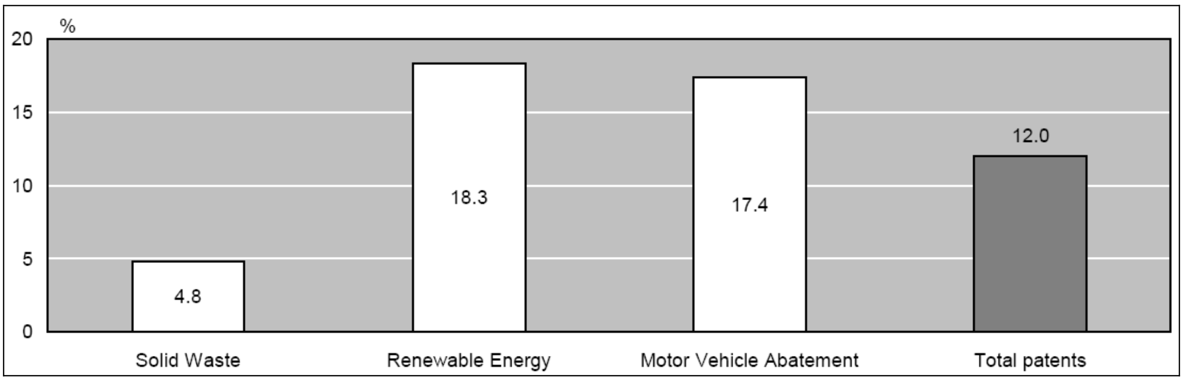
If the combination results from nothing more than "ordinary innovation" and "does no more than yield predictable results", the court reasoned, it is not entitled to the exclusive rights that a patent conveys. "Were it otherwise," Justice Kennedy wrote for the unanimous court, "patents might stifle, rather than promote, the progress of useful arts".

Because most inventions combine previously known elements, the court's more liberal approach to determining "obviousness" will almost certainly make American patents harder to obtain and defend in litigation. "Granting patent protection to advances that would occur in the ordinary course without real innovation retards progress", Kennedy wrote. He added that such patents (based on only incremental improvements) were also undesirable because they might deprive earlier innovations of "their value or utility". It is very possible that the effects of the more stringent patentability standards may be felt and that biofuels patenting could slow down as a result (Raciti et al., 2008). Other senior courts such as the House of Lords have espoused similar reasoning[60] (Herder and Gold, 2007).

2. Europe

In recent years, the growth rate in the area of renewable energy technologies has been higher than the growth rate of total European Patent Office (EPO) applications (Johnstone et al., 2008). The late 1990s saw the emergence of patents related to progress in energy-related technologies. Among environmental technology patents, inventions relating to renewable energy and motor vehicle abatement evolved rapidly since the mid-1990s (around 18 per cent a year on average, as can be seen in figure 5.4) (OECD, 2007).

Figure 5.4. Trends in patents filed in selected environmental technologies[61]
Average annual growth rate, 1995–2004



Source: OECD, Patent database, OECD (2007).

60 *Synthon BV v. Smithkline Beecham* plc [2005] UKHL 59.

61 Patent counts are based on the priority date, the inventor's country of residence and fractional counts. Patent applications filed under the Patent Cooperation Treaty (PCT), at the international phase, designating the EPO.

B. Trends in funding of biofuels research and development

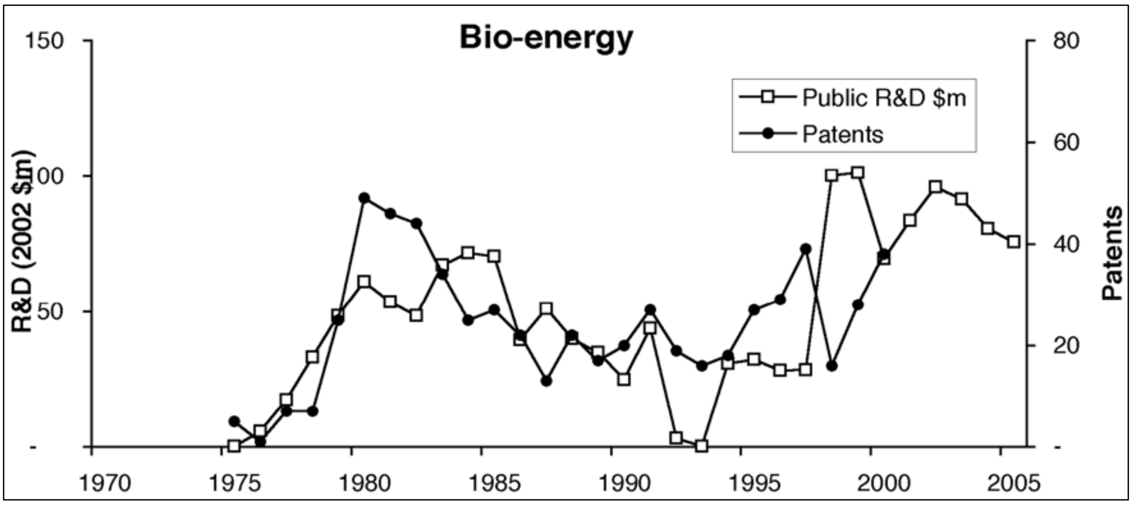
1. United States

Some of the contributing factors to the increasing patenting trends in biofuel technology are United States Government funding of research and development in biofuels and increasing United States venture capital funding in the biofuels sector. In the United States, there is a strong correlation between public research and development spending and patenting across a variety of energy technologies, including bioenergy (figure 5.5) (Nemet, 2007).

Moreover, the United States Federal Government has allocated, for the period 2008–2015, $500 million in grants under the Energy Independence and Security Act of 2007, to promote the development of advanced biofuels. Grant monies have also been appropriated for the research and development of commercial applications of biofuel production technologies, for research and development of cellulosic ethanol and biofuels and for a pilot programme for the establishment of refuelling infrastructure corridors for renewable fuel blends (Hill, 2008; Kamis and Joshi, 2008).

Furthermore, government-funded research results are increasingly transferred to the private sector under exclusive patent rights, made possible by the Bayh-Dole Act of 1980.[62] Because some bioenergy technologies are not yet inexpensive enough to be used for general application and firms are hesitant to invest in substantial research on their own, much of the research in these areas is funded by the United States Government and such subsidized research will almost certainly be transferred to the private sector under exclusive patent rights (Barton, 2007; Maskus and Reichman, 2005).

Figure 5.5. Patenting and federal research and development



Source: Nemet (2007).

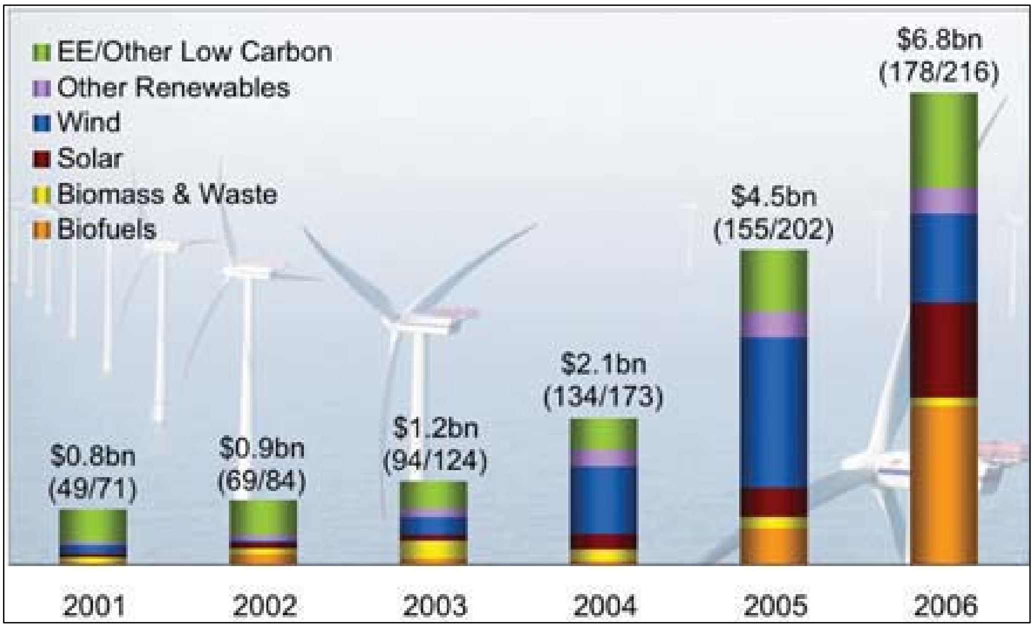
Increased United States venture capital funding in the biofuels sector is also probably influencing patent trends. Based on high energy prices, concerns about global warming and a growth of subsidies in the renewable energy industries, some venture capital-funded firms are entering the industry. The United States leads in venture capital investment, with over 60 per cent of the world's venture capital in clean energy during 2006, including biofuels, much of which was for developing and commercializing technologies for converting cellulose to ethanol (REN21, 2008).

Venture entities invested $2.9 billion in the biofuels industry sector in 2007, with more expected in the coming years (Kamis and Joshi, 2008). Venture capital firms prefer to invest in

[62] It requires that the licensee of technology developed under the grant commit itself that the relevant products "be manufactured substantially" in the United States.

start-ups having a strong proprietary position, with an emphasis on patents developed by the entrepreneurs themselves or technology obtained from a university or the government under license (Barton, 2007). As venture funding and government funding in the United States and outside the United States increase in the coming years, the number of biofuel patents (and specifically agricultural biotechnology biofuel patents) will likely increase as transgenic plant technology is directed to biofuel applications.

Figure 5.6. Venture capital/private equity investment by sector, 2000–2006 (global)



Source: SEFI, New Energy Finance as shown in Greenwood et al. (2007).
Note: Grossed-up values based on disclosed deals. The figures include private equity buyouts, but exclude OTC (over-the-counter) and PIPE (private investments in public equities) deals. Figures in brackets refer to (disclosed deals / total deals).

2. Canada

All across Canada, more and more funds are being established for clean and alternative energy technology companies. Because bioproducts and renewable biomass resources are expected to amount to Can$100 billion (US$95.9 billion) of Canada's GDP by 2020, a commitment to renewable fuels continues to grow among federal and provincial governments (Mergent, 2007).

In March 2007, the Canadian Federal Government announced an additional Can$10 million (US$9.6 million) in funding for the Biofuels Opportunities for Producers Initiative (BOPI), which doubled the total BOPI funding up to Can$20 million (US$19.2 million) over two years.

3. Global

Global venture capital financing for renewable energy boomed during 2006/2007, particularly for solar PV (photovoltaic) and biofuels, exceeding $3 billion worldwide in 2006 (figure 5.6). Individual venture capital sums now exceed the $100 million level, either in single funding rounds or spread over extended technology development periods (REN21, 2008).

C. Biofuels intellectual property scenarios

Policymakers and stakeholders in developing countries frequently raise concerns about potential barriers that increased patenting and intellectual property policies may pose for access to renewable energy technologies and specifically biofuels. The intellectual property system is usually associated with a number of limitations related to the access and dissemination of technologies in certain fields. Examples of those limitations are high transaction costs for obtaining information, negotiating and acquiring protected technologies and a lack of clarity in defining what is (not) protected. Market failures can be exacerbated by these information asymmetries (Barton, 2007). Some groups, such as the Third World Network, are expressing concern that patents on the new technologies may be keeping prices high and restricting access by developing countries (World Intellectual Property Organization (WIPO), 2008).

The application of second generation technologies will entail greater systems complexity, integrated engineering design and other technical parameters that may limit the diffusion of such technologies to most developing countries.

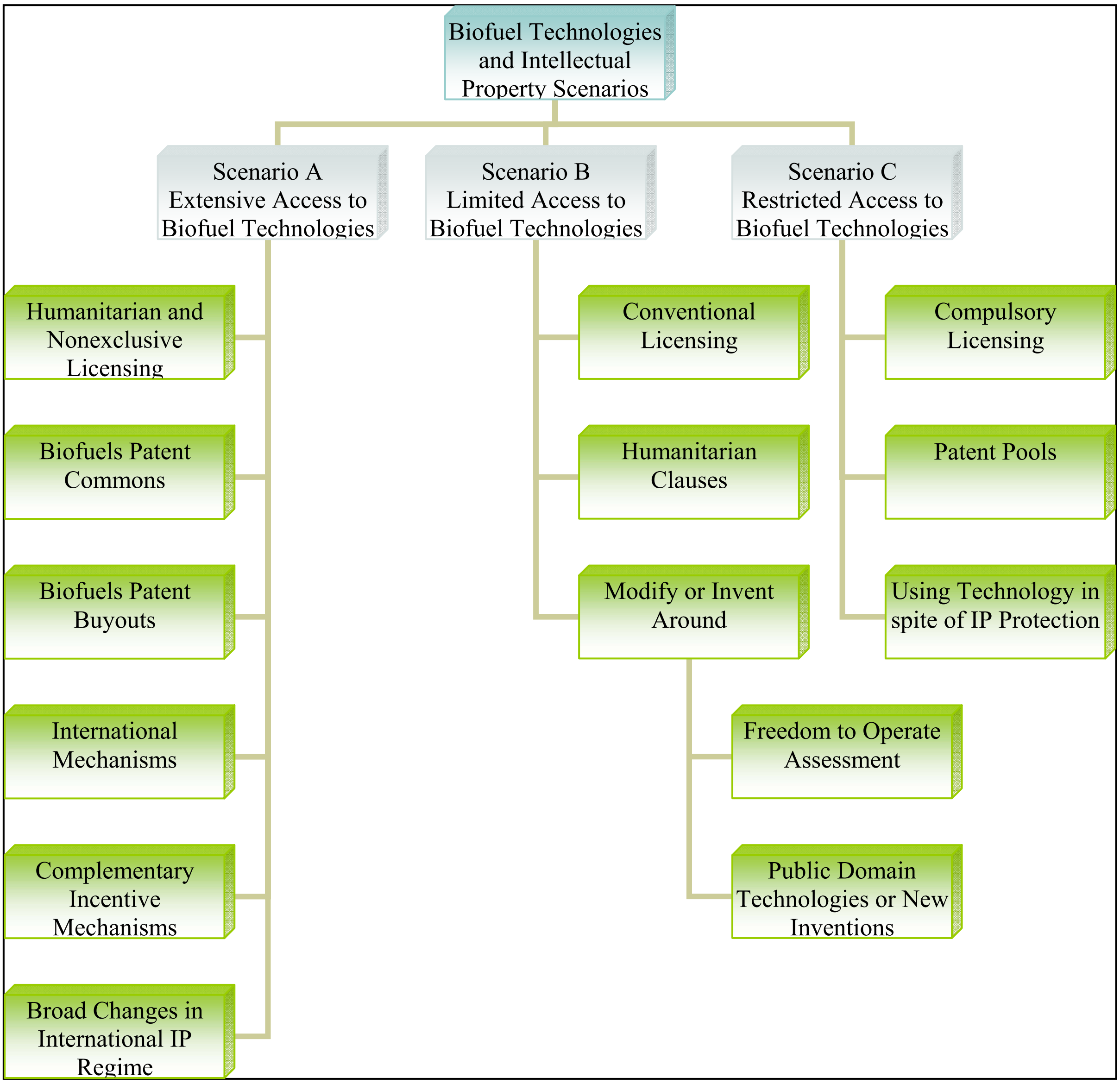
The United States and other developed country governments usually patent subsidized research with a preference for national firms in the licensing process. Indeed, technological developments are supported with the aim of assisting national manufacturers. In the United States, the law imposes favouritism for American manufacturers[63] (Barton, 2007). Some fear that the national preference may hinder developing countries from accessing biofuel technologies developed in the United States and other developed countries.

Others think that intellectual property is rarely an issue in accessing biofuel technology. The most serious patent issues, they say, may likely arise from broad patenting of new technologies, potentially complicating the development of a major category of more efficient and less expensive technologies. From their perspective, trade and tariff barriers and other restrictions associated with international sugar and ethanol markets, not intellectual property, pose the greatest threats to the access of biofuel technologies for developing countries (Barton, 2007).

Because the future of the intellectual property landscape in advanced biofuels is highly uncertain, this chapter maps out three hypothetical scenarios (figure 5.7), including extensive access, restricted access and limited access to biofuel technologies. Each section below lays out the context and likelihood of each scenario, as well as mechanisms that developing countries could use to access technologies within the framework of each scenario.

[63] According to section 204 of the Bayh-Dole Act, the key legislation on intellectual property related to government grants to universities.

Figure 5.7. Scenarios and mechanisms for accessing intellectual property



Source: authors.

Scenario A: extensive access to biofuel technologies

The "extensive access to proprietary biofuel technologies" scenario is a situation in which the developed world freely makes available all or most of its biofuel technologies at little or no cost to the public domain and specifically to the developing world.

Unfortunately, nothing indicates that this is likely to happen. In the context of the United Nations summit on climate change in Bali, Indonesia, in December 2007, a senior representative of the United States, Ambassador C. Boyden Gray, voiced potential disagreement ahead over the intellectual property rules governing the transfer to developing countries of technologies like carbon capture and storage (CCS) and second generation biofuels. He worried that if industries were forced to make these technologies freely available to other countries, it would discourage them from developing such technologies, as they might not be able to recoup their investments (Europolitics, 2007).

Furthermore, some American clean energy companies are reluctant to deploy their most cutting edge technologies in Asia for fear that their know-how will be copied. "It's a concern for anybody trying to export advanced and novel technology to markets where they don't have strong regulatory systems around patent issues", says Benjamin Phillips, president of Emery Energy, the Salt Lake City (United States) start-up that is marketing a proprietary system that can create a biofuel from the organic waste in municipal garbage (Spencer, 2007). Therefore, it seems particularly unrealistic that innovative firms will transfer technology to help a potential licensee become a competitor in the global market (Correa, 2005).

Perhaps a potential slowdown in biofuels patenting due to the stricter patentability requirements could make some biofuels technologies (primarily built upon existing knowledge with modest technological changes) more accessible for developing countries. However, this will not necessarily affect patent filings on brand new, disruptive technology that fundamentally changes the biofuels market. Below, we discuss particular mechanisms that would be reflective of this scenario and facilitate the access to widely available biofuels intellectual property.

1. Humanitarian and nonexclusive licensing of biofuels intellectual property

Universities and research institutes developing biofuel technologies can explicitly reserve rights to support humanitarian applications of such technologies. Though many universities routinely use a reservation of rights to guarantee continued use of licensed technologies within the ongoing research or educational programmes of the university, clauses included in license agreements to reserve rights for humanitarian use of technology are still rare (Bennett, 2007).

In the context of non-exclusive licensing, the licensor retains the freedom to license the technology to other parties in addition to the primary license agreement. Some institutions (e.g., the United States National Institutes of Health) wish to use non-exclusive licensing or to license to multiple companies whenever possible. If an institution can accomplish technology transfer to the private sector through non-exclusive licensing, it has the liberty to subsequently license the technology for humanitarian applications (Brewster et al., 2007).

2. Biofuel patent commons

Developed nations and their respective technology institutions could go even further by devoting a portion of their biofuel technology development to the special needs of the developing nations and to the public domain in general (Barton, 2007; Herder and Gold, 2007). One possible approach is the creation of a Knowledge Fund as the repository of patents dealing with technologies that are critical to the fundamental needs of developing countries, such as environmentally sound technologies or technologies related to food and drugs.

Patent holders would thus be encouraged to deposit patents of interest to developing countries in the Knowledge Fund. Patents could be made available to developing countries by placing patents in the public domain or by granting developing countries automatic and royalty-free licences for the patents listed in the Knowledge Fund. The Knowledge Fund could help ensure that the tacit knowledge required to work these patents locally is also transferred (Mytelka, 2007).

Some of the world's biggest companies have joined together to create a public online database for sharing patents for environmentally responsible products. The new Eco-Patent Commons was created to encourage researchers, entrepreneurs, and companies to develop more ecofriendly practices and incorporate them into their work, according to the World Business Council for Sustainable Development, a coalition of some 200 leading companies, which helped launch the project (Herro, 2008). Massachusetts Institute of Technology (MIT) scientists involved with the Registry of Standard Biological Parts have created the BioBricks Foundation, which might serve to coordinate a synthetic biology "commons".

Placing synthetic biology in the public domain may help developing countries access techniques that could assist in the production of industrial materials, including biofuels such as hydrogen and ethanol (Rai and Boyle, 2007). The limiting factor with respect to the concept of a patent commons is that many leading companies and research and development institutions will probably not be willing to relinquish technologies that are an essential source of competitive advantage in the renewable energy sector. Also, defensive termination provisions may effectively limit third party rights to the technologies provided.[64]

3. Biofuel patent buyouts

Developed countries could purchase patents on key biofuel technologies for free use in developing countries, potentially maintaining the incentive to invest in research and development while lowering the cost of acquisition for poor countries (Hoekman et al., 2004; Herder and Gold, 2007). Some suggest that patent buyouts could be facilitated as part of overseas development assistance (ODA) provided by developed to developing countries. Potential benefits include reduced litigation costs and exoneration from charges of "economic imperialism" (Kingston, 2005). Patent buyouts would not impede innovation because the innovating firm would be well paid for its research. Indeed, the patent buyer could easily increase the incentive to innovate by raising the buyout price.

4. International mechanisms for biofuel technology transfer

At the international level, Noordwijk Medicines Agenda, the World Intellectual Property Organization (WIPO) Development Agenda and recent work by the Intergovernmental Working Group on Public Health, Innovation and Intellectual Property at the World Health Organization (WHO) all point to the need to create and disseminate new models for the licensing and sharing of intellectual property. Though working models have not yet been developed, they would likely include mechanisms for bundling intellectual property (e.g., through pools, clearinghouses and public–private partnerships), willingness not to enforce certain patent rights, developing consortia and other collaborative measures for knowledge and information sharing (Herder and Gold, 2007).

The development of the United Nations Adaptation and Technology Funds may also help countries cope with the consequences of climate change and enable them to cut emissions by harnessing new technologies (Europolitics, 2007).

5. Complementary incentive mechanisms for biofuels intellectual property

Another option to explore could be setting up complementary incentive mechanisms, such as direct government grants to the private sector, "advance market commitments" and "prize funds" in lieu of traditional patenting mechanisms for protecting biofuels intellectual property. With the exception of a few pilot studies currently under way, there is presently no empirical data as to whether these mechanisms provide sufficient or comparable incentives to encourage researchers and firms to engage in research and development projects intended to address the needs of developing countries.

Where such mechanisms do guarantee net profits, they still may not be sufficient to encourage larger Western firms because of the "opportunity costs" of forgoing other areas of

[64] According to Rosen (2006), "Defensive termination is a form of implicit cross licensing of patent or other intellectual property rights. Consider a case where company A licenses patent A to company B. One of the conditions of the license agreement is that if company B should ever sue company A for infringing one of company B's own patents, such as patent B, then company A can terminate the license to patent A. Thus company A would be able to counter sue company B for infringing patent A. This is a strong incentive to prevent company B from suing company A for any future patent it might receive after it has licensed patent A."

research and development with Western markets. Furthermore, there exists less (or virtually no) evidence about the effect of these alternative mechanisms on industrial biotechnology (including biofuels) in developing countries, and there has been minimal effort to adapt these alternative mechanisms to the industrial biotechnology (and biofuels) sector (Herder and Gold, 2007).

6. Broad changes in the international intellectual property regime

Several broad, fundamental changes in the international intellectual property regime could have implications for making second generation biofuels more accessible to developing countries. The first is a global recommendation for governments to forgo favouritism in licensing biofuel patents to national manufacturers, similar to the "humanitarian clauses" being considered in the medical and agricultural areas.

For example, section 204 of the United States Bayh-Dole Act could be waived by the Government of the United States. There is history of such waivers by the United States National Institutes of Health Office of Technology Transfer with respect to licenses of tropical disease technologies to developing nation entities (Barton, 2007). Others suggest that modifying the provision of regulations such as the Bayh-Dole Act that favour local manufacturing may be more practical for countries that lack research-intensive industries or manufacturing capability (Boettiger and Bennett, 2006). Another proposal is to create a formal gatekeeping mechanism to weed out patents on foundational, broadly enabling platform technologies with significant social value (Herder and Gold, 2007).

Scenario B: limited access to biofuel technologies

The "limited access to proprietary biofuel technologies" scenario is a situation requiring some effort on the part of developing countries to gain access to technologies and reasonable substitute technologies. Though intellectual property may be protected by a diversity of firms (both large and small), universities and other research institutes, technology transfer could be facilitated through conventional (and unconventional) licensing mechanisms as well as alternative product development schemes (e.g., inventing around). Below we discuss a few mechanisms for accessing intellectual property in the context of this scenario.

1. Conventional licensing mechanisms

In the context of second generation technologies, methods, enzymes and new micro-organisms for cellulosic breakdown will likely be patented. However, it is also probable that the patent holders will be willing to license their technology for use everywhere because of the costs of biomass transport and the need to decentralize production. In other words, biofuels and feedstock production is expected to take place in many different countries and regions. The licensing fees for these technologies are unlikely to be kept at a high level for very long, due to competition. Intellectual property plays a considerably different role in the renewable energy industries than it does in the pharmaceutical sector where the basic approaches to solving the specific technological problems have long been off-patent and what is usually patented are specific improvements or features.

Thus, there is competition between a number of patented products and also between the sectors and alternative energy sources, ultimately reducing the licensing fees. In other cases where there are patent disputes, cross-licenses among firms may permit each to use some of the technological features developed by others or product modifications can be implemented in a non-monopolistic way. Thus, licensing fees alone are unlikely to be an impediment to developing nations' access to technologies to produce biofuels. Where there are direct private technology transfers from a developed nation firm to a developing country firm, a patent with clearly defined rights can actually help facilitate the negotiation of a license (Barton, 2007).

2. Humanitarian clauses

If a commercial licensee insists upon an exclusive license, the university or research institute licensors can limit the exclusive license to developed country markets and for specific product applications. The opportunity as well as the challenge with developing humanitarian clauses is the issue of market segmentation. With a market segmentation (or dual market) approach, an exclusive license might give a private sector entity the sole right to use a technology in profitable markets, while allowing others to use the technology at no cost or reduced royalties to serve market segments that do not interest the private sector.

The primary challenge is the containment of the intellectual property within the targeted markets. This poses a challenge to many developing countries who are considering developing second generation biofuels not only for their domestic markets but for the emerging global biofuels market. Market segmentation, unfortunately, is most successful where non-commercial markets can be sharply delineated by region, which makes it easier to exclude spillovers to non-targeted markets. Furthermore, market segmentation often requires intense negotiation, the development of trust between partners, and the capacity to enforce agreements (Brewster et al., 2007).

3. Modifying or inventing around patented technologies

An alternative to licensing is to change the product specifications, either by modifying the product with technologies available in the public domain or by inventing around the patented technology with new technologies altogether. These strategies are preceded by a "freedom to operate" assessment, which provides an analysis of the intellectual property opportunities and challenges related to the use of certain technologies. It must be noted that the costs of working around patents may actually limit who is able to participate in the second generation biofuels technologies (Herder and Gold, 2007).

4. Freedom to operate

Freedom to operate (FTO) assessment is a process whereby an institution conducts thorough due diligence to gain a clear picture of the patent rights supporting its technology (Boettiger and Bennett, 2006; Raciti et al., 2008). Due diligence helps mitigate the risks of litigation. If an FTO assessment is conducted later in the commercialization stage, it can create a situation where proprietarily-owned technologies are embedded and re-engineering the innovation to use other technologies may be financially or technically infeasible. Many Western commercial firms evaluate promising research projects early on for intellectual property considerations, providing greater flexibility and allowing FTO information to be accounted for in weighing the costs and benefits of commercialization (Boettiger and Bennett, 2006).

Because many developing countries do not have well-trained intellectual property management staff in the area of agricultural technology, the Public Intellectual Property Resource for Agriculture (PIPRA)[65] serves to address FTO issues, delivering services that individual universities are not designed to provide. One PIPRA programme involves building an intellectual property database. Using the database, patents are searchable with respect to various parameters, including licensing status.

The goal of the database is to inform public sector researchers about their freedom to operate and help them clear all intellectual property barriers to bring a new product to the market. The software also finds ways to invalidate patents and minimize the chances of patent blocking.

[65] PIPRA is a non-profit organization whose aim is to improve technology transfer to developing countries: http://www.pipra.org/en/about.en.html.

The database and PIPRA's analytical services are free for academic research and humanitarian purposes (Eiss et al., 2007). This patent database could perhaps be helpful where new agricultural biotechnological innovations are being developed for feedstocks for second generation biofuels.

5. Identifying alternative public domain technologies

One way to avoid potential intellectual property infringement issues identified in the FTO analysis is to locate alternative technologies in the public domain that would satisfy the technical requirements for the technological process(es) (Krattiger, 2007a). Published scientific literature, trade journals, conference proceedings, abandoned patents, expired patents and public domain technologies (e.g., Biofuels Patent Commons) are all potentially viable sources for finding public domain technologies. With respect to expired and abandoned patents, overlapping claims from other patents may still be active and could affect the freedom to use the technology (Krattiger, 2007b).

6. Inventing around

Another option following the FTO exercise is to "invent around" intellectual property by creating a similar technology that does not infringe on any existing patents (Mahoney and Krattiger, 2007). Choosing the "invent around" option would require a research team to search for alternative ways to develop the product in question. Though this could delay biofuels product development, it could lead to significant benefits in terms of new inventions, new intellectual property for cross-licensing and perhaps even better products. The main challenge is the actual capacity to invent new technological processes and the costs (both in terms of time and money) that may not be feasible for developing country public sector organizations. The costs of licensing versus the costs of inventing a significantly new product should be weighed using a risk/benefit analysis (Krattiger, 2007a).

Scenario C: restricted access to biofuel technologies

The "restricted access to biofuel technologies" scenario is one in which the most significant, foundational technologies to produce second generation biofuels are controlled by a few very large firms that restrict developing countries' access to the new technologies. This could happen if the trajectory of the global biofuels market follows the path of the agricultural biotechnology industry.

Through divestitures, mergers and acquisitions, there has been a process of consolidation in the global agribusiness in recent years. The outcome has been a few major integrated companies, each controlling proprietary lines of agricultural chemicals, seeds and biotech traits. Beginning in the late 1990s, intellectual property ownership has increasingly consolidated in this dwindling number of large multinational corporations.

Though small start-up companies still figure prominently as acquisition targets or as licensors to the large corporations, by 2002 95 per cent of patents originally held by seed or small agrobiotech firms had been acquired by large chemical or multinational corporations. When a few multinational companies are backed by a broad portfolio of patents, including proprietary entitlements on key enabling technologies, it may impede access to technologies if they refuse to license (UNCTAD, 2006).

Currently, second generation biofuels are only in pilot production and there are no clear leaders in this emerging sector where technologies are still being tested for viability and cost-effectiveness. It is too early to predict if the market will mature into a few, large multinational companies with the essential portfolio of technologies to dominate the development of second generation biofuel technologies. However, the patenting trends in the biotechnology and other sectors and the possibility that large oil, gas and chemical companies will license or acquire new biofuel technologies (Raciti et al., 2008) are fanning the fears that access to second generation biofuel technologies may be restricted.

Another hypothetical restricted access scenario could emerge if many different patented technologies (for the agricultural and industrial processes) are required for producing second generation biofuels. Indeed, it would be extremely cost prohibitive to license all the technologies, especially in developing countries. This phenomenon, called the “tragedy of the anticommons”, occurs when multiple owners each have a right to exclude others from a scarce resource and no one has an effective privilege of use (Heller and Eisenberg, 1998).

An anticommons can result, in theory, in any technological field where a proliferation of patent rights has occurred, bringing attention to the patenting trends of biofuels (Herder and Gold, 2007). Despite the large number of patents and the numerous, heterogeneous actors (i.e., large pharmaceutical firms, biotech startups, universities and governments), studies examining the incidence of anticommons problems in academics and industry (including data from Australia, Germany, Japan and the United States) find them relatively rare (Caulfield et al., 2006).

Another aspect of this scenario could be “blocking” or “hold-up”. This is the case where no industrialized patent holders of second generation biofuel technologies are willing to license their technologies to manufacturers in developing countries or engage in alternative intellectual property transfer mechanisms (humanitarian clauses, non-exclusive licensing, etc.) because of exclusive licensing. Some assert that broad patenting and anticompetitive “strategic” use of patents could possibly result in expensive licensing, limited scientific communication for patent licensees and time-consuming measures to avoid patent infringement.

Broad patents may be filed or purchased not for the purposes of product development, but to enable “strategic use” of the patents to prevent competitors from developing products (Suppan, 2007). These fears may also be compounded by the reality that there is no special treatment or flexibility for access to environmentally sound technologies (like there is for health or nutrition) within the World Trade Organization Agreement on Trade-Related Intellectual Property Rights (TRIPS) (Barton, 2007).

Some policy analysts argue that there are not yet cases of “blocking patents” in the industrial biotechnology sector, though this does not mean that this problem does not exist or will not exist in the future. It may merely reflect the fact that, given its sensitivity, health issues are better tracked and analysed than other issues (Herder and Gold, 2007). Others, however, posit that patent lock-up is already happening with, for example, critical enzymes in the biofuels production process (Ortiz et al., 2006). Below we discuss a few mechanisms that could be used by developing countries to access second generation biofuel technologies in the context of this patent lock-up scenario.

1. Compulsory licensing

When there are no close substitutes for a biofuels technological product or process, compulsory licensing may be an option. A compulsory license is an authorization given by a national authority to a natural or legal person for the exploitation of the subject matter protected by a patent; the consent of the patent title holder is not necessary. Compulsory licenses may be required to import or produce a given product or to use a patented technology for research (Correa, 2007). Compulsory licenses are granted in order to attain various public policy objectives, including counteracting anticompetitive business practices.

Less technically endowed firms are unlikely to benefit from a mechanism that does not ensure access to required know-how and technical assistance, which may be essential for the absorption and putting into operation of the relevant technology (Correa, 2005). On the whole, compulsory licensing may be a blunt instrument that is unlikely to promote technological innovation.

2. Patent pools

Another approach is the potential use of patent pools. Some of the benefits of this option include: (a) increased speed and efficiency in obtaining rights to patented technology through one-stop licensing mechanisms; (b) distribution of risks associated with research and development; (c) avoidance of patent litigation through the elimination of blocking patents and stacking licenses; (d) significant decrease in research and administrative costs; and (e) institutionalized exchanges of otherwise proprietary know-how (trade secrets) through cooperative efforts.

Though patent pools have been established in the consumer electronics industry, patent pools in biotechnology have not developed as a response to fragmented patent ownership. In the case of agricultural biotechnology, for example, cross-licensing and mergers and acquisitions have been the common response (Clift, 2007; Krattiger and Kowalski, 2007). In fact, there are no examples of functioning patent pools in the life sciences or biotechnology (Herder and Gold, 2007; Rai and Boyle, 2007).

If patent pools are a possibility in the area of biofuels, they are probably unlikely to change the underlying structural barriers to technology transfer. Patent pools are difficult to establish because of the divergent strategic interests of industry players, and are effective for technology transfer only in partial or modified form (table 5.1). On a practical level, patent pools may assist with the process of licensing intellectual property but not necessarily with the sharing of know-how and trade secrets.

If biofuels represent a potentially profitable energy subsector in the future, it is unlikely that the most innovative technology will be used and traded globally without some legal recourse.

Moreover, depending on how a patent pool is organized and implemented, it either cuts through patent-thicket blockages to facilitate access to critical biofuel technologies or can lead to antitrust issues (e.g., where horizontal competitors abuse the system to form an anticompetitive cartel). Though patent pools can be a useful intellectual property management tactic with positive implications for access to technologies, they may not be the best way to achieve the transfer of technology (Krattiger and Kowalski, 2007). Table 5.1 presents a summary of the pros and cons of patent pools as discussed in Krattiger and Kowalski (2007).

Table 5.1. Pros and cons of patent pools

PROS	*CONS*
Integrates complementary technologies	Difficult to agree on the value of individual patents contributed to a pool
Reduces transaction costs	Complex to set up and avoid antitrust problems (collusion and price fixing)
Clears blocking positions	
Avoids costly infringement litigation	May inflate licensing costs through nonblocking or unnecessary patents
Promotes the dissemination of technology	Complex when many patents are under litigation, as is the case with biotechnology
Levels the playing field	May shield invalid patents and thus prevent much technology from entering the public domain

Source: Krattiger and Kowalski (2007).

3. Using technology irrespective of intellectual property protection

There are other ways that developing countries can address "blocking patents." One strategy is to develop and market the products in countries where patents have not yet been filed. If an expert opinion determines that the blocking patents might not withstand legal challenge, then one could possibly proceed without a license (Mahoney and Krattiger, 2007; Hall, 2007; Caulfield et al., 2006).

Case studies conducted by the Organization for Economic Cooperation and Development (OECD) in the early 1990s observed that even when clean technologies were under patent, these patents were not a major concern either to importers or exporters. In general, exporters were willing to accept the risk of patent infringements, because technological developments were moving so quickly that by the time a competitor could effectively copy a particular process, the technology was likely to have been overtaken by new technologies (Less and McMillan, 2005).

If biofuels represent a potentially profitable energy subsector in the future, it is unlikely that the most innovative technology will be used and traded globally without some legal recourse. Some intellectual property experts contend that the next wave of large patent litigation disputes will arise with respect to methods and processes for converting biomass into biogas, biodiesel and bioethanol and genetically engineered plants grown specifically for the purposes of energy production (Portfolio Media, 2007). Moreover, many poor countries are extremely reluctant to engage in expensive litigation in the case of patent infringement (Love, 2002).

D. Developing countries' capacity to participate in second generation biofuels

What will be the capacity of developing countries to effectively participate in the emerging second generation biofuels sector?

The 2006/2007 period marked the beginnings of commercial investments in advanced second generation biofuels plants in Canada, Germany, Japan, the Netherlands, Sweden and the United States. Much of this investment went beyond pilot-scale plants, with government support tied to private investment as an important factor. Canada created a Can$500 million fund to invest in private companies developing large-scale facilities for producing both ethanol and biodiesel from cellulose.

The United States announced in early 2007 that it would invest up to $390 million in six cellulosic ethanol production plants over the coming four years, with total capacity of 500 million litres (132 million gallons) per year. The world's first commercial wood-to-ethanol plant began operation in Japan in 2007, with a capacity of 1.4 million litres per year (0.37 million gallons). The first wood-to-ethanol plant in the United States was planned to be completed by 2008 with an initial output of 75 million litres (19.8 million gallons) per year. In Europe, a Dutch firm was building a $200 million plant that would produce 200 million litres (52.8 million gallons) per year from wheat chaff and other wastes by late 2008 (REN21, 2008).

However, developing countries are noticeably absent from this picture. The premise of the authors is that second generation biofuels will probably be commercialized in advanced developing countries where there is reasonable infrastructure, existing capacity in biofuels production and an enabling environment for innovation in general and in the biofuels sector in particular.

One way to forecast possible developing country actors in the second generation biofuel sector is to identify those countries that have the current capacity to produce biofuels and possibly become early movers in the emerging technologies. The Ernst and Young Biofuels Country Attractiveness Indices, ranking the attractiveness of global markets for investment in biologically derived renewable fuels, which include both ethanol and biodiesel, are a useful proxy[66] (Ernst & Young, 2008).

As noted in table 5.2, several developing countries rank quite high in the biofuels attractiveness indices. For the purposes of this report, we focus on Brazil, China and India. China held its position as the world's third largest producer of bioethanol in 2007, despite the stagnation of investment in the subsector caused by uncertainty over the political framework. The government has set targets of 2.5 billion litres of capacity by 2010 and 12.7 billion litres by 2020.

Table 5.2. All Biofuels Index at Q4 2007

*Ranking**	*Country*	*All Biofuels*	*Ethanol*	*Biodiesel*	*Infrastructure*
1 (1)	USA	75	80	69	86
2 (2)	Brazil	71	75	67	94
3 (4)	Germany	60	65	60	81
4 (3)	France	59	64	56	67
5 (5)	Spain	57	60	55	60
5 (6)	Canada	57	59	53	72
7 (9)	Thailand	53	56	50	47
7 (11)	China	53	56	50	47
9 (7)	UK	52	55	49	56
10 (8)	Sweden	51	54	48	66
10 (11)	Colombia	51	54	48	50
10 (11)	India	51	53	48	50
13 (14)	The Netherlands	48	50	48	48
13 (9)	Italy	48	49	47	47
13 (-)	Philippines	48	48	47	46

Source: Ernst & Young (2008).
*Ranking in the Q3 2007 All Biofuels Index in brackets.

However, research suggests that ethanol production capacity remained unchanged in 2007, at 1.3 billion litres (0.34 billion gallons) per year. China is now searching for a more manageable way to expand the industry, with its new policy framework giving incentives to new feedstocks and processing technologies. Though China may never be an exporter of bioethanol, it remains aggressive in acquiring foreign technology, particularly for cellulosic ethanol. Chinese biodiesel production is at a very early stage of development in part because biodiesel feedstocks are in short supply. The government has only recently decided to actively support the industry, trialling non-traditional biodiesel crops such as jatropha (jatropha is analysed in detail in chapter VI).

The greatest opportunities in the industry, however, stem from the programme to build coal-to-liquids plants, in which $20–25 billion is being invested. The Fischer-Tropsch process, the dominant technology used in the plants, can also produce synthetic diesel from gasified biomass. It is envisaged that China's biodiesel production will hit 6.5 billion litres (1.7 billion gallons) per year by 2020, of which more than half will be produced through the Fischer-Tropsch process. Because of China's dependence on coal and lack of domestic oil, it seeks to ensure its

[66] The Biofuels Index provides scores out of 100 and is made up of a Biofuels Infrastructure Index (35 per cent) and Fuel-Specific Indices (65 per cent). The Biofuels Infrastructure Index is an assessment by country of the general regulatory infrastructure for biofuels, considering on a weighted basis: market regulatory risk (29 per cent), supporting infrastructure (42 per cent) and access to finance (29 per cent). The Fuel-Specific Indices comprise two indices providing fuel-specific assessments for each country, namely ethanol and biodiesel. Each of the Fuel-Specific Indices consider, on a weighted basis: offtake incentives (25 per cent), tax climate (8 per cent), grants and soft loans (8 per cent), project size (8 per cent), current installed base (11 per cent), domestic market growth potential (15 per cent), export potential (15 per cent) and feedstock (10 per cent).

energy security with renewable energy playing a significant role. China is working to build a local equipment industry, foster the creation of competitive local suppliers and buy the best foreign technologies so that it can become a supplier of low-carbon technologies to the rest of the world (New Energy Finance, 2008; Greenwood et al., 2007).

Though other developing countries are establishing biofuel industries, most of them are not engaged in the development of advanced biofuel technologies. Brazil, home to the world's largest renewable energy market with its long-established bioethanol industry, is primarily engaged in first generation biofuels. The same can be said of India's well-established bioethanol industry and its nascent biodiesel industry (Greenwood et al., 2007). In poorer developing countries, and particularly in sub-Saharan Africa, investment in renewable energy is very low and only for first generation biofuel technologies.

E. Building an innovation system for biofuels

Transferring biofuel technology involves not only access to intellectual property per se but, most importantly, the capacity to understand the tacit knowledge embedded in technology. Without the soft knowledge that accompanies the technological hardware involved in technology transfer, it may not be easy to replicate technological change, including in the biofuels sector (Worldwatch Institute, 2007).

Any biofuels development strategy that focuses only on intellectual property issues is bound to fail and may even be counterproductive. Efforts to promote compulsory licensing, for example, aiming at making biofuel technologies available in developing countries at low prices, must overcome not only intellectual property difficulties but also the obstacles presented by other components of innovation. These include the existence of manufacturing facilities that meet international standards, the availability of funds to procure the products for both domestic and international distribution and the cost of obtaining regulatory approval for products manufactured under compulsory licenses (Mahoney and Krattiger, 2007). While licensing is an important source of technical transformation, successful transfer generally requires the capacity to learn, improve information flows and make adaptive investments (Hoekman et al., 2004).

The licensing of technological products and processes has in some ways become a substitute for learning and innovation. Historically, current "developed" countries complemented the importation of foreign technology with local initiatives to recreate the technology (Bell and Pavitt, 1992). In the chemical and shipbuilding industries, Japan licensed the technology and made substantial investments in developing the capabilities to diffuse, modify and innovate upon the imported technology. Technology transfer in Japan, as well as in other developing countries having similar strategies in place, was viewed in the context of building the capacity to innovate technologically (Mytelka, 2007).

A country's general economic situation, the strength of its educational system as well as its communication infrastructure and quality of government might impact the extent and quality of technology transfer to a far greater extent than the particular level of intellectual property protection under which the transfer of technology takes place. In the case of India, the mathematical, information and language skills of Indian programmers probably have contributed more to its success as an outsourcing country than the intellectual property protection granted under Indian copyright law to computer programmes (Dreier, 2007). Similarly, one of the drivers of Brazil's success in biofuels – through its "Proálcool" programme – was its strong foundation in research, education and training, providing a knowledge platform that was able to develop technology and absorb, adapt and improve upon transferred technologies. Creating the domestic capacity to understand, utilize and replicate existing biofuel technologies requires a broader system of innovation that can facilitate knowledge and technical flows among different stakeholders (Worldwatch Institute, 2007).

1. National system of innovation for transfer of biofuel technology

Governments can reduce the technological "distance" between local and foreign firms by establishing national or regional innovation systems that encourage local research and development and transfer of knowledge from universities and public laboratories to domestic firms (Hoekman et al., 2004). As mentioned above, such an innovation system is one of the key reasons for the success of the Brazilian ethanol programme. Other developing nations who wish to follow the Brazilian example should establish or enhance such a national system (Larson, 2007).

Figure 5.8 illustrates the concept of an innovation system, sketching all the actors and activities in the economy that are necessary for industrial and commercial innovation to take place and to lead to economic development (Arnold and Bell, 2001). In an innovation system, the domestic capacity to engage in innovation depends not only on knowledge-producing institutions (universities and research institutes) or technology centres, but also on other institutional factors such as financial infrastructure, availability of human resources, physical infrastructure, network linkages and synergistic collaboration, innovation support services, and demand and framework conditions (UNCTAD, 2007).

In the sections below, we discuss the role of some of the actors and institutions involved in the process of helping developing countries build innovation systems for biofuels.

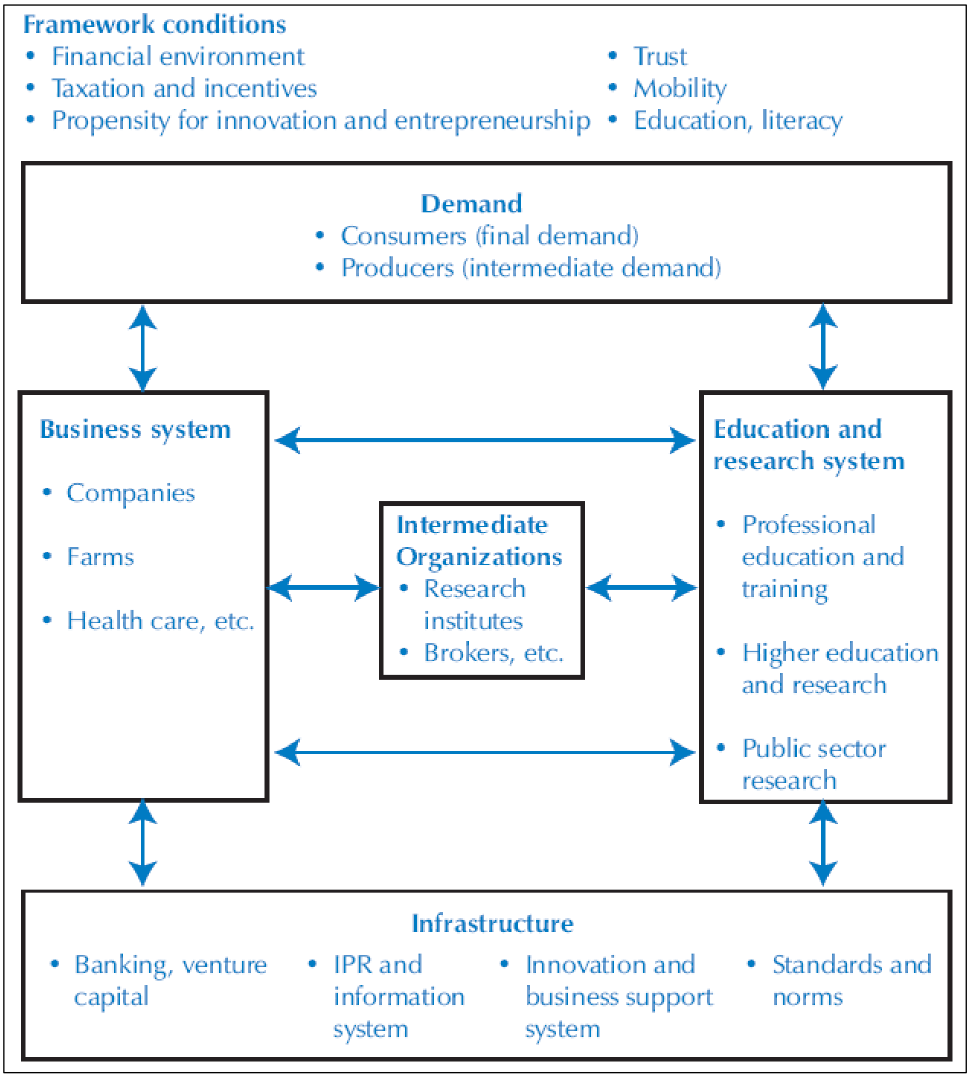
2. National governments

Governments can support the development of a robust biofuels industry through long-term investments in research and development and infrastructure, policies that provide incentives for biofuels production and use (such as the mandatory blends analysed in chapter I) and strategic diplomacy to promote transfer of biofuel technology.

Strategic diplomacy through bilateral and multilateral technological cooperation can also promote the transfer of biofuel technology. For example, Brazil's ethanol technology was developed in the context of collaborative agreements between Brazil and a host of other developing countries (Worldwatch Institute, 2007). Ministries of foreign affairs can promote international technology cooperation and forge strategic alliances with countries holding a leading position in biofuel technology, as well as engage and coordinate transnational diasporic communities in biofuel technology development programmes (Juma and Serageldin, 2008).[67] Bilateral and multilateral information sharing between countries can also play an important role in information dissemination and technical exchange (Worldwatch Institute, 2007; Kartha et al., 2005).

[67] The Indian and Taiwanese diasporic communities in Silicon Valley played a critical role in establishing IT and semiconductor industries in their home countries, respectively (Saxenian, 2006).

Figure 5.8. Elements of a national system of innovation



Source: UNCTAD (2007) and Arnold and Bell (2001).

3. Knowledge institutions

Research is needed specifically to improve feedstock production as well as technologies for harvesting, processing, transporting and storing feedstocks and fuels. Research and development is also required to better understand the potential environmental and societal impacts of biofuels throughout the entire supply chain (table 5.3) (Worldwatch Institute, 2007).

Knowledge institutions can collaborate with international partners for research and development training abroad and/or research cooperation. In the late 1970s, Copersucar (a major cooperative of mills in Brazil) sent a dozen Brazilians to Mauritius for one year to learn sugar and ethanol production. Upon returning, this group became the core of the industrial unit of Copersucar's research centre, Centro de Tecnologia Copersucar (CTC), which focused on sugar cane cultivation in São Paulo (SP varieties). Copersucar also led an international consortium of groups from Australia, South Africa, the United States and other countries. In 2001, these developments led, for the first time in Brazil, to the genetic mapping of the sugar cane plant (Worldwatch Institute, 2007).

Table 5.3. Research and development agenda for biofuels development

Research Area	Specific Research Initiatives
Feedstock production	Improve conventional feedstocks Develop next-generation feedstocks Advance alternatives to chemical inputs Assess the risks of genetic modification Supplement environmental life-cycle studies Develop metholodology for measuring life-cycle greenhouse gas (GHG) emissions
Feedstock collection and handling	Improve equipment and harvesting practices Ascertain sustainable residue removal rates Improve waste-handling practices Optimize feedstock storage and transport methods
Processing	Maximize efficiency of input use Advance the biorefinery concept
Fuel distribution and end use	Advance fuel and power train development Optimize vehicles Develop materials Develop fuel additives

Source: Worldwatch Institute (2007).

4. Private sector

Because technology flows are typically driven by the private sector, the business community can play a critical role in diffusing biofuel technologies to developing countries. The Proálcool programme was successful in part due to the Brazilian private sector's willingness to receive and adapt foreign technologies to local conditions (Worldwatch Institute, 2007). The setting up of joint ventures is a way to transfer technology, using foreign private sector actors who have experience, technical expertise and investment capital to contribute to the project.

One example is of a Swedish firm that formed joint ventures with small companies in Estonia, Latvia and Lithuania for manufacturing biomass feedstock. The joint ventures eventually expanded the use of biomass in the heating and agroprocessing sectors, reaching markets that neither the Swedish firm nor the small firms could have reached on their own (Kartha et al., 2005).

Developing countries can use their favourable climates for biomass production as a bargaining tool to engage in international joint ventures, contributing host sites for demonstrations and first commercial plants as well as avenues for entering local biofuels markets (Larson, 2008).

Consulting firms and private laboratories can also facilitate the transfer of biofuel technology through consulting services and analysis, convening training for capacity-building and mobilizing professionals from various sectors for collaboration (Ueki, 2007). Centro de Tecnologia Copersucar's industrial unit transferred foreign technologies, in part, through contracts with foreign and Brazilian companies, consultants, research centres and universities. In the 1970s and 1980s, Australian and South African consultants helped develop the Brazilian roller mill (Worldwatch Institute, 2007).

5. Financial institutions

Government financing of sugar cane and ethanol production in Brazil was critical for the success of the Proálcool programme (Worldwatch Institute, 2007). Various financing initiatives can be pursued to stimulate biofuels production and use, as described in the earlier section on infrastructure. However, governments can also support capacity-building activities within financial institutions to support an emerging biofuels industry, with a focus on: understanding biofuel technologies and their levels of commercial maturity; appreciating the financial benefits of using biomass resources; understanding feedstock procurement risks and mechanisms for risk mitigation; accounting for the effects of supply seasonality on cash flow in negotiating repayment terms; considering similar projects as candidates for bundling into larger loans with lower transaction costs; and understanding policy incentives (e.g., renewable portfolio standards, power purchase agreements and carbon offset arrangements) that contribute to biofuels project viability (Kartha et al., 2005).

6. Intellectual property regime

The actual effect of intellectual property regimes on transfers of environmentally sound technologies is difficult to measure, and there is a lack of empirical data to support literature (Less and McMillan, 2005). Much uncertainty remains regarding the effects of intellectual property on technology transfer to developing countries, with the effects probably depending on the level of development of a receiving country, the specific technological fields involved, the behaviour and absorptive capacity of single local firms and the general macroeconomic environment of the host country (Roffe, 2005).

7. Regional innovation communities

In the case of smaller developing countries with inadequate human, financial and social capital to build national innovation systems for biofuels, regional innovation communities can help overcome “institutional thinness” through regional collaboration. Regional cooperation in science and technology can take various forms, including joint science projects, sharing of information, conferences, building and sharing joint laboratories, setting common standards for research and development, and exchange of expertise.

Some of the potential benefits of regional innovation communities include access to new knowledge; foreign skills and training opportunities that may not be available at the national level; access to large and often expensive research facilities; enrichment of political and social relations between countries; larger groups that are more attractive for major international grants; and building or strengthening domestic research and development institutions (Juma and Serageldin, 2008). A starting point for regional innovation is the development of comprehensive regional biofuels policies, strategies, and research and development agendas (Jumbe and Msiska, 2007).

F. Concluding remarks

The future of biofuels, especially second generation technological systems, will be characterized by technological complexity and integration of a diversity of engineering subsystems. In addition, these technologies are being developed in a period when there is increased interest in strengthening intellectual property protection activities.

These trends may be coupled by business models that follow the approach of the biotechnology industry, therefore allowing limited technological spillovers in countries that provide feedstocks. Given this outlook, this chapter assumes a rather restricted intellectual property regime that will demand greater technological effort by developing countries wishing to enter the second generation biofuels phase.

Because of increased patenting and venture capital investments in the advanced biofuels sector, probably only the most advanced developing countries with existing biofuels capacity and innovative strength will be able to forge ahead into second generation biofuel technologies.

Though a number of mechanisms exist for accessing advanced biofuel technologies irrespective of the future intellectual property landscape, the capacity to innovate will effectively determine the countries that are able to participate in this emerging field. All developing countries, however, can make efforts to strengthen their innovation systems to eventually take advantage of the latest biofuel technologies for domestic use and global trade of renewable energy.

Technological developments also have a role to play in expanding the number of feedstocks available for conversion into biofuels, and increasing their energy yield. The last chapter of this volume analyses a specific feedstock, jatropha.

References

Arnold E and Bell M (2001). Some new ideas about research for development. In: *Partnerships at the Leading Edge: A Danish Vision for Knowledge, Research and Development*. Copenhagen, DANIDA/Ministry of Foreign Affairs: 279–316.

Barton JH (2007). Intellectual property and access to clean energy technologies in developing countries: an analysis of solar photovoltaic, biofuel and wind technologies. ICTSD trade and sustainable energy series issue paper 2. International Centre for Trade and Sustainable Development. Geneva.

Bell M and Pavitt K (1992). Accumulating technological capability in developing countries. In: *Proceedings of the World Bank Annual Conference on Development*. 257–281.

Bennett AB (2007). Reservation of rights for humanitarian uses. In: Krattiger A et al., eds. *Intellectual Property Management in Health and Agricultural Innovation: A Handbook of Best Practices.* Oxford and Davis, MIHR and PIPRA: 41–45.

Boettiger S and Bennett A (2006). The Bayh-Dole Act: implications for developing countries. *IDEA: The Intellectual Property Law Review*. 46(2): 261–281.

Brewster AL et al. (2007). Facilitating humanitarian access to pharmaceutical and agricultural innovation. In: Krattiger A et al., eds. *Intellectual Property Management in Health and Agricultural Innovation: A Handbook of Best Practices*. Oxford and Davis, MIHR and PIPRA: 47–61.

Caulfield T et al. (2006). Evidence and anecdotes: an analysis of human gene patenting controversies. *Nature Biotechnology*. 24(9): 1091–1094.

Clift C (2007). Patenting and licensing research tools. In: Krattiger A et al., eds. *Intellectual Property Management in Health and Agricultural Innovation: A Handbook of Best Practices.* Oxford and Davis, MIHR and PIPRA: 79–88.

Correa CM (2005). Can the TRIPS Agreement foster technology transfer to developing countries? In: Maskus KE and Reichman JE, eds. *International Public Goods and Transfer of Technology Under a Globalized Intellectual Property Regime.* Cambridge, Cambridge University Press: 227–256.

Correa CM (2007). Compulsory licensing: how to gain access to patented technology. In: Krattiger A et al., eds. *Intellectual Property Management in Health and Agricultural Innovation: A Handbook of Best Practices*. Oxford and Davis, MIHR and PIPRA: 273–279.

Dreier T (2007). Shaping a fair international IPR regime in a globalized world. In: Govaere I and Ullrich H, eds. *Intellectual Property, Public Policy, and International Trade*. Brussels, P.I.E. Peter Lang: 43–75.

Eiss R et al. (2007). Ensuring global access through effective IP management: strategies of product-development partnerships. In: Krattiger A et al., eds. *Intellectual Property Management in Health and Agricultural Innovation: A Handbook of Best Practices*. Oxford and Davis, MIHR and PIPRA: 63–78.

Ernst & Young (2008). *Biofuels country attractiveness indices: Q4 2007*. London, EYGM Limited.

Europolitics (2007). Climate change: US afraid Bali summit going in "wrong direction". 14 December.

Greenwood C et al. (2007). *Global trends in sustainable energy investment 2007: analysis of trends and issues in the financing of renewable energy and energy efficiency in OECD and developing countries.* Nairobi, United Nations Environment Programme.

Hall BH (2007). Patents and public policy. *Oxford Review of Economic Policy*. 23(4): 568–587.

Heller MA and Eisenberg RS (1998). Can patents deter innovation? The anticommons in biomedical research. *Science*. 280: 698–701.

Herder M and Gold ER (2007). *Intellectual Property Issues in Biotechnology: Health and Industry. Report Prepared for the OECD International Futures Project on "The Bioeconomy to 2030: Designing a Policy Agenda"*. Paris, OECD.

Herro A (2008). Eco-friendly patents up for grabs in new high-tech "commons". *Eye on Earth.* 23 January.

Hill M (2008). 2007 Energy Act presents opportunities. *Mondaq Business Briefing*. 22 January.

Hoekman BM et al. (2004). Transfer of technology to developing countries: unilateral and multilateral policy options. World Bank policy research working paper 3332. World Bank. Washington DC.

Johnstone N et al. (2008). Renewable energy policies and technological innovation: evidence based on patent counts. NBER working paper 13760. National Bureau of Economic Research. Cambridge.

Juma C and Serageldin I (2008). *Freedom to innovate: biotechnology in Africa's development, a report of the High-Level African Panel on Modern Biotechnology.* Addis Ababa and Pretoria, African Union (AU) and the New Partnership for Africa's Development (NEPAD).

Jumbe C and Msiska F (2007). Report on international and regional policies and biofuels sector development in sub-Saharan Africa. Submitted by Food Agriculture and Natural Resources Policy Analysis Network (FANRPAN) to WIP-Renewable Energies, Germany, for COMPETE (Competence Platform on Energy Crop and Agroforestry Systems for Arid and Semiarid Ecosystems-Africa. December.

Kamis R Joshi M (2008). *Biofuel patents are booming.* Washington DC, Baker & Daniels LLP.

Kartha S et al. (2005). Implementing bioenergy programs. In: *Advancing Bioenergy for Sustainable Development: Guideline for Policymakers and Investors Volume I.* The International Bank for Reconstruction and Development / The World Bank.

Kingston W (2005). An agenda for radical intellectual property reform. In: Maskus KE and Reichman JH, eds. *International Public Goods and Transfer of Technology Under a Globalized Intellectual Property Regime.* Cambridge and New York, Cambridge University Press: 653–661.

Krattiger A (2007a). Freedom to operate, public sector research, and product-development partnerships: strategies and risk-management options. In: Krattiger A et al., eds. *Intellectual Property Management in Health and Agricultural Innovation: A Handbook of Best Practices*. Oxford and Davis, MIHR and PIPRA: 1317–1327.

Krattiger A (2007b). The use of nonassertion covenants: a tool to facilitate humanitarian licensing, manage liability, and foster global access. In: Krattiger A et al., eds. *Intellectual Property Management in Health and Agricultural Innovation: A Handbook of Best Practices.* Oxford and Davis, MIHR and PIPRA: 739–744.

Krattiger A and Kowalski SP (2007). Facilitating assembly of and access to intellectual property: focus on patent pools and a review of other mechanisms. In: Krattiger A et al., eds. *Intellectual Property Management in Health and Agricultural Innovation: A Handbook of Best Practices*. Oxford and Davis, MIHR and PIPRA: 131–144.

Larson ED (2008). *Biofuel production technologies: status, prospects, and implications for trade and development,* UNCTAD/DITC/TED/2007/10. New York and Geneva, United Nations.

Less CT and McMillan S (2005). Achieving the successful transfer of environmentally sound technologies: trade-related aspects. OECD trade and environment working paper 2005-02. OECD. Paris.

Love J (2002). Access to medicine and compliance with the WTO TRIPS Accord: models for state practice in developing countries. In: Drahos P and Mayne R, eds. *Global Intellectual Property Rights: Knowledge, Access and Development.* London and New York, Palgrave Macmillan: 74–89.

Mahoney RT and Krattiger A (2007). The role of IP management in health and agricultural innovation. In: Krattiger A et al., eds. *Intellectual Property Management in Health and Agricultural Innovation: A Handbook of Best Practices.* Oxford and Davis, MIHR and PIPRA: 3–12.

Maskus KE and Reichman JH (2005). The globalization of private knowledge goods and the privatization of global public goods. In: Maskus KE and Reichman JH, eds. *International Public Goods and Transfer of Technology Under a Globalized Intellectual Property Regime*. Cambridge and New York, Cambridge University Press: 3–45.

Mergent (2007). Biotechnology – North America. *Mergent Industry Reports*. 625.

Mytelka L (2007). Technology transfer issues in environmental goods and services: an illustrative analysis of sectors relevant to air pollution and renewable energy. ICTSD trade and environment series issue paper 6. International Centre for Trade and Sustainable Development (ICTSD). Geneva.

Nemet GF (2007). *Policy and Innovation in Low-Carbon Energy Technologies*. Berkeley, University of California at Berkeley.

New Energy Finance (2008b). *Interesting times 2.0: second focus report on clean energy opportunities in China*. London, New Energy Finance Limited.

OECD (2007). *Compendium of patent statistics*. Paris, OECD.

Ortiz R et al. (2006). Bioenergy and agriculture: promises and challenges. Focus 14, brief 7 of 12. International Food Policy Research Institute (IFPRI). Washington DC.

Portfolio Media (2007). Q&A with Fish & Richardson's Ron Lundquist. *IP Law 360.* 14 October.

Raciti E et al. (2008). Patent standards and investment in alternative energy. *Energy Law 360.* 1 February.

Rai A and Boyle J (2007). Synthetic biology: caught between property rights, the public domain, and the commons. *PloS Biology*. 5(3): 0389–0393.

REN21 (2008). *Renewables 2007 Global Status Report.* Paris and Washington DC, REN21 Secretariat and Worldwatch Institute.

Roffe P (2005). Comment I: technology transfer on the international agenda. In: Maskus KE and Reichman JH, eds. *International Public Goods and Transfer of Technology Under a Globalized Intellectual Property Regime.* Cambridge and New York, Cambridge University Press: 257–264.

Rosen L (2006). Defining open standards (draft). In: *The Standards Edge Series.* Menlo Park, Bolin Communications.

Saxenian A (2006). *The New Argonauts: Regional Advantage in a Global Economy.* Cambridge, Harvard University Press.

Suppan S (2007). *Patents: Taken for Granted in Plans for a Global Biofuels Market.* Minneapolis, Institute for Agriculture and Trade Policy.

Ueki Y (2007). Industrial development and the innovation system of the ethanol sector in Brazil. Discussion paper 109. Institute of Developing Economies (IDE), Japan External Trade Organization (JETRO). Chiba.

UNCTAD (2006). *Tracking the Trend towards Market Concentration: The Case of the Agricultural Input Industry,* UNCTAD/DITC/COM/2005/16. Geneva.

UNCTAD (2007). Report of the Ad Hoc Expert Group Meeting on Biofuels: Trade and Development Implications of Present and Emerging Technologies, UNCTAD/DITC/MISC/2007/8. Geneva.

Wall Street Journal (2007). Politics and economics: clean-energy firms make pitch to Asia—US trade mission aims to capitalize on growing commitment in China, India. 18 April: A9.

WIPO (2008). Climate change: the technology challenge. *WIPO Magazine.* 2008/1: 2–3.

Worldwatch Institute (2007). *Biofuels for Transport: Global Potential and Implications for Sustainable Energy*. London and Sterling, Earthscan.

VI. Biodiesel: the potential role of jatropha[68]

The previous two chapters analysed the commercial viability of second generation technologies and the related intellectual property aspects. Technological developments also have a role to play in expanding the number and yields of feedstocks available for conversion into biofuels. For biodiesel, the task is to introduce crops with high oil content that would significantly increase the energy yield per unit of productive land. In this chapter we analyse one specific feedstock – jatropha – that can potentially contribute to the expansion of the biodiesel sector, while at the same time avoiding some of the undesirable outcomes of such an expansion.

Several feedstocks are currently being produced on a limited basis and explored for potential widespread use, such as sweet sorghum, cassava and jatropha. We focus on jatropha because if it were to emerge as a dominant feedstock due to its advantageous characteristics, it would significantly change the pattern of production and export of biodiesel. Several developing countries with thousands of hectares of waste, degraded and semi-arid land suitable for jatropha production could become significant players in the biodiesel market. Such a development could mitigate the pressure on agricultural prices, since jatropha production has the potential to be expanded to land not currently allocated to agricultural production.

The interest of analysing jatropha is to explore the potential that alternative feedstocks have to contribute to the expansion of the biofuels sector, while keeping agricultural commodity prices at a level that balances the benefits to the agriculture and rural sector with affordable food prices. Indeed, many national agencies, international organizations and research institutes are currently investigating the feasibility of using jatropha as a large-scale feedstock for biodiesel.

In this chapter we define two possible scenarios for jatropha production: the first assumes that jatropha will supply any additional EU demand for biodiesel from 2007 on, and the other assumes that jatropha will supply all of the EU's biodiesel demand by the year 2016.

The chapter starts with a discussion about the properties of jatropha as a feedstock for biodiesel, followed by a brief analysis of the biodiesel market. It then discusses some of the challenges that must be overcome for jatropha to become a major biodiesel feedstock. Finally, we present the two scenarios and assess the possible impact of expanded jatropha production on the vegetable oils market and on the price of biodiesel.

A. Jatropha as a feedstock for biodiesel

Jatropha yields per hectare from a well managed and irrigated field compare favourably with most other biodiesel feedstocks, as indicated by table 6.1. Moreover, jatropha's seedcake can be used as fertilizer, turned into biogas or used as a briquette for cooking fuel. The oil can also be used in oil lamps and cooking stoves and to make soap.

[68] This chapter was prepared by Daniel G. de la Torre Ugarte, Professor, Agricultural Policy Analysis Centre, Department of Agricultural Economics, University of Tennessee, United States.

Table 6.1. Typical biodiesel yields

Plant Species	*liters / hectare*	*gallons / hectare*
Castor Bean	2000	528
Coconut	1750	462
Cotton	160	42
Groundnuts	800	211
Jatropha	**3500**	**925**
Linseed	700	185
Mustard Seed	570	151
Palm Oil	3800	1004
Rapeseed	800	211
Safflower	780	206
Sesame	1270	335
Soybean	320	85
Sunflowers	850	225
Tung Oil	1700	449

Source: Bereens (2007), Johnston et al. (2007).

Extensive experimental and research data regarding costs, yields, life cycle energy and environmental costs and benefits of jatropha biodiesel are not yet widely available. However, recent research comparing biodiesel and fossil fuel diesel found that the former reduces GHG emissions by 41 to 78 per cent (Frondel, 2007).

Jatropha establishes from seed in one to two years. Plant yields vary substantially with specific variety and growing conditions. Even though the plant survives well on marginal land, yields are significantly lower than for fertile lands. Yields can be reduced by as much as 50 per cent during periods of water shortage (i.e., 200 mm per year or less). Therefore, under both drought and flood, considerable yield reductions should be expected. Indeed, yields range globally between 0.4 to 12 ton/hectare/year. Similarly, the number of trees per hectare has been reported to vary from 1,100 to 3,300 (445 to 1,335 trees per acre) (Openshaw, 2000).

Evidence to support optimum seed and oil yield estimates for a given context remain sparse. Estimations of 12 tons per hectare are almost certainly exaggerated, and are far above the Indian and Tanzanian figures of 3–4 tons/hectare reported by Punia and Beerens (Punia, 2007; Beerens, 2007). Globally, reported yields generally lie between 0.9 to 6.6 tons per hectare for hand planted, tended and harvested fields. While reasonable when considered against estimates in comparative studies (Benge, 2006), these figures may be somewhat low if compared to measurements in India (Punia, 2007).

Based on the literature reviewed, it is possible to develop ranges for potential yields per hectare of jatropha biodiesel. The figures in table 6.2 present three ranges: “minimum” represents the state of the art if jatropha continues to be predominantly planted in traditional settings reflecting very low levels of agricultural management and improvement. “Maximum” indicates a jatropha hectare managed to maximize production, in which irrigation and soil quality are key elements.

Table 6.2. Estimated jatropha biodiesel yield per hectare

	Minimum	*Mid-range*	*Maximum*
Raw Yield (tons/hectare)	0.8	6.4	12
Percentage oil yield		30 - 39 percent	
Oil yield (liters/hectare)*	240 - 310	1920 - 2500	3600 - 4680
Oil yield (gallons/hectare)*	63.4 - 81.9	507.2 - 660	951 - 1236

*Transesterified biodiesel based on 1000 liters per ton (Traoré); will also yield glycerol and methanol at 10% by weight.

Source: author.

It should be noted that the viscosity of jatropha oil is higher than that of conventional diesel fuel. Therefore, if pure jatropha oil were used in engines, some problems would likely occur: premature wear of parts and clogging and inability to start, especially in cool weather (Heller, 1996). These problems can be addressed by mixing the oil with methanol and caustic soda (International Programs Washington State, 2003). Other alternatives include fitting vehicles with dual fuel tank systems, performing engine adaptations and blending jatropha with conventional diesel, which reportedly works well up to a proportion of 40–50 per cent jatropha (Pramanik, 2003). Thus, direct use of jatropha oil in engines designed to burn fossil fuel diesel requires some engine modification.

Even though jatropha is a promising alternative to currently used feedstocks, we are still lacking a comprehensive picture of the plant's potential in different environments, for different applications and at different production scales.

Despite jatropha's mentioned benefits (see box 6.1), some doubts have been raised about the actual impact and economic viability of jatropha as a biofuel feedstock. A review of jatropha projects in Belize, India and Nicaragua stated that "actual economic, social and environmental effects have been mostly not noticeable, poor or disastrous".

This study was conducted in 2004 under the auspices of the Global Facilitation Unit for Underutilized Species and operating partly under the Food and Agriculture Organization of the United Nations. The case studies found that projected yields for plants with limited or no inputs had been significantly overestimated and recommended further research to provide reliable estimates of inputs and yields under a variety of circumstances (Euler, 2004).

Jongschaap et al. (2007) summarize the state of the art regarding jatropha, emphasizing that there is extensive scientific evidence of water conservation, erosion control and green manure regarding the use of jatropha for soap production and insecticide and medicinal use. However, with respect to jatropha's high oil yield production, Jongschaap concludes that claims of low nutrient requirement, low water use and low labour intensity, as well as tolerance to pests and diseases, are not yet sustained by scientific literature.

Box 6.1. Jatropha characteristics

Jatropha is a drought-resistant perennial shrub or tree belonging to the plant genus Euphorbiaceae, generally taller than 2 m, up to 10 m. The term "drought resistance" is associated with the fact that while yields are severely affected by drought, the plant itself can withstand it and consequently there is no need for replanting. Indeed, jatropha is adapted to a wide range of climates and soils. It can grow almost on any type of soil whether gravelly, sandy or saline and thrives even on the poorest stony soils and rock crevices. The shrub produces an oily green fruit approximately 1.5 inches in length, which turns yellow as it matures. It is believed to have originated in Central and South America but has been spread throughout Africa, South-East Asia and India (Schmook et al., 1997). It is mainly distributed in tropical very dry to moist areas, through subtropical to wet forest zones. Jatropha is propagated easily through cuttings or seeding. Although the berries are toxic throughout their growth cycle, virtually all parts of the plant have been used for a variety of purposes from traditional medicine to spice for food (Duke, 1983; Hartwell, 1967, 1968, 1969a, 1969b, 1969c, 1970a, 1970b, 1971a, 1971b, 1971c, 1971d).

Jatropha's appropriateness as a feedstock for biodiesel results from a combination of traits: its ability to grow under conditions where soil, moisture and other factors make food crops difficult or unprofitable to grow; its general toxicity that makes it unsuitable for consumption as food and limits the need to protect seeds from insect and animal predators; and its ability as a woody plant species to sequester carbon in both its branch and root systems (Duke, 1983; Ouwens et al., 2007). The oil content of the seeds varies with origin and growing conditions, ranging between 30 and 40 per cent of seed weight. The seedcake that is left after pressing is relatively rich in nitrogen. The production (or processing) stage involves pressing of seeds to expel the oil, leaving seedcake. Using a hand-operated screw press, the extraction rate is about 1 litre of oil (0.264 gallons) per 5 kg of seed, generating about 1.5 litres per hour (0.4 gallons per hour) (Henning, 2004). Such a rate is quite convenient for small village and rural subsistence. Power-operated screw presses have a higher yield, of 50 litres per hour (Van Eijck et al., 2006) and leave a drier residue seedcake.

Moreover, it has been pointed out that the most profitable use for jatropha oil is soap making and that other parts of the plant have potential medicinal uses that might be ignored in the push for exclusive use of the plant for its biofuel potential (Openshaw, 2000).

Therefore, even though jatropha is a promising alternative to currently used feedstocks, we still lack a comprehensive picture of the plant's potential in different environments, for different applications and at different production scales. As Jongchaap points out, it is especially relevant to further investigate jatropha's potential yield under suboptimal and marginal conditions. The several jatropha projects currently being carried out by the private sector, research institutes and governmental agencies, mainly in Africa and Asia, are likely to shed light on these issues in a near future.[69]

Box 6.2. Jatropha's biodiesel powering aircrafts

In December 2008, the world witnessed the first flight partly powered by biodiesel from jatropha. Aiming at cutting fuel consumption and carbon emissions, Air New Zealand used a 50/50 blend of standard jet fuel and jatropha oil in one of the four engines of a 747-400 jet. The three-hour test flight from Auckland marked a promising step for the airline industry to find cheaper and environmentally friendly alternatives to fossil fuel (ethanol is not an alternative for the airlines because it freezes easily at high altitudes). Air New Zealand announced plans for jatropha fuel to represent 10 per cent of its fuel consumption by 2013 (the equivalent of 1 million barrels of biofuels a year). The jatropha nuts were harvested from trees in India, Malawi, Mozambique and the United Republic of Tanzania, on land where other crops could not be grown.

On 6 January 2009, Continental Airlines, the United States' fourth largest airline, became the first American commercial carrier to conduct a demonstration flight powered in part by biodiesel from algae and jatropha seeds.

These successful tests have the potential to provide additional incentives for jatropha production directed to the airline industry. However, it should be noted that the test flights are far from representing the end of kerosene use in jet engines, since the challenge is to produce in an efficient way the quantities of biodiesel the aviation industry would need.

[69] For more information on jatropha case studies: http://www.ifad.org/events/jatropha/index.htm.

B. The biodiesel sector

The expansion of the production and use of biodiesel has been pushed by policy mechanisms and market instruments, such as mandatory blending targets, as seen in chapter I, and/or promotional fiscal mechanisms. Biodiesel still represents a small share of the total biofuels market, but biodiesel production is expected to grow quickly, as demand is expected to grow at a faster rate than demand for ethanol (IEA, 2004). The EU is currently the main producer of biodiesel: production has increased more than sixfold between 2000 and 2006 and the EU's share of biofuels production represented 76 per cent of the world's total in 2006 (table 6.3) and 63 per cent in 2007.

Of the total produced by Europe in 2007, 54 per cent comes from Germany, 15 per cent from France, 9 per cent from Italy and 4 per cent from the United Kingdom. Together these countries account for three quarters of European production. However, biodiesel production has risen sharply in several new EU member states: in 2006, around 7.2 per cent of total EU production originated from these countries. The Czech Republic, Estonia and Poland have the largest installed capacity. In Asia, Malaysia and Thailand have recently started to produce biodiesel for Europe, while in Latin America the main producer is Argentina.

Table 6.3 also indicates that the EU's share of world biodiesel production fell from 98 per cent in 2000 to 76 per cent by 2006. However, some of the increase in non-EU biodiesel production may have been imported and consumed in the EU. Consequently, in terms of biodiesel consumption, the EU's share is probably bigger than its production share. In the United States, production and use of biodiesel remain of little significance, and for that reason we focus on the EU demand for biodiesel.

Box 6.3. Biofuels from algae: another promising source for biofuels production

Many researches believe marine algae may be a key source of energy in a near future, as it does not compete with food and it provides a sink for carbon in addition to being an input for biodiesel production. As part of the photosynthesis process, algae produce oil and can generate 15 times more oil per acre than other plants used for biofuels, such as maize and switchgrass. Researchers at the Centre for Biorefining at the University of Minnesota estimate that algae can produce 5,000 gallons of oil per acre (or 56,825 litres per hectare), in comparison with 18 gallons for maize, 48 for soybean, 635 for palm oil and 127 for rapeseed. They can grow in salt water, freshwater or even polluted water (pollutants are cleaned up by the algae that absorb them as nutrient), at sea or in ponds, and on land not suitable for food production. Additionally, algae grow faster with a rich supply of CO2, and therefore carbon sequestration can be realized while substantially increasing algae yields, resulting in potential high CO2 savings. Because of these advantages, big oil companies and industrial powerhouses are investing in algae projects. However, the commercial production of biodiesel from algae is not yet economically feasible and further cost reductions are being investigated.

Source: http://oakhavenpc.org/cultivating_algae.htm

Table 6.3. World biodiesel production (MT – million tons)

Year	EU-27	World
2000	707	721
2001	820	893
2002	1,094	1,238
2003	1,518	1,698
2004	1,853	1,999
2005	2,637	2,972
2006	4,465	5,866

Source: F.O.Licht's (2007).

A recent analysis by Thoenes indicates that the current global production of biodiesel is largely based on the conversion of rapeseed oil (Thoenes, 2006). Rapeseed is the main source of locally produced vegetable oil in the European Union and the set of mandates and incentives in place benefit the use of local feedstock. Sunflower oil is another important feedstock in the European Union, while soybean oil is primarily used in the United States. The low level of palm oil utilization – despite the fact that palm oil has historically been the least expensive oil available – is a consequence of policy measures that prioritize the use of local feedstock both in the European Union and in the United States and dominate the expansion of biofuels production and use.

Table 6.4. Global biodiesel feedstock use

Feedstock	*% use*
Rapessed oil	84
Sunflower oil	13
Soybean oil	2
Palm oil	1

Source: Thoenes, 2006.

While the EU Biofuels Directive[70] establishes a target of 5.75 per cent of biofuels use (on an energy basis) by the year 2010, there is little confidence that the target can actually be achieved. OECD/FAO and FAPRI (the Food and Agricultural Policy Research Institute) acknowledge the relevance of the EU target but their projections reflect levels of use significantly below it. The two projections are presented in table 6.5. The same table presents an estimate of biodiesel use by the year 2010 if the EU target is to be achieved (F.O. Licht's, 2007).

Table 6.5. Projections of use of biofuels in the EU (million tons)

Year	F.O Licht's	OECD – FAO	FAPRI
2007	5,786	4,605	6,082
2008	8,104	4,700	5,303
2009	10,521	5,735	4,744
2010	12,782	6,791	6,196
2011	.n.a.	7,868	6,368
2012	.n.a.	8,966	6,430
2013	.n.a.	10,085	6,871
2014	.n.a.	10,868	7,191
2015	.n.a.	11,666	7,529
2016	.n.a.	12,479	7,853

Source: F.O.Licht's, OECD/FAO, FAPRI.
Note: F.O. Licht's and OECD/FAO is EU-27; FAPRI is EU-25.

The growth of biofuels use assumed by OECD/FAO indicates that there is an expectation that biodiesel use could reach the 2010 target level estimated by F.O. Licht's in the year 2016. Both the OECD/FAO and FAPRI outlooks project a level of biodiesel production by 2010 consistent with achieving 50 per cent of the EU target. Beyond 2010, OECD/FAO assumes a continuous upward trend in the use of biodiesel while FAPRI's projection indicates only a modest increase in the use of biodiesel.

Increasing biodiesel production and the consequent additional demand for vegetable oils has contributed to the recent spikes in vegetable oils prices. The expansion of biodiesel use has

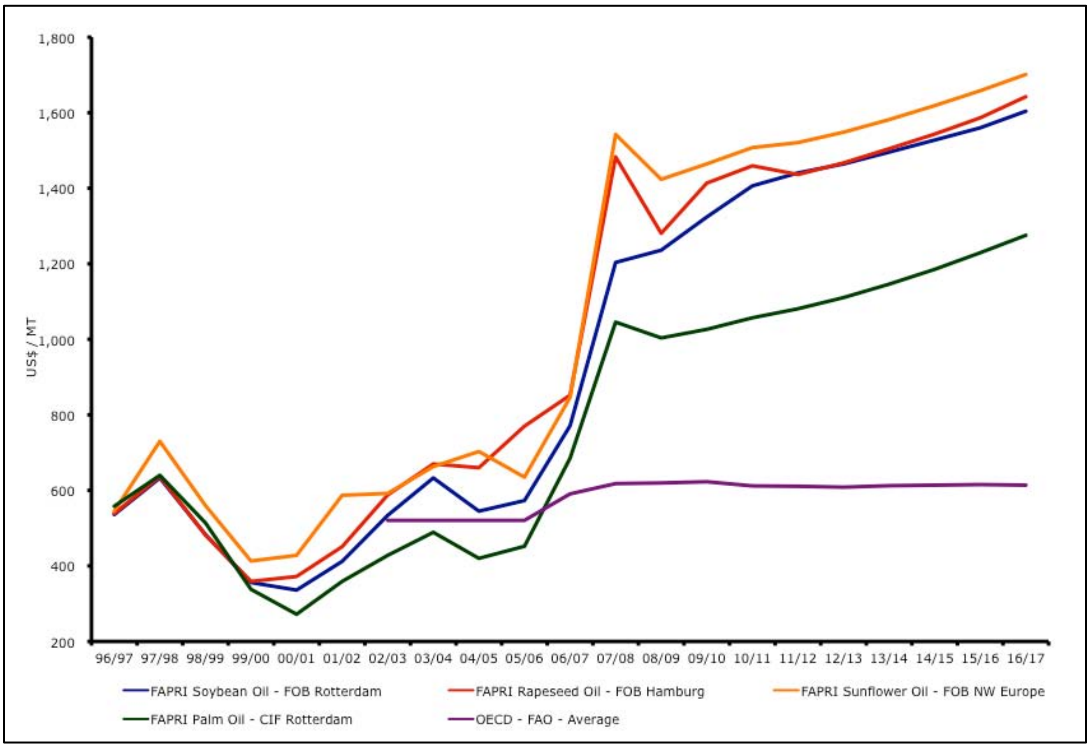
[70] Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport, Official Journal L 123 of 17.05.2003, at 42-46. The Directive requires that member states introduce legislation and take the necessary measures to ensure that, beginning in 2005, biofuels account for a minimum proportion of the fuel sold on their territory, up to 5.75 per cent by December 2010 (compared with 0.6 per cent in 2002).

occurred in parallel with the expansion of ethanol use; hence, price increases for vegetable oils also reflect the shifting of land use from oilseeds to cereals production, especially in the United States, where ethanol is produced from maize.

The evolution of prices presented in figure 6.1 (from FAPRI and OECD) indicates that prices for all vegetable oils felt the additional pressure from the expanded production and use of biodiesel. The price trend seems to indicate that the expansion of demand has outpaced the expansion of supply. Moreover, as mentioned above, although palm oil is the cheapest source of feedstock for biodiesel, the existence of incentives for the use of local feedstock in the EU and in the United States has resulted in a preference for other vegetable oils.

The price gap between palm oil and the other three vegetable oils considered – soy, rapeseed and sunflower – is projected to widen from 2007/2008 through the period 2016/2017. This is consistent with the fact that most biodiesel demand is supposed to be, or rather, probably will be filled by rapeseed, sunflower and soybean oil, and that the land competition with cereals and other grains is more intense for those oilseeds than for palm oil. Therefore, any additional biodiesel production should be based on increasing utilization of palm oil as feedstock,[71] in order to alleviate price increases of the other vegetable oils.

Figure 6.1. Prices of vegetable oils used to produce biodiesel from 1996/1997 to 2016/2017



Source: FAPRI and OECD/FAO.

C. Potential role of jatropha in the biodiesel sector

None of the reviewed projections considers that jatropha will make a significant contribution to the world's biodiesel production through the year 2016. This may simply reflect

[71] Both projections estimate price levels higher than those of the early 2000s. However, the OECD/FAO price projections are lower than those of FAPRI, despite the fact that the projected EU use of biodiesel is considerably higher in the OECD/FAO outlook than in the FAPRI outlook. This could reflect the fact that the FAPRI projections were released a year later (in 2008) and thus they are probably based on more up-to-date conditions prevailing in agricultural markets.

the fact that most jatropha initiatives are in early stage of implementation. However, it is worth investigating what could potentially be the role of jatropha given the described outlook for the biodiesel industry. Therefore, considering the projected biodiesel use in the EU, we analyse what would be the required increase in hectares of jatropha to achieve the EU target and eventually supply all the EU's biodiesel. We also investigate what are the foreseeable challenges to increase jatropha production.

We define two possible scenarios for jatropha production: one assumes that jatropha supplies any additional EU demand for biodiesel from 2007 on. The second scenario assumes that jatropha will supply all the EU's biodiesel by the year 2016. The production targets for jatropha corresponding to these two scenarios – and to both the OECD/FAO and FAPRI projections – are presented in table 6.6.

Table 6.6. Biodiesel that would be replaced by jatropha, by outlook and scenario (thousand metric tons)

	OECD-FAO Outlook		FAPRI Outlook	
	Additional Use	All Use	Additional Use	All Use
2008	95	556	-779	-171
2009	1,130	2,051	-1,338	-122
2010	2,186	3,568	114	1,939
2011	3,263	5,105	286	2,719
2012	4,361	6,664	348	3,389
2013	5,480	8,243	789	4,438
2014	6,263	9,487	1,109	5,366
2015	7,061	10,975	1,447	6,617
2016	7,874	12,479	1,771	7,853

Source: OECD/FAO, FAPRI.

To compute the amount of hectares of jatropha necessary to provide the above levels of biodiesel, we use the information provided in table 6.3. It defines three yield ranges based on yield per hectare and on an average content of oil per metric ton of jatropha. In addition, for conversion of jatropha fruit to oil content, the density of biodiesel is assumed to be 88 per cent of that of water. Consequently, the number of hectares of jatropha required per scenario and per yield level are described in tables 6.7 (OECD/FAO outlook) and 6.8 (FAPRI outlook).

Table 6.7. Jatropha hectares required, per use and yield scenario under the OECD/FAO outlook (million hectares)

	Additional EU Use			All EU Use		
Year	Add Min	Add Mid	Add Max	All Min	All Mid	All Max
2008	0.2	0.1	0	0.9	0.3	0.2
2009	1.9	0.6	0.4	3.4	1.1	0.6
2010	3.7	1.2	0.7	6	2	1.1
2011	5.5	1.8	1	8.6	2.9	1.6
2012	7.3	2.4	1.4	11.2	3.7	2.1
2013	9.2	3.1	1.7	13.8	4.6	2.6
2014	10.5	3.5	2	15.9	5.3	3
2015	11.8	3.9	2.2	18.4	6.1	3.4
2016	13.2	4.4	2.5	20.9	7	3.9

Source: own calculations.

Table 6.8. Jatropha hectares under the FAPRI outlook for each use and yield scenario (million hectares)

Year	Additional EU Use Add Min	Add Mid	Add Max	All EU Use All Min	All Mid	All Max
2008	-1.3	-0.4	-0.2	-0.3	-0.1	-0.1
2009	-2.2	-0.7	-0.4	-0.2	-0.1	0
2010	0.2	0.1	0	3.2	1.1	0.6
2011	0.5	0.2	0.1	4.6	1.5	0.9
2012	0.6	0.2	0.1	5.7	1.9	1.1
2013	1.3	0.4	0.2	7.4	2.5	1.4
2014	1.9	0.6	0.3	9	3	1.7
2015	2.4	0.8	0.5	11.1	3.7	2.1
2016	3	1	0.6	13.2	4.4	2.5

Source: own calculations.

The results indicate that, in the (unlikely) case that yields of jatropha are very low, 13.2 million hectares (Mha) of the plant would be required to meet additional use in the EU by 2016 under the OECD/FAO outlook. Under the FAPRI outlook, this number falls to 3 Mha. The hectares required obviously decrease as yield increases to more optimistic levels: when yields are at maximum level, the number of hectares required drops to 2.5 million (and to 0.6 using FAPRI estimates). If the objective is to replace all EU biodiesel with biodisel from jatropha, 20.9 and 3.9 million hectares are needed, for the minimum and maximum yield cases respectively (13.2 and 2.5 using FAPRI estimations).

In all yield cases, the required hectares of jatropha are not exceptionally large. Indeed, improvements in management practices, better seed quality, the type of soil available and the capital investment required in both the agricultural and conversion phases seem to be more crucial than land requirements to allow the use of jatropha as a large-scale biodiesel feedstock. Therefore, the key issue seems to be the competitiveness of jatropha in comparison with currently used vegetable oils, especially palm oil.

The use of jatropha to supply either the additional demand from the EU or its total demand would probably affect other vegetable oil prices, given reduced demand for those. Thus, the reference price for jatropha would not only have to be competitive with palm oil, but with a palm oil price that is below that shown in the price outlook above (figure 6.1).

Introducing new crops is not only the result of market incentives, but also of investments in infrastructure, research and extension, as well as of the availability of capital and institutional arrangements that would reduce the risks. Countries with a relatively mature institutional system, such as China, India or Indonesia, would likely be in a better position to meet this challenge successfully than African countries.

D. Outlook for large-scale production and use of jatropha

The outlook for significant global expansion in the cultivation of jatropha as a major source of biofuels is uncertain. Significant investments are being made in large jatropha plantations in Africa and Asia. Attention to jatropha as a new biofuel source has expanded greatly as a result of India's 2003 decision to make the plant the focus of its National Mission on Biofuels and a similar move by the Indonesian Government in 2005 to use jatropha for development in barren lands. By 2005, work on developing jatropha plantations in arid and semi-arid wastelands had begun in 16 of India's 28 states. (Pelkmans et al., 2005). The Center for Jatropha Promotion (CJP) in India is set to implement its New Biodiesel Tree Plantation (NBTP) Project, which aims to plant 5 trillion jatropha trees in the states of Gujarat, Madhya Pradesh and Rajasthan. The target is to produce 10 million tons of jatropha biodiesel per year and to initiate a sustainable biofuels industry in the above-mentioned states.

Box 6.4. China: investments in jatropha

Several investments in jatropha have been taking place in China in the last few years, involving both national and foreign players. At the national level, both the private and public sectors have been implementing projects for boosting jatropha production. This feedstock is especially interesting for China, a country with serious food security challenges and for which the feasible way to embark in biofuels production is through the use of non-arable land. Examples of investments in jatropha in China include, in 2007, the State Forestry Administration (SFA) and China National Petroleum Corporation (CNPC) signing a contract to collaborate in the cultivation and exploration of energy forests based on Jatropha curcas L. The same year, SFA signed a similar agreement with COFCO, China's largest oils and food trader, and a leading food manufacturer. COFCO will invest in a demonstration project to produce at least 20,000 tons per year of liquid biofuel in the Guizhou province. Furthermore, the China National Offshore Oil Corp. (CNOOC) also plans to invest 2.3 billion RMB ($300 million, using the November 2008 exchange rate) until 2010 to develop 33,000 hectares of jatropha forest in Panzhihua, Sichuan Province.

Regarding foreign investments, the Biodiesel Manufacturing Company (United Kingdom) plans to plant over 30,000 ha of Jatropha in Guangxi Province, with an expected capacity of 100,000 tons per year as feedstock. By 2009, this project should yield more than 10,000 tons of biodiesel per year. The British Sunshine Technology Group (United Kingdom) planted a 267-ha jatropha forest in 2006, and is planning to plant 20,000 ha more in the Basin of Honghe River of Yunnan Province in the 2008–2012 period. In Sichuan Province, the investor plans to develop over 650,000 ha of Jatropha curcas L. forests at a total investment of over 4 billion RMB ($600 million). The Baker Biofuel Company (United States) planted 10,000 ha of Jatropha curcas L. forests in Panzhihua, Sichuan Province, in 2005. A further investment of over $2 billion in the energy forest of Panzhihua is planned, with the purpose to construct the biggest biofuels feedstock base in the world within the next few years.

India's former President A.P.J. Abdul Kalam has repeatedly endorsed jatropha as a way to bring greening and economic self-sufficiency to the 233 million hectares of Indian land not suitable for food and other cash crops. As indicated above, Abdul Kalam's efforts bore fruit when India undertook the National Mission on Biofuels to spread jatropha throughout the country in 2003. An estimated 500,000–600,000 hectares have been planted with jatropha.

China is also exploring jatropha as a potential source of renewable energy with substantial advantages in GHG emissions over fossil fuels (more details on current investments in China are presented in box 6.4). However, current research is inconclusive regarding the ability of jatropha biodiesel to compete effectively with ethanol and other biodiesel sources. The recent development of a mechanical harvester for jatropha berries together with a commitment to a 320 million gallon (1,211 million litres) production facility in the United States may bring the small green berries to the centre of biodiesel competition with ethanol.

The estimated production cost for transesterified jatropha biodiesel in India in 2007 ranges between $0.13 and $0.28 per litre (about $0.50–$1.05 per gallon), depending on the price for which the glycerin and seedcake by-products can be marketed.[72] Transportation and marketing costs will, of course, vary depending on the country and local conditions (Punia, 2007). Production costs for locally produced and consumed non-transesterified jatropha biodiesel would be substantially less, without the necessity of a conversion facility. By comparison, gasoline was sold in India for approximately $5.15 per gallon ($1.35 per litre) in November 2007 and fossil fuel diesel was selling at $2.12 per gallon ($0.56 per litre).

Jatropha can potentially provide a 30–50 year sustainable yield of biofuel feedstocks on limited inputs of water and fertilizer. At the same time, the ability to process the hand-harvested fruit with hand-operated or simple diesel-powered mechanical presses makes it particularly

[72] To be competitive relative to fossil fuel diesel, jatropha biodiesel must be converted through transesterification.

attractive in rural and underdeveloped areas of Africa, China and India, where labour costs are relatively low and food production is extremely difficult because of the quality of the soil. This will open rural development opportunities without diverting land from food or feed use.

Significant private investment in jatropha plantations is also taking place in other places (Renner, 2007). A joint venture between British Petroleum (BP) and D1 Oils intends to invest \$160 million in jatropha development over the 2008–2012 period. In addition to the 172,000 hectares of D1 Oils plantations in India, the joint venture intends to plant an additional one million hectares by the end of the first four years with 300,000 additional hectares to be planted every year thereafter. New acreage will be in Southern Africa, Central and South America, South-East Asia and India. BP estimates a "regulation led" demand for biodiesel of 11 million metric tons per year by 2010 (BP, 2007).

Guatemala, Myanmar, Namibia, Nicaragua, the Philippines and other African and South American countries have jatropha projects underway (Fairless, 2007; Foidl, 1996; Winkler, 1997). Indonesia recently received an infusion of \$500 million in investment capital to add another 100,000 hectares to its jatropha acreage (Mahabir, 2007).

Finally, Smiling Earth Energy Technology in the United States recently announced the development of a mechanical harvester for jatropha. Claiming a harvesting cost 30 times cheaper, the company has announced plans to begin construction of a 1.211 billion litre (320 million gallon) per year biodiesel facility on the Chesapeake Bay in Virginia, United States. The plant will use jatropha harvested in Mexico as feedstock for its water-free processing (Shirek, 2007). Smiling Earth Energy Technology has announced that their recently invented mechanical harvester for jatropha berries will enable marketing of jatropha-based biodiesel at prices competitive with American soy and rapeseed biodiesel (Smiling Earth Energy, 2007).

Jatropha plantation has also the potential to generate extra revenue through the Clean Development Mechanism (see box 6.5).

Box 6.5. Jatropha and the Clean Development Mechanism

Jatropha production can have a key role as an energy-producing carbon sink and therefore can be considered a suitable candidate for projects under the Clean Development Mechanism (CDM). Indeed, the jatropha tree satisfies the conditions under the United Nations Kyoto Protocol as it can be used for afforestation/reforestation to accomplish carbon sequestration. According to the CDM rules, in afforestation/reforestation projects the forested land should last for at least 50 years. Furthermore, a single minimum tree crown cover value should be 10 to 30 per cent and the minimum height should be between 2 and 5 meters. The development of an average size crown cover (canopy) by the tree reduces soil moisture evaporation and prevents the complete dryness of the soil and thus preserves soil nutrients. Jatropha plantations seem to fulfil all these requirements (life cycle, crown cover value and average height) and therefore can be considered a valuable candidate for the implementation of a CDM reforestation project. The jatropha projects in Ghana can be taken as an example of that. Since 2002, Ghana has been pursuing a jatropha pilot project with Anuanom Industrial Bio Products Ltd, aiming to develop 1 million hectares of jatropha plantations on available idle and degraded lands. The promoters now intend to develop the project for Clean Development Mechanism (CDM) financing. The area was degraded in the late 1960s and therefore qualifies for use for an afforestation project with CDM financing (http://www.unctad.org/sections/wcmu/docs/ditc_comb_Jatropha001_en.pdf).

E. Concluding remarks

Jatropha's advantages as a feedstock for biodiesel results from a combination of characteristics: its ability to grow under difficult conditions where soil, moisture and other factors make food crops difficult or unprofitable to be grown; its general toxicity that makes it unsuitable for consumption as a food source and limits the need to protect seeds from insect and animal predators; and its ability as a woody plant species to sequester carbon in both its branch and root systems.

Even though jatropha can survive both drought and flood, good yields are linked to the use of reasonably good land. There is no clear evidence that jatropha can be at the same time a high yield source of oil and be grown under conditions of low nutrient requirement, water use and labour intensity. This raises some doubts about the environmental and economic potential of jatropha.

Until now jatropha has been mainly used to power simple engines. Ongoing production expansion, especially in China and India, is mainly for this purpose more than to power vehicles. Jatropha's consolidation as a feedstock for biodiesel production would mitigate the impact of biodiesel use on agricultural prices. The expansion of the production and use of biofuels, among other reasons, has resulted in higher vegetable oils prices. This price trend will continue as long as the expansion of demand continues to outpace the expansion of supply. One way to enhance the production capacity of the agricultural sector is to expand agronomic knowledge and plant breeding programmes, to ensure the production of high energy yield feedstocks – such as jatropha – on land not currently allocated to agricultural production.

In this chapter we defined two possible scenarios for jatropha production: the first assumes that jatropha supplies any additional EU demand for biodiesel from 2007 on and the other assumes that jatropha will supply all the EU's biodiesel by the year 2016. The analysis indicates that successful expansion of jatropha would not be constrained by land availability, but more by technological and investment factors. Countries like China, India and Indonesia seem better placed than African countries to put into place the technological improvements and the investments needed to make jatropha a viable alternative to other seed oils currently used as biodiesel feedstocks.

References

Asia CleanTech (2007). Another US$500+ million jatropha project in Indonesia? Right… 3 September.

Beerens P (2007). *Screw-Pressing of Jatropha Seeds for Fuelling Purposes in Less Developed Countries*. Eindhoven, Eindhoven University.

Benge M (2006). *Assessment of the Potential of Jatropha Curcas (Biodiesel Tree) for Energy Production and Other Uses in Developing Countries*. United States Agency for International Development.

British Petroleum (2007). BP and D1 Oils form joint venture to develop jatropha biodiesel feedstock. Press release. June 29.

Duke J (1983). *A Handbook of Energy Crops*. Purdue University.

Euler H and Gorriz D (2004). Case study "Jatropha Curcas". Global Facilitation Unit for Underutilized Species (GFU), Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

F.O. Licht's (2007). *World Ethanol and Biofuels Report*, *Vol. 6 No. 2*. Agra Informa Ltd.

Fairless D (2007). Biofuel: the little shrub that could – maybe. *Nature*. 449: 652–655.

Food and Agricultural Policy Research Institute – FAPRI (2008). *U.S. and World Agricultural Outlook*. FAPRI.

Foidl N et al (1996). Jatropha Curcas L. as a source for the production of biofuel in Nicaragua. *Bioresource Technology*. 58: 77–82.

Frondel M et al. (2007). Biodiesel: a new oildorado? *Energy Policy*. 35: 1675–1684.

Hartwell JL (1967). Plants used against cancer. A survey. *Lloydia*. 30: 379–436.

Hartwell JL (1968). Plants used against cancer. A survey. *Lloydia*. 31: 71–170.

Hartwell JL (1969a). Plants used against cancer. A survey. *Lloydia*. 32: 79–107.

Hartwell JL (1969b). Plants used against cancer. A survey. *Lloydia*. 32: 153–205.

Hartwell JL (1969c). Plants used against cancer. A survey. *Lloydia*. 32: 247–296.

Hartwell JL (1970a). Plants used against cancer. A survey. *Lloydia*. 33: 97–194.

Hartwell JL (1970b). Plants used against cancer. A survey. *Lloydia*. 33: 288–392.

Hartwell JL (1971a). Plants used against cancer. A survey. *Lloydia*. 34: 103–160.

Hartwell JL (1971b). Plants used against cancer. A survey. *Lloydia*. 34: 204–255.

Hartwell JL (1971c). Plants used against cancer. A survey. *Lloydia*. 34: 310–361.

Hartwell JL (1971d). Plants used against cancer. A survey. *Lloydia*. 34: 386–425.

Heller J (1996). Physic nut Jatropha Curcas L. Promoting the conservation and use of underutilized and neglected crops. Institute of Plant Genetics and Crop Plant Research, Gatersleben and International Plant Genetic Resources Institute. Rome.

Henning R (2004). The jatropha system – economy and dissemination strategy. Presented at the International Conference on Renewables. Bonn June 2004.

International Energy Agency (IEA) (2004). *Biofuels for Transport – An International Perspective*. Paris, OECD/IEA.

International Programs Washington State University-led Research Group (2003). *An Industry and Market Study on Six Plants Products in Southern Africa*. United States Department of Agriculture and United States Agency for International Development.

Jongschaap REE et al. (2007). Claims and facts on Jatropha curcas L.: global Jatropha curcas evaluation. Breeding and propagation programme. *Wageningen: Plant Research International*. 158.

Johnston et al. (2007). A global comparison of national biodiesel production potentials. *Environmental Science and Technology*. 10.1021 es062459k.

OECD/FAO (2007). *OECD-FAO Agricultural Outlook 2007-2016*. Paris, OECD.

Openshaw K (2000). A review of Jatropha curcas: an oil plant of unfulfilled promise. *Biomass and Bioenergy*. 19.

Ouwens KD et al. (2007). Position paper on Jatropha curcas: state of the art, small and large scale project. FACT.

Pelkmans L et al. (2005). Biofuels in India. *PREMIA WP2*. December.

Pramanik K (2003). Properties and use of jatropha curcas oil and diesel fuel blends in compression ignition engine. *Renewable Energy*. 28.

Punia MS (2007). Current status of research and development on jatropha (Jatropha curcus) for sustainable biofuel production in India. Presented to the USDA Global Conference on Agricultural Biofuels: Research and Economics. August.

Renner R (2007). Green gold in a shrub: entrepreneurs target the jatropha plant as the next big biofuel. *Scientific American*. 296.

Schmook B et al. (1997). J. curcas: distribution and uses in the Yucatan Peninsula of Mexico. In: *Biofuels and Industrial Products from Jatropha Curcas*, *Proceedings from the "Jatropha 97" Symposium in Managua, Nicaragua.*

Smiling Earth Energy Technology (2007). *Mission Statement*.

Shirek M (2007). 320 MMgy biodiesel plant to begin construction. *Biodiesel Magazine*. May.

Thoenes P (2006). *Biofuels and Commodity Markets – Palm Oil Focus*. FAO, Commodities and Trade Division.

Van Eijck J et al. (2006). Prospects for jatropha biofuels in developing countries: an analysis for Tanzania with strategic niche management. Presented at the Fourth Annual Globelics Conference "Innovation Systems for Competitiveness and Shared Prosperity in Developing Countries". Thiruvananthapuram, India. 4–7 October.

Winkler E et al. (1997). Enzyme supported oil extraction from Jatropha curcas seeds. In: *Proceedings of Eighteenth Symposium on Biotechnology for Fuels and Chemicals*.