ECONOMIC BACKGROUND OF BIOFUELS: EMERGENCE AS A VIABLE OPTION

Francis X. Johnson
Energy and Climate, Stockholm Environment Institute

Abstract

Biofuels have emerged in recent years as a strategic element in the global transition to sustainable energy, based on a confluence of factors—higher oil prices, climate change, and the need for renewed emphasis on the agricultural sector in the developing world. The economics of biofuels are, however, more complicated than almost any other class of energy sources, because they are dependent on land and water availability as well as being dynamically intertwined with the supply and prices of many agro-industrial products and socio-economic variables. They are also a class of energy resources whose implications—and in some cases—complications—have spread from the local to the national to the global. In this paper, an overview of the economics of biofuels is discussed from a broad historical perspective but also from a micro-perspective for the case of individual fuels and regions. Some key examples are reviewed and some of the main linkages across scales and sectors are considered.

KEYWORDS

Biofuels, sustainability, economics, environmental impacts, social impact

1. Introduction

Biofuels have been used in the transport sector for over a hundred years, and have historically been quite important in times of conflict when oil supplies were reduced. More recently—in the past few decades—it has been recognised that they are not only valuable in terms of energy security but also that they can make a significant contribution to reducing greenhouse gases and addressing other environmental impacts of fossil fuels.

A paper presented at the SAARC Regional Training Workshop on Biofuels, Kandalama, Sri Lanka, 22nd to 26th September 2008.

Biofuels are also linked to the emerging bio-economy, since various co-products can find useful markets and further substitute for non-renewable resources, thereby making an additional contribution to the overall sustainability transition. Biomass resources can provide food, feed, fuel, fibre and many other types of products and services.

The role envisioned for liquid biofuels for transport has come under increased scrutiny in the past few years, due to the potential social and environmental impacts associated with scaling up biofuels production and use from its low level—currently representing about 1% of transport fuels globally. At such low levels, the amount of land and resources required is relatively low, but if biofuels were to be expanded to ten times that amount or more, there are legitimate concerns about the impacts on the food supply, deforestation, socio-economic changes, and other impacts that are associated with large-scale use of land resources.

The economics of bio-ethanol from sugar cane are well understood from the experience in Brazil, which began its program in the early 1970s. Today, most cars produced in Brazil are flex-fuel and more than half of the fuel used in gasoline engines in Brazil is bio-ethanol, a major economic advantage since ethanol is much cheaper at today's oil prices. The economics of other biofuels are less favourable but are similar in structure and over time can benefit from the same type of learning curve and cost reductions that comes with experience.

The GHG balances from biofuels are generally positive, since carbon is sequestered and thereby cycled back from the atmosphere; however some biofuel crops have much better GHG balances than others. The use of first generation biofuels in temperate climates is land-intensive and inefficient in technical and environmental terms, whereas first generation biofuels in tropical climates and second generation biofuels in general can offer a much more effective use of land resources.

The calculation of GHG emissions associated with biofuels is complicated by the addition of factors associated with land use change, since the GHG impacts of land use change are beset by uncertainty both in physical terms as well as in the attribution of particular changes to production of particular biofuels. A further complication is introduced when indirect land use changes are incorporated, since these occur through combinations of market forces, illegal land use transformation, and regulatory efforts. More analysis and research is needed in order to improve the incorporation of land use change into estimates of GHG emissions from biofuels.

The socio-economic impacts of biofuels production depend on many factors, including the crop, scale of operations, and resource management approach. Some impacts—such as wages and conditions faced by labourers—are similar in many respects to any type of agricultural operations, while other impacts may be related to the industrial structure in the case of larger-scale operations. Since harvesting will often be manual in less developed countries, most social impacts are associated with the agricultural side. Other social impacts are associated with land tenure in the case of small farmers, the possibility of expropriation of land by companies or government agencies, and the more general conditions of access to technology and credit for smaller farmers and businesses.

This paper begins with some historical background on the emergence of biofuels and reviews the experiences in some of the key regions where biofuels markets are expanding. A review of economic aspects and cost calculations is considered, followed by a discussion on environmental impacts and socio-economic factors. A discussion on land use change is provided, including the controversies concerning the calculation of GHG emissions from direct and indirect land use change. Other aspects considered briefly are the issue of accounting for co-products and also the carbon finance implications associated with biofuels and bioenergy under the Clean Development Mechanism. In the final section, a review of biofuels sustainability criteria efforts is given.

2. Historical Background

Biofuels have been around for over a hundred years, and bio-ethanol in particular saw significant use in the early part of the twentieth century. Before the era of cheap oil and during times of conflict such as World War II, biofuels have been recognised as a valuable domestic alternative to imported oil. The resurgence of interest in biofuels in recent years is in part for similar reasons of energy security, but now the added issues of rural development and climate mitigation make the case for biofuels even more compelling. An interesting historical note is that the Model T introduced by Henry Ford during 1908-1926 could run on either petrol or ethanol; consequently the dual-fuel vehicles introduced in recent years are simply a somewhat more sophisticated re-introduction of a capability that was already available at the dawn of the auto age!

2.1 Ethanol

Ethanol fuel played a key role in the first four decades of the 20th Century. By the mid-1920s ethanol was widely blended with gasoline in many industrial countries. In the Scandinavian countries, a 10-20% blend was common, produced mostly from paper mill waste; in most of the continental Europe ethanol was obtained from surplus grapes, potatoes, wheat, etc.; in Australia, Brazil, and many other sugarcane producing countries, ethanol was produced from cane juice and molasses.

After WW II, few countries showed any interest in ethanol as there was plentiful cheap oil around. In the 1970s, after the oil shock, many countries began to again consider the ethanol fuel option, notably Brazil. During most of the 1990s the low price of oil again had a negative effect on ethanol fuel programmes, with many schemes being either abandoned or scaled down significantly. The past several years have witnessed a growing interest in fuel ethanol as a substitute to petrol in the transportation sector on a global scale; this is due to a combination of factors, ranging from environmental and social benefits to climate mitigation and energy security.

There are three broad market categories for ethanol—fuel, industrial, and potable—with the largest volume market today being for fuel. The industrial market is generally associated with chemical and pharmaceutical industries that require ethanol as a feedstock for fine chemicals and various products. The industrial market generally has greater purity requirements than fuel alcohol, since it is directed to specialised production processes rather than combustion as a fuel. The potable market includes distilled spirits and liquors. However, surplus wine alcohol is sometimes re-directed to other markets, such as is the case in some Caribbean countries, which re-process the wine alcohol for export to the U.S. under special trading arrangements.

Not all ethanol is bio-based. Synthetic fuels—both diesel and ethanol—can be produced from coal or natural gas through the Fischer-Tropsch process, as is common in South Africa. Synthetic ethanol is often used in the industrial market, due to specific purity requirements. Synthetic ethanol is chemically identical to bio-ethanol, and market data is not necessarily reported separately; consequently Table 1 gives total ethanol production. Although synthetic ethanol production is generally not cost-competitive with bio-ethanol, the higher levels of purity required can acquire a price premium for certain applications. Production in South Africa was initially a result of the political isolation against the apartheid regime in the 1970s; trade sanctions required greater reliance on domestic energy sources where feasible, and South Africa has plentiful supplies of coal. Having all the infrastructure in place, South Africa has continued for many years now after apartheid with its synthetic production. The process for gas-to-liquids is analogous to the production of second-generation biofuels in the future via gasification of biomass.

As illustrated in Table 1, world ethanol production has increased significantly in recent years. The two largest producers—Brazil and USA—have generally been responsible for 60-70% of world ethanol production. All ethanol produced in Brazil is bio-ethanol, as is nearly all ethanol produced in the U.S. Synthetic ethanol is produced in a number of European countries as well as in Middle Eastern countries, South Africa, and some Asian countries. Ethanol can also be processed into ETBE (ethyl-tertio-butyl-ether) by reaction with isobutylene, a refinery by-product. Such re-processing is popular in the EU due to the fuel standards adopted by the automobile industry in EU markets and the preferences of oil distributors in the EU for ETBE rather than bio-ethanol as a final product for blending. In a few EU countries such as Sweden, ethanol is blended directly rather than using ETBE. Sweden is also one of the few countries to run a significant fleet of E100 vehicles; much of the bus fleet runs on ethanol, using specially-designed engines.

2.2 Biodiesel

The process of trans-esterification for making bio-diesel has been known for well over a hundred years, although bio-diesel as it has come to be known emerged only in the past twenty years, in terms of the use of refined vegetable oils on a large-scale. Rudolf Diesel first demonstrated his breakthrough engine design in 1893, and it was powered by peanut oil. He believed that the utilization of a biomass fuel represented the future for his engine. In 1911, he said "The diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries which use it." The emergence of cheap fossil fuels, however, encouraged the diesel engine manufacturers to alter their engines to utilise the lower viscosity petroleum diesel.

Research into the use of trans-esterified sunflower oil and refining it to diesel fuel standard was initiated in South Africa in 1979. By 1983 the process to produce fuel quality engine-tested bio-diesel was completed and published internationally (SAE, 1983). An Austrian Company, Gaskoks, obtained the technology from the South African Agricultural Engineers, put up the first pilot plant for bio-diesel in November 1987 and the erection of the first industrial bio-diesel plant in April 1989, with a capacity of processing 30 000 tons of rapeseed as feedstock per annum. Throughout the 1990s, plants were opened in many European countries, especially in the Czech Republic, France, Germany, and Italy.

Globally, production of bio-diesel is concentrated in a few countries, with Germany and France accounting for nearly half of global production and consumption, as shown in Table 2. Global production has been increasing at a tremendous pace, with most of the growth in the EU as a result of fairly generous tax benefits and subsidies. From 2000 to 2007, biodiesel production increased globally more than seven-fold, from under 1 billion litres to over 7 billion litres; production in Germany alone increased more than ten-fold over the same period. New financial incentives in the U.S.A. starting in 2005 have significantly stimulated production there.

Table 1: Global Ethanol Production by country/region (billion litres)								
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Brazil	10.6	11.5	12.6	14.7	14.7	16.1	17.0	19.0
U.S.A.	7.6	8.1	9.6	12.1	14.3	16.2	18.4	24.6
EU	2.4	2.6	2.5	2.5	2.5	2.7	3.4	3.6
Asia	5.9	6.1	6.2	6.7	6.6	6.8	7.2	7.2
other	5.2	5.5	5.5	5.5	5.6	5.8	5.9	7.0
Total	**31.7**	**33.7**	**36.5**	**41.5**	**43.6**	**47.6**	51.9	61.5
Source: F.O.Licht's, 2007; EBIO 2008; NRF 2008 NOTE: Figures include bio-ethanol and synthetic ethanol; about 85-90% of total world ethanol market is bio-ethanol; about 80% of total world ethanol market is for fuel; Some ethanol is processed into ETBE for blending, particularly in the EU.								

Table 2: Global Biodiesel Production by country/region (million litres)								
	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Germany	250	315	511	813	1176	1897	2343	2543
France	373	364	416	406	395	559	654	767
EU-total	813	912	1210	1630	2265	3618	4303	5027
U.S.A.	8	19	57	76	95	284	948	1706
other	125	190	256	284	273	307	368	405
World	**945**	**1121**	**1523**	**1989**	**2633**	**4209**	**5619**	**7138**
Sources: estimated based on European Biodiesel Board, 2008; National Biodiesel Board, 2008.								

2.3 Other Biofuels

There are other biofuels and other applications, such as the use of unrefined oils or straight vegetable oils, but unlike ethanol and biodiesel they are not global fuel commodities with specific properties. Biogas is also considered a biofuel, although it also has less relevance for international trade and is therefore not treated here in detail. Other fuels such as butanol have also sparked some interest.

3. Regional Overview

3.1 Biofuels in Brazil

The rapid development of ethanol production capability in Brazil took place only after the creation of the Brazilian Alcohol Program, known as PROALCOOL, in 1975, with the purpose of producing anhydrous ethanol for blending with gasoline. After the second oil shock in 1979, the government decided to expand production to include hydrated ethanol to be used as neat fuel in modified engines. Sugarcane and ethanol production has increased several-fold during the past three decades.

The continued expansion of the sugarcane industry in Brazil, particularly in the last decade, has been the result of various factors, ranging from high demand for sugar and ethanol both in the domestic and international market to continuous improvements in productivity. Such improvements include the whole chain system, ranging from better varieties, soil management, pest and disease control, transportation, technical improvement in conversion, to end use.

With dozens of new industrial units in different stages of construction, ethanol production capacity is set to expand considerably in the coming years. Brazil has the capacity—land, technical know-how and even finance—to expand its ethanol production capacity 8-10-fold in the next 20-30 years. The implications of such an expansion are being evaluated at the University of Campinas, one of Brazil's premier research Universities (Cortez, 2006).

With the lowest cost of production in the word, Brazil has become the largest exporter of ethanol. The main priority in Brazil has thus far nevertheless been to supply the domestic market. Alcohol is used as an octane booster blended with gasoline, alone as "neat" fuel, and in flex-fuel vehicles, and also as a chemical feedstock and other industrial applications. The flex-fuel vehicles, introduced in 2003-2004 run on any combination of gasoline and alcohol.

3.1.1 Biodiesel in Brazil

A Brazilian programme for biodiesel has been initiated, with similar objectives to those of the bio-ethanol programme. However, the approach will be different, in that small farmers are expected to provide feedstock for the industrial producers of biodiesel. A regulatory instrument will be used to enforce the social and environmental profile, known as "The Social Fuel seal," which will be awarded by the Ministry of Agrarian Development, as a condition for industrial producers of biodiesel to obtain tax benefits and credits. In order to receive the seal, an industrial producer must purchase feedstock from family farmers, enter into a legally binding agreement with them to establish specific income levels, and guarantee technical assistance and training (PNPB, 2005).

Unlike the large-scale approach used in the case of ethanol from sugarcane, the benefits of building a new industry could be better distributed. Economies-of-scale are somewhat different for biodiesel, and so a different approach may be useful. However, it is not clear whether the small-scale approach will ultimately prove to be economic in a global market. Government legislation will provide security for the market demand; a blend of 2% (B2) will be mandatory for all diesel fuel as of 2008, while 5% (B5) will be mandatory starting in 2013 (MDA, 2005). There are support schemes for research and development, in addition to the support for implementation, via the tax credits associated with the Social Fuel seal. There is growing criticism within the business community of the conditions imposed by government, which seems more concerned with social development rather than energy at competitive price. They argue that the conditions attached to biodiesel production, particularly in the Northeast will make biodiesel uncompetitive.

3.2 U.S.A.

Ethanol is produced mainly from corn in the U.S., and domestic producers receive a subsidy of $0.52/gallon ($0.14/litre). Partly as a result of these support schemes and the recent rise in oil prices, U.S. production exceeded Brazilian production for the first time in 2005. Ethanol is sold in most States as an octane enhancer or oxygenate blended with gasoline, and in the Midwest there are also E85 or ethanol-only vehicles, including buses.

Bio-diesel production has also been increasing significantly due to the generous tax credits provided by legislation enacted during 2004-2005. The tax credit is $0.50/gallon ($0.13/litre) of biodiesel made from waste grease or used cooking oil and ($0.26/litre) for biodiesel. If the fuel is used in a mixture, the credit is 1 cent per percentage point of agribiodiesel used or 1/2 cent per percentage point of waste-grease biodiesel. For small biodiesel producers (i.e. production capacity of less than 60 million gallons annually), an additional $0.10 ($0.03/litre) tax credit is provided for each gallon of biodiesel produced by small producers. This tax credit is capped after the first 15 million gallons produced annually (US-DOE, 2004).

In September of 2005 Minnesota became the first state to require that all diesel fuel sold in that state contain part biodiesel. The Minnesota law requires at least 2% biodiesel (B2) in all diesel fuel sold. In March 2006, Washington State became the second state to pass a 2% biodiesel mandate, with a start-date set for December 1, 2008 (WA, 2006).

3.3 EU Biofuels Policies

EU policies with respect to biofuels are relevant with respect to international trade, as it is recognised that a rapid increase in biofuels within the EU cannot be achieved without imports. Biomass and bio-energy are promoted through a variety of programmes and policies within the EU, and is widely recognised that bio-energy will be among the major renewable energy sources in the near-term. The policies and strategies adopted include liquid biofuels, solid biomass, and biogas. The sector coverage includes heat & power production, transport, and direct uses in households and businesses. A biomass action plan was released by the EC in late 2005 and a biofuels strategy in early 2006 (EC, 2005; EC, 2006).

In 2001, the EC launched its policy to promote biofuels for transport, the motivation for which includes several dimensions:

- to reduce greenhouse gas emissions;
- to reduce the environmental impact of transport;
- to increase the security of supply;
- to stimulate technological innovation; and
- to promote agricultural diversification

The policy was to be market-based, but would include indicative (i.e. non-binding) targets and financial incentives in order to maintain progress. The targets were to be based on the percentage of biofuels in the transport market, which was only 0.6% in 2002.

The EU Directive on biofuels came into force in May 2003, under which Member States shall ensure a minimum 2% share for biofuels by 31 December 2005 and 5.75% by December 2010 (EC, 2003a). Only Sweden with 2.2% and Germany with 3.8% exceeded the 2% target in 2005 (EC, 2006); Sweden accomplished this mainly through bio-ethanol, while Germany relied on bio-diesel. The biofuels component within the overall roadmap for renewable energy has been revised somewhat in light of the slow progress by Member States; a more recent policy document acknowledges that the 2010 targets will be difficult to meet, but nevertheless proposes a target of 10% for 2020, with the assumption that policy instruments must be made more effective (EC, 2006). The integrated energy-climate package that was put forth by the Commission also retains biofuels as a major component of strategies aimed at the goals of energy security, competitiveness, and sustainability (EC, 2007).

Another component of the EU biofuel legislation relates to fuel quality. In 2003, the environmental specifications for market fuels were amended to establish specifications for gasoline and diesel. The previous Fuel Quality Directive was thus amended, and applies to biofuels as well as to petrol and diesel (EC, 2003c). The European Committee for Standardization (CEN) has set limits on biodiesel blending to no more than a 5 percent share by volume for technical reasons. This strict technical requirement represents an obstacle to achieving the targets set in the Biofuels Use Directive. Consequently, it is proposed that the Fuel Quality Directive be revised again in order to remove such technical barrier as well as to address related issues that may constrain the use of biofuels.

The EU currently has a special aid programme for energy crops grown on non-set-aside land, i.e. land that is not already within the 10% of land that farmers are requested to set aside under the EU Common Agricultural Policy (CAP). The energy crops can receive a premium of Euro 45 per hectare, within a maximum guaranteed area of 1.5 million hectares. In 2005, an estimated 0.5 million hectares received the energy crop payment. The generous support mechanisms available for bio-diesel have resulted in twenty of the twenty-five Member States of the EU producing biofuels, as of the end of 2005 (EURobserver, 2006).

EU biofuels production is generally not cost-competitive, due mainly to high-priced feedstocks, which is rapeseed in the case of biodiesel and sugar beet, corn, or wheat in the case of bioethanol. In spite of recent sugar sector reforms, the EU internal sugar prices are expected to remain substantially above international market prices and consequently sugar beet will continue to be an expensive feedstock. With recent significant increases in world oil prices, biofuels have become more competitive, particularly biodiesel. Imported bio-ethanol will generally be cheaper than EU-bioethanol, particularly from Brazil, which is very cost-competitive at current oil prices. However, since most EU countries continue to charge customs duties based on the higher agricultural tariffs, even imported ethanol can be more expensive.

In early 2006, the EC released a biofuels strategy, in which the overall aims of the biofuels initiatives were reviewed, progress was assessed, and specific implementation issues were addressed in terms of meeting future targets (EC, 2006). It was recognized that only about half of the target for 2010 could be met through production within the EU, and the remainder would need to be met through imports.

In early 2008, the Commission included new targets of 10% by 2020 for renewable transport fuels in its proposal for a new Renewable energy Directive. The targets would be binding on member states. Sustainability criteria were also proposed, including a minimum GHG reduction of 35% and prohibitions on biofuels grown in ecologically sensitive regions. Since that time, the European Parliament has voted in favour of scaling back some aspects of the biofuels proposal, increasing the required GHG reductions, mandating an interim review of the targets, and setting a target of 5% for 2015, which is lower than the 5.75% target in the previous Directive

3.4 Biofuels in other countries/regions

A number of other regions are significant producers of biofuels or could become significant producers in the near-term. Countries with large domestic markets (U.S., China, and India) are unlikely to become exporters. Other regions could become major exporters in the future, particularly southern Africa and some parts of Southeast Asia. Smaller African producers such as Malawi are discussed in section 5 along with the other summary case studies. The situation in China and India are briefly mentioned below, since these countries could be major producers but also potentially major importers in the future, depending on market developments.

3.4.1 China

Although China cannot be regarded today as a major player in biofuels, this could change dramatically in the near future. China is potentially a hugely untapped vehicle market; in 2004 there were only 27 million privately owned vehicles, most of them concentrated in large cities (Brown, 2004), which is very low by western standards. The Chinese automobile use has been growing faster than in any other country; during the past 5-6 years, automobile use has nearly doubled. If this trend continues, the size of the Chinese automobile industry will have significant implications for fuel demand, and some of this demand may very well be met through biofuels.

3.4.2 India

With the growing mobility of India's increasing population, demand for crude oil long ago surpassed domestic production; diesel demand is much higher than petrol, due to the significant amount of freight transported by road. Bio-diesel production offers the possibility for fuel produced from renewable sources to sustain the growing demand. Some oil-bearing crops such as jatropha, can be grown on degraded lands, which are not well-suited to traditional agricultural crops. Over 65 million hectares of land has been declared "wasteland" in India, and another 174 million hectares are close to being called wasteland, and this may present an excellent opportunity for energy crops like Jatropha.

In April 2003, the national committee on development of Biofuel recommended a major multi-dimensional programme to replace 20% of India's diesel consumption. The National Planning Commission has integrated the Ministries of Petroleum, Rural Development, Poverty Alleviation and the Environmental Ministry and others. One objective is to blend petro-diesel with a planned 13 Million t of bio-diesel by 2013, produced mainly from non-edible Jatropha oil, a smaller part from Pongomia. For this end, eleven millions ha of presently unused lands are to be cultivated with jatropha. One of the difficulties is lack of experience with large scale production of Jatropha, compounded by its low productivity in terms of fuel produced per hectare.

3.5 International Trade in biofuels

The case of bio-ethanol is of particular interest for international trade, as it is different from other biofuels and especially from biomass generally in several respects. First, the opportunity to export a value-added product such as ethanol rather than raw biomass is important for developing countries. Second, there are many significant potential producers of bio-ethanol; any of the more than 100 countries that grow sugarcane could enter the market fairly easily in the absence of protectionist measures. Third, the most economical biomass source or feedstock, sugarcane, is found almost exclusively in the developing world. Fourth, unlike biomass or wood products, ethanol markets are impacted significantly by trade barriers and tariffs. While many small sugarcane–producing developing countries are potential producers, both sugar and ethanol are protected products in most markets. Preferential sugar prices have been a disincentive for developing countries to switch to ethanol, since they can obtain more money from subsidised sugar exports.

Some projections suggest that ethanol trade will increase by a factor of 3-4 by 2010 (Rosillo-Calle & Walter, 2006). Between 2010 and 2015, trade is expected to more than double (F.O.Lichts, 2006). More significantly, the number of exporting countries/regions will increase significantly, with countries other than Brazil and U.S.A. making up about 30% of the total, compared to less than 5% in 2005. Exports are increasing as a growing number of countries are developing ethanol fuel policies and programmes, due to several driving forces:

- Progress on climate change: implementation of Kyoto and further post-Kyoto decisions
- Clearer long-term policy in U.S.A. in favour of alternative transport fuels
- Improving attitude of the automobile industry toward alternative fuels
- Technological progress, including cellulose-based ethanol

- Interest in supporting rural development in developing and developed countries alike

International trade of fuel ethanol also faces some specific barriers, including:

- Tariff and non-tariff trade barriers
- Focus on domestic rather than the external market in most countries
- New investments in infrastructure and adaptations to new programmes.
- Direct domestic production subsidies actually hinder longer-term market development because of market risk perceptions in light of political uncertainty of future support schemes.

Present trends indicate that it would be possible to create sizeable production and consumption centres outside the USA and Brazil, e.g. EU, China, India, Japan, Thailand, and Southern Africa. It is relatively easy and cheap to transport ethanol by ship, just as oil is transported; the transport cost is generally between 1-2 US¢/litre. Currently, between 3 and 4 billion litres of ethanol is traded annually, with Brazil and the USA being the main exporters, and Japan and EU the main importers. The EU and Japan could become the major importers in the future, given the interest in creating renewable fuels markets based on environmental and energy security reasons, and the low availability of cost-effective domestic production. Although in the case of the EU the strong agricultural lobby is pushing for domestic production rather than imports.

Fulton (2005) has studied the potential large-scale ethanol production from sugarcane up to 2050, estimated at 633 B/l/yr (14.5 EJ/yr or about 20% of the estimated projected world gasoline demand in 2050). This scenario considers only a maximum of 10% of the cropland area to be used for sugarcane (excluding Brazil). Brazil accounts for nearly half of the total ethanol production in this scenario. It is estimated that 3,460 new industrial plants would have to be built up to 2050, of which 1,720 will be in Brazil; the cumulative associated investment is estimated at US$215 billion. This appears to be an optimistic scenario in terms of a total market size equal to 20% of gasoline demand; on the other hand, the estimated amount of cropland required may in fact be less, given the historical improvement in yields and the possibility to focus production on the most high-yielding regions and the varieties best-suited to those regions.

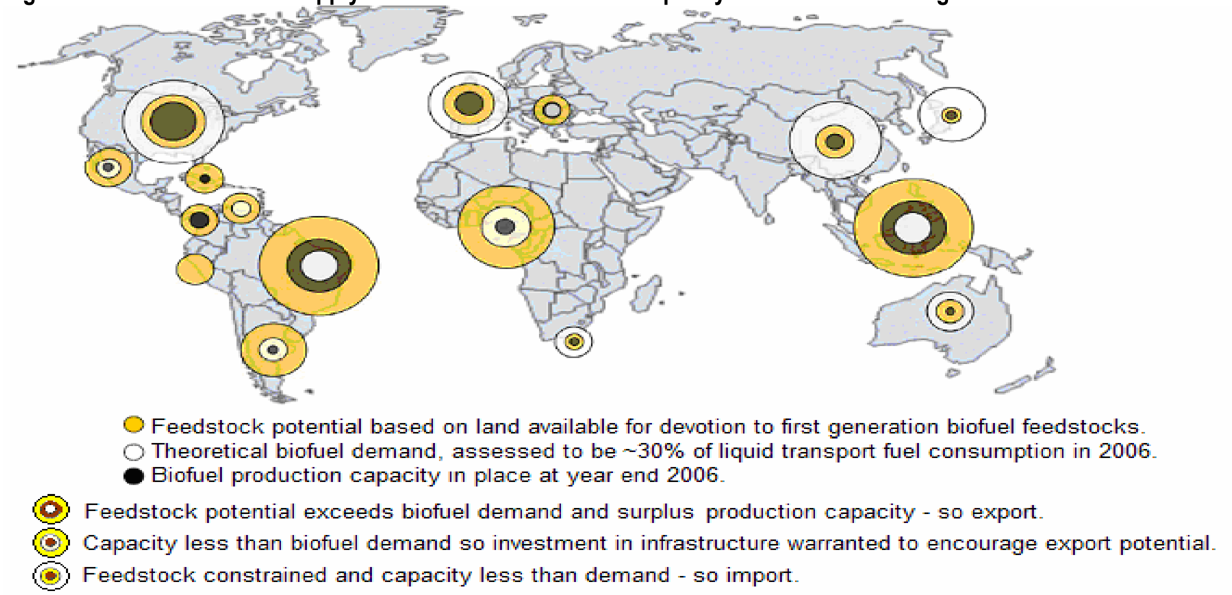
An estimate of potential global trade in biofuels in relation to supply capacity and demand is shown in Figure 1. The high potential in the region of sub-Saharan Africa is coupled with very low demand there (except for South Africa) and consequently there is an excellent opportunity to become a major next exporter; indeed, without exports, biofuels will be less competitive due to the low liquid fuels demand and subsequent lower economies of scale that would result from focusing on domestic demand (Johnson and Matsika, 2006). Consequently, the notion that countries should meet domestic demand first comes in conflict in many cases with the market/trade principles of comparative advantage. Low demand and high potential is also found in Southeast Asia and parts of Latin America, which would also therefore suggest increased investment in capacity in those regions. High-consuming regions in temperate climates such as North America and Europe will need to import under nearly any cost-competitive scenario with relatively free trade in biofuels.

4. Resources and Conversion

There are many different routes for converting biomass to bioenergy, involving various biological, chemical, and thermal processes; the major routes are depicted in Figure 1. There can be intermediate steps and the various processing routes are not always mutually exclusive. Furthermore, there are often multiple energy and non-energy products or services from a particular conversion route, some of which may or may not have reached commercial levels. Figure 1 shows only the energy-related products or fuels; simple combustion is assumed and not pictured, in order to simplify the diagram. So-called second generation biofuels include those produced through Fischer-Tropsch synthesis (F-T in Figure 1) as well as ligno-cellulosic conversion to ethanol. First-generation biofuels include oil crops esterified into biodiesel and direct fermentation of sugar and starch crops.

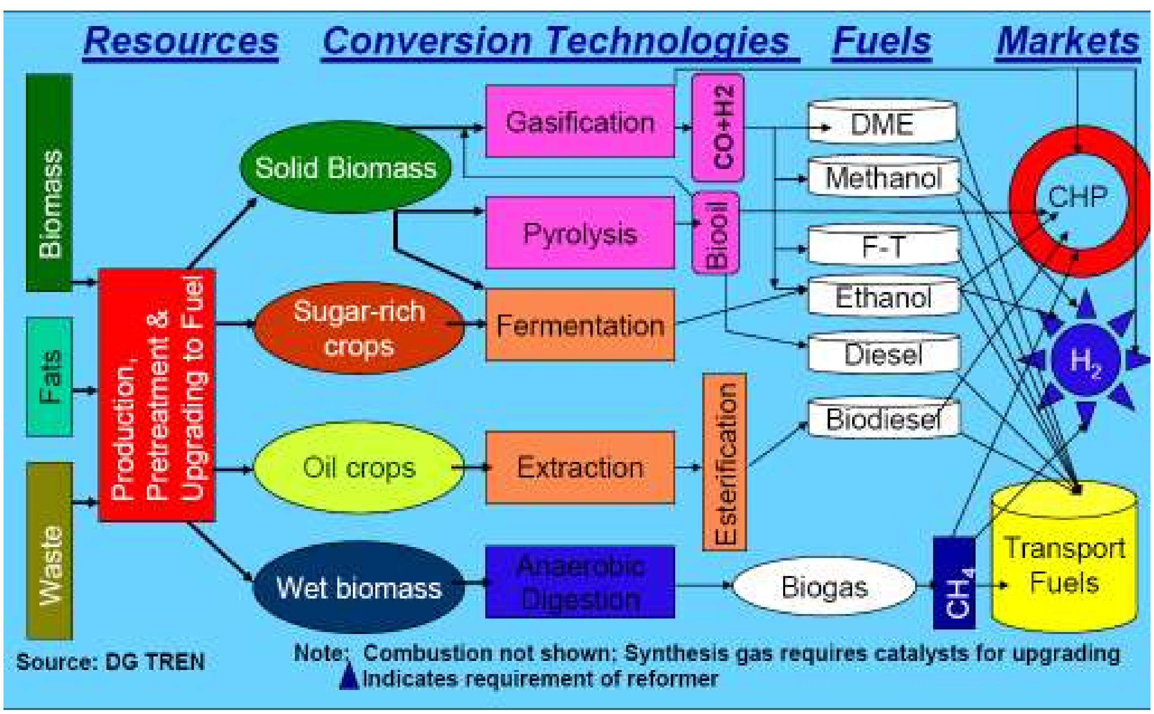
Due to the variety of conversion options and final products, it is more difficult to make comparisons of efficiency in biomass utilization than it is for other energy options; bioenergy extends across all energy carriers and involves many different pathways and processes. The efficiency of biomass and bioenergy production needs to be assessed across the various parts of the chain—from the land and inputs used for cultivating biomass through intermediate processing to the useful

Figure 1: Estimated biofuel supply and demand in relation to capacity for various world regions



Source: New Energy Finance, 2007

Figure 2: Steps and resources in biomass conversion to energy products and fuels



Source: EC DG-TREN, 2006

energy that can be harnessed for particular products and applications.

On the agricultural or resource side, efficiency depends on choosing crop species and varieties well-suited to local soils and climate. In Brazil, for example, over 500 varieties of sugar cane are used for bio-ethanol production, some of which are designed and developed for optimal growth in particular micro-climates. The productivity of biomass crops grown in tropical and sub-tropical regions, in terms of energy per unit of land, is 4-6 time higher on average than typical crops grown in the temperate climates of Europe. But even within Europe, there is considerable variation in the productivity of different energy crops (discussed in section 7; see Table 7 for a summary).

In terms of minimising overall losses in the industrial conversion side of the production chain, the most efficient use of biomass for energy is for heat, including combined heat and power, where overall system efficiencies can be as high as 80-90%. Matching conversion systems to the scale and structure of demand for heat and power is necessary to minimise costs. Some conversion systems are technologically mature for use of biomass, such as steam turbines and steam engines. Other systems are still under development, such as Stirling engines and the Organic Rankine cycle. Systems differ in scale efficiencies, service requirements, and other characteristics; choice of the optimal system is thus often site-specific (Vamvuka et al, 2007).

Liquid and gaseous biofuels are useful in extending the value of biomass to other sectors, including transport sector or in substituting for natural gas. The efficiency in conversion tends to be on the order of 55-65%. Biogas from animal wastes and other types of "wet" biomass is produced through anaerobic digestion, which is the decomposition of biomass using micro-organisms in a low-oxygen environment. Biogas can be used for many different applications: direct use for cooking or heating, electricity generation, compression for use in transport, or it can also be fed into the natural gas grid after clean-up or purification.

Due to the variety of conversion options and final products, it is more difficult to make comparisons of efficiency in biomass utilization than it is for other energy options; bioenergy extends to all energy carriers and involves many different pathways and processes. The efficiency of biomass and bioenergy production needs to be assessed across the various parts of the chain—from the land and inputs used for cultivating biomass through intermediate processing to the useful energy that can be harnessed for particular products and applications.

On the agricultural or resource side, efficiency depends on choosing crop species and varieties well-suited to local soils and climate. In Brazil, for example, over 500 varieties of sugar cane are used for bio-ethanol production, some of which are designed and developed for optimal growth in particular micro-climates. The productivity of biomass crops grown in tropical and sub-tropical regions, in terms of energy per unit of land, is 5 times higher on average than typical crops grown in the temperate climates of Europe (Bassam, 1998).

In terms of minimising overall losses in the industrial conversion side of the production chain, the most efficient use of biomass for energy is for heat, including combined heat and power, where overall system efficiencies can be as high as 80-90%. Matching conversion systems to the scale and structure of demand for heat and power is necessary to minimise costs. Some conversion systems are technologically mature for use of biomass, such as steam turbines and steam engines. Other systems are still under development, such as Stirling engines and the Organic Rankine cycle. Systems differ in scale efficiencies, service requirements, and other characteristics; choice of the optimal system is thus often site-specific (Vamvuka et al, 2007).

Liquid and gaseous biofuels are useful in extending the value of biomass to other sectors, including transport sector or in substituting for natural gas. The efficiency in conversion tends to be on the order of 55-65%. Biogas from animal wastes and other types of "wet" biomass is produced through anaerobic digestion, which is the decomposition of biomass using micro-organisms in a low-oxygen environment. Biogas can be used for many different applications: direct use for cooking or heating, electricity generation, compression for use in transport, or it can also be fed into the natural gas grid after clean-up or purification.

5. Bibliography

Bassam, N (1998) "Energy Plant Species-Their Use and Impact on Environment and Development," James and James: London.

Birur, D.K., Hertel, T.W. and Tyler, W.E., "The Biofuels Boom: Implications for World Food Markets," prepared for the Food Economy Conference, Dutch Ministry of Agriculture, The Hague, 18-19 October 2007.

California Air Resources Board (2008), "Proposed Concept Outline for the California Low Carbon Fuel Standard Regulation," March 2008.

Cederberg, C & Stadig, M, "System expansion and allocation in life cycle assessment of milk and beef production," Int. J. LCA 8 (2003) pp. 350-356.

Center for Clean Air Policy (CCAP), (2008). Beyond Offsets: Options for Reducing GHG Emissions from Forests and Agriculture in California.

COM (2008) yyy final, "Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the promotion of the use of energy from renewable sources," European Commission, Brussels, 23.01.2008.

Cramer Commission (2007). The GHG calculation methodology for biomass-based electricity, heat and fuels. Project group Sustainable Biomass. The Netherlands. Report from Working Group CO2 Methodology. Final Draft, January 2007.

Crutzen, P.J., Mosier, A.R., Smith, K. A. Winiwater, W. (2007) "N2O release from agro-biofuel production negates climate effect of fossil fuel derived CO2 savings," Atmos. Chem. Phys. Discuss., 7, 11191–11205.

Daily, G.C. (2005) Restoring Value to the World's Degraded Lands

Dregne, H. E. and N.Chou (1992) "Global desertification and costs" *in Degradation and restoration of arid lands*, H. E. Dregne (ed.), Texas Tech University, Lubbock, pp. 249 –282.

Dufey, A. (2006) "Biofuels production, trade and sustainable development: emerging issues", Environmental Economics Programme/Sustainable Markets Group

EC-DG-TREN (2006) "Biomass Action Plan," European Commission Directorate-General for Energy and Transport.

EEA (2006) "How much bioenergy can Europe produce without harming the environment?," Copenhagen, EEA Report No 7/2006. ISBN 92–9167–849-X.

Faaij, A.P.C. (2006) "Bio-energy in Europe: changing technology choices," Energy Policy 34 (2006) 322–342.

Faiij, A.P.C. (2008) "Sustainable Biofuels," presentation at Rockefeller Bellagio Conference on North-South Biopact, 25 March, Bellagio, Italy.

FAOSTAT (2007). Statistical database, Food and Agriculture Organisation of the United Nations (FAO), www.fao.org.

Fargione, J., Hill, J., Tilman, D., Polasky, S. and Hawthorne, P. (2008) "Land Clearing and the Biofuel Carbon Debt," Science, Vol. 319, pp. 1235-1238, 29 February.

Farrell, A. and M. O'Hare, (2008). Greenhouse gas emissions from indirect land use change. Memorandum for the California Air Resources Board. Energy & Resources Group, University of California Berkeley, pp.4.

Fischer, G., Hizsnyik, E., Prieler, S., and van Velthuizen, H. (2007) "Assessment of biomass potentials for biofuel feedstock production in Europe: Methodology and results," REFUEL project report, July, online available: http://www.refuel.eu/.

Francis, G. Edinger, R. and Becker, K., (2005) "A concept for simultaneous wasteland reclamation, fuel production and socio-economic development in degraded areas in India: Need, potential and perspectives of Jatropha plantations," Natural Resources Forum 29:12-24.

Fritsche, U. (2008) "Impacts of Biofuels on GHG Emissions," Presentation at the FAO Expert Meeting 5/6. February 18-20, 2008. Rome.

IEA (2004). Biofuels for Transport-An International Perspective, International Energy Agency, Paris.

Gnansounou et al. (2008). Accounting for indirect land-use changes in GHG balances of biofuels: Review of current approaches. Available at: http://infoscience.epfl.ch/record/121496

Hamelinck, C.N., Suurs, R.A.A. and Faaij, A.P.C. (2005) "International bioenergy transport costs and energy balance," Biomass and Bioenergy, Vol. 29: 2, 114-134, August.

Hoogwijk, M., A. Faaij, R. van den Broek, G. Berndes. D. Gielen and W. Turkenburg (2003) "Exploration of the ranges of the global potential of biomass for energy", *Biomass and Bioenergy*, 25: 119-133.

IEA (2007) "Renewables in Global Energy Supply: an IEA fact sheet," International Energy Agency, Paris, France; January; www.iea.org.

IIASA (2000). Global Agro-Ecological Zones. FAO and IIASA. Available at: http://www.iiasa.ac.at/Research/LUC/GAEZ/index.htm

IPCC (2000). IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories: Agriculture.

IPCC (2000a). Land Use, Land-Use Change, and Forestry (LULUCF), Cambridge University Press.

IPCC (2006). Revised 1996 Guidelines for National Greenhouse Gas Inventories.

ISO (1998) International Organization for Standardization, ISO 14041 Environmental Management – Life Cycle Assessment – Goal and Scope Definition and Inventory Analysis, §6.5.3.

Johnson, F. and Matsika, E (2006) "Bioenergy Trade and Regional Development: the case of bio-ethanol in southern Africa," Energy for Sustainable Development, Vol. X No. 1, March.

Kharin, N., R. Tateishi and H. Harahsheh (1999) "Degradation of the drylands of Asia", Center for environmental remote sensing (CEReS), Chiba University, Japan.

Kim, S & Dale, B, "Allocation Procedure in Ethanol Production System from Corn Grain," Int. J. LCA 7 (2002) pp. 237-243.

Kløverpris, J., Wenzel, H., Banse, M., Canals, L.M., and Reenberg, A., (2008) "Global Land use Implications of Biofuels: State-of-the-Art," Intl J LCA 13(3) 178-183.

Kniivila, M. (2004) Land Degradation and Land Use/Cover Data Sources", Working Document, Department of Economic and Social Affairs

Lal, R, "Soil Carbon Sequestration Impacts on Global Climate Change and Food Security," Science 304 (2004) pp. 1623-1627.

Leach, G and Johnson, F. (1999) "Modern Bioenergy – a primer," Renewable Energy for Development, Stockholm Environment Institute, May.

Marland, G., West, T.O., Schlamadinger, B., and Canella, L. (2003) "Managing soil organic carbon in agriculture: the net effect on greenhouse gas emissions," Tellus 55B, 613-621.

Middleton, N. and D. Thomas, (eds.) (1997) *World Atlas of Desertification*, UNEP.

Millennium Ecosystem Assessment (2005) *Ecosystem and Human Well-Being.*

New Energy Finance (2007) Biofuels market analysis; www.newenergyfinance.com.

Nielsen, J.B.H., Oleskowicz-Popiel, P., and Al Seadi, T. (2007) "Energy Crop Potentials for Bioenergy in EU-27," Proceedings of the 15th European Biomass Conference & Exhibition: From Research to Market Deployment, Berlin, Germany, 7-11 May.

Oldeman, L.R., Hakkeling, R.T.A. and Sombroek, W.G. (1991) "World Map of the Status of Human-Induced Soil Degradation: A Brief Explanatory Note", World Soil Information (ISRIC), Wageningen.

Ragossnig (2007) "Heating up the EU biomass market," Renewable Energy Focus, Nov/Dec., p.56-58.

Rosentrater, K A, "Expanding the role of systems modeling: considering byproduct generation from biofuel production," Ecology and Society 11 (2005) r2, http://www.ecologyandsociety.org/vol11/iss1/resp2/.

Sakar, A. and Kartha, S, (2007) "Bioenergy and Sustainable Development?" Annual Review of Environment and Resources 32:131-67; online http://environ.annualreviews.org.

Schlegel, S. and Kaphengst, T., "European Union Policy on Bioenergy and the Role of Sustainability Criteria and Certification Systems," Journal of Agricultural and Food Industrial Organization, Vol. 5, Article 7.

Searchinger, T et al (2008) "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change," Science 319, pp. 1238-1240.

Shapouri, H; Duffield, J A.; Wang, M, The Energy Balance of Corn Ethanol: An Update, Agricultural

Economic Report 814, Washington, DC: United States Department of Agriculture 2002.

Sims, R.H., Hastings, A., Schlamadinger, B., Taylor, G. and Smith, P., "Energy Crops: current status and future prospects," Global Change Biology 12: 2054-2076.

Smeets, E.M. & Faaij, A.P.C. (2007) "Bioenergy potentials from forestry in 2050: An assessment of the drivers that determine the potentials," Climatic Change 81:353-390.

Sparovek, G., Berndes, G., Egeskog, A., de Freitas, F.L.M., Gustafsson, S., and Hansson, J. (2007) "Sugarcane ethanol production in Brazil: an expansion model sensitive to socioeconomic and environmental concerns," Biofuels, Bioproducts and Biorefining 1: 270-282; DOI: 10.1002/bbb.

State of California (2007) Executive Order S-01-07, January 18, 2007.

Status of Human-Induced Soil Degradation: A Brief Explanatory Note", World Soil Information (ISRIC), Wageningen.

Tilman, D; Hill, J; Lehman, C (2006) "Carbon-negative Biofuels from Low-Input High-Diversity Grassland Biomass," Science 314, pp. 1598-1600.

Tilman, D; Hill, J; Lehman, C, "Carbon-negative Biofuels from Low-Input High-Diversity Grassland Biomass," Science 314 (2006) pp. 1598-1600.

U.S. (2008) 110th Cong. H.R.6 §§201-202.

U.S. Congressional Record 72, May 1, 2007, p. 23908.

UNCTAD (2008) "Making Certification work for Sustainable Development: The case of Biofuels," UNCTAD/DITC/TED/2008/1, Geneva.

UNEP (1992a) Desertification, land degradation [definitions]. Desertification Control Bulletin 21.

UNEP (1992b) World Atlas of Desertification

UNEP (2007) Global Environmental Outlook 4

UNFCCC (2006) Methodology ACM0006, "Consolidated Methodology for Electricity Generation from Biomass Residues," www.unfccc.int.

UNFCCC (2007a) Methodology AM0047, "Production of Biodiesel Based on Waste Oils and/or Waste Fats from Biogenic Origin for Use as Fuel," www.unfccc.int.

UNFCCC (2007b). NM0185: Baseline methodology for the production of sugar cane based anhydrous bioethanol for transportation using LCA. Available online from: http://cdm.unfccc.int/UserManagement/FileStorage/UQKGKMUCPPWF3BQUIT02HYBO3EMI9B.

US EPA (2005). Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture. EPA 430-R-05-006. November 2005.

Vamvuka, D., Mavrou, E., Bandelis, G., Tsoutsos, T. and Papamicheal, I. (2007), "Biomass Cogeneration in Europe: economical, technical and environmental evaluation," Proceedings of the European Combustion Meeting (ECM).

Van Lynden, G.W.J. and L.R. Oldeman (1997) "Assessment of the Status of Human-induced soil degradation in South and South East Asia". International Soil Reference and Information Centre, Wageningen.

Verdonk, M., Dieperink, C.,and Faiij, A.P.C. (2007) "Governance of the emerging bio-energy markets," Energy Policy 35: 3909-3924.

Webb, P. (2001) "Land degradation in developing countries: what is the problem?", *International Journal of Agricultural Resources, Governance and Ecology*, 1(2): 124-135.