# Chapter 6 Demand for bioethanol for transport

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## **1. Introduction**

The utilization of ethanol either as a straight fuel or blended to gasoline (in various proportions) has been fully proven in various countries and it is regarded as technically feasible with existing internal combustion engine technologies. Because ethanol offers immediate possibilities of partially substituting fossil fuels, it has become the most popular transport biofuel in use. Production of ethanol, which has been rising fast, is expected to reach 70 billion litres by the end of 2008. Approximately 80% of this volume will be used in the transport sector while the rest will go into alcoholic beverages or will be either used for industrial purposes (solvent, disinfectant, chemical feedstock, etc.).

Although a growing number of countries, including China and India, have been introducing ethanol in the transport fuels market, it is in Brazil, in the USA and in Sweden where this use has gained most relevance. In March 2008, consumption of ethanol surpassed that of gasoline in Brazil, largely due to the success of the flex-fuel vehicles (FFVs) and resulting steep increase in straight ethanol (E100) consumption. In the USA, in addition to a rising utilization of FFVs and high ethanol content blends with up to 85% ethanol content (E85), over 50% of the gasoline marketed now contains ethanol, mostly 10% (E10). Sweden has been leading ethanol use in Europe with the 5% gasoline blend consumed nationwide (E5), an upward demand of E85 and a fleet of 600 ethanol-fuelled buses.

The international interest on ethanol in the transport sector has been based on various reasons including energy security, trade balance, rural development, urban pollution and mitigation of global warming. The challenge for the near future is to achieve wide acceptance of ethanol as a sustainable energy commodity and global growth of its demand. In the transport sector this includes increased supply of ethanol produced from a variety of renewable energy sources in an efficient, sustainable and cost-effective way. In many countries, 2<sup>nd</sup> generation biofuels (including ethanol) produced fromlignocellulosic biomass instead of food crops, is thought to deliver such performance, but commercial technology to convert biomass from residues, trees and grasses to liquid fuels is not yet available. On the demand side, it comprises the optimisation of existing engine technologies and development of new ones that could make the best possible use of ethanol and be introduced in the market in a large scale. Ethanol is a well suited and high quality fuel for more efficient flex fuel engines, ethanol-fuelled hybrid drive chains and dual-fuel combustion systems. Such technologies can boost vehicle efficiency and increase demand for ethanol use in various transport applications.

# 2. Development of the ethanol market

#### 2.1. Growth in demand and production

Liquid biofuels play so far a limited role in global energy supply, and represent only 10% of total bioenergy, 1.38% of renewable energy and 0.18% of total world energy supply. They are of significance mainly for the transport sector, but even here they supplied only 0.8% of total transport fuel consumption in 2005, up from 0.3% in 1990. In recent years, liquid biofuels have shown rapid growth in terms of volumes and share of global demand for transport energy. Ethanol production is rising rapidly in many parts of the world in response to higher oil prices, which are making ethanol more competitive. In 2007 the world fuel ethanol production was estimated as 50 billion litres, being the production in USA (24.6 billion litres) and Brazil (19 billion litres) equivalent to 88% of the total; in EU the production was almost 2.2 billion litres, in China 1.8 billion litres and in Canada 800 million litres (RFA, 2008, based on Licht, 2007).

Production of ethanol via fermentation of sugars is a classic conversion route, yet the most popular, which is applied for sugarcane, maize and cereals on a large scale, especially in Brazil, the United States and to a lesser extent the EU and China. Ethanol production from food crops like maize and cereals has been linked to food price increase, although estimates to what extent vary widely and many factors apart from biofuels play a role in those price increases (FAO, 2008). In addition bioethanol from such feedstocks has only been competitive to gasoline and diesel when supported by subsidies. Despite of some advances in its production process, ethanol from food crops is not likely to achieve major cost reduction in the short and medium terms.

In contrast, the impact of sugarcane based ethanol production (dominated by Brazil) on food prices seems minimal, given reduced world sugar prices in recent years. It's production achieved competitive performance levels with fossil fuel prices without the need of subsidies (Wall-Bake *et al.*, 2008). Also it has been gaining an increasingly relevant position in other countries in tropical regions (such as India, Thailand, Colombia and various countries in Sub-Saharan Africa). Production costs of ethanol in Brazil have steadily declined over the past few decades and have reached a point where ethanol is competitive with production costs of gasoline (Rosillo-Calle and Cortez, 1998; Wall-Bake *et al.*, 2008). As a result, ethanol is no longer financially supported in Brazil and competes openly with gasoline (Goldemberg *et al.*, 2004).

Figure 1 shows the learning curves of sugarcane and ethanol from sugarcane in Brazil since late 1970s. The estimated progress ratio (PR) of 0.68 in case of sugarcane imply that its costs of production have reduced, on average, 32% each time its cumulative production has doubled (19% in case of ethanol costs, excluding feedstock costs). The figure also shows



Cumulative ethanol production (10<sup>6</sup> m<sup>3</sup>)

Figure 1. Learning curves and estimated future costs of sugarcane and ethanol production (excluding feedstock costs) assuming 8% annual growth of sugarcane and ethanol production (Wall-Bake *et al.*, 2008).

estimated costs of sugarcane and ethanol production by 2020, supposing a certain growth path of sugarcane and ethanol production.

Larger facilities, better use of bagasse and trash residues from sugarcane production, e.g. with advanced power generation (gasification based) or hydrolysis techniques (see below), and further improvements in cropping systems, offer further perspectives for sugarcane based ethanol production (Damen, 2001; Hamelinck *et al.*, 2005).

The growth in the use of ethanol has been facilitated by its ability to be blended with gasoline in existing vehicles and be stored and transported using current facilities, equipment and tanks. Blending anhydrous ethanol with gasoline at ratios that generally are limited to E10 has been the fastest and most effective way of introducing ethanol in the fuel marketplace.

In Brazil fuel retailers are required to market high ethanol-content blends, with a percentage that can vary from 20% to 25% by volume (E20 – E25). Vehicles are customized for these

blends by car manufacturers or, in the case of imported cars (around 10% of the market), at the origin or by the importers themselves.

FFVs in the USA, Sweden and elsewhere can operate within a range that varies from straight gasoline to E85 blends, while in Brazil they are built to run in a range that varies from E20–E25 blends to E100. Up to 2006 car manufacturers in Brazil used to market dedicated E100 vehicles, which were later substituted by the FFVs.

Considering that current world's gasoline demand stands in the order of 1.2 trillion litres per year (information brochure produced by Hart Energy Consulting for CD Technologies, 2008) fuel ethanol supply will reach approximately 5% of this volume in 2008, which in energy terms represents 3% of current gasoline demand.

Ethanol has the advantage that it lowers various noxious emissions (carbon monoxide, hydrocarbons, sulphur oxides, nitrogen oxides and particulates) when compared to straight gasoline. Nevertheless the extent of emission reduction depends on a number of variables mainly engine characteristics, the way ethanol is used and emission control system features.

With regard to GHG emissions it has been demonstrated that on a life-cycle basis sugarcane ethanol produced in Brazil can reduce these emissions by 86% under current manufacturing conditions and use when compared to gasoline (Macedo *et al.*, 2008). Avoided emissions due to the use of ethanol produced from maize (USA) and wheat (EU) are estimated as 20-40% on life-cycle basis (IEA, 2004). In case of ethanol from sugarcane further reductions of GHG emissions are possible in short to mid-term, with advances in the manufacturing process (i.e. replacement of mineral diesel with biodiesel or ethanol in the tractors and trucks, end of pre-harvest sugarcane burning and capture of fermentation-generated  $CO_2$ ) (Macedo *et al.*, 2008; Damen, 2001; Faaij, 2006).

### 2.2. International trade

The development of truly international markets for bioenergy has become an essential driver to develop available biomass resources and bioenergy potentials, which are currently underutilised in many world regions. This is true for both residues as well as for dedicated biomass production (through energy crops or multifunctional systems, such as agroforestry). The possibilities to export biomass-derived commodities for the world's energy market can provide a stable and reliable demand for rural communities in many developing countries, thus creating an important incentive and market access that is much needed in many areas in the world. The same is true for biomass users and importers that rely on a stable and reliable supply of biomass to enable often very large investments in infrastructure and conversion capacity.

Figures 2 and 3 show the top ten ethanol importers and exporters in 2006, when the total volume traded was estimated as 6.5 billion litres, i.e. almost 13% of the whole production (Valdes, 2007). At that year more than 60 countries exported ethanol, but only ten surpassed 100 million litres traded and the most important 15 exporters covered 90% of the whole trade. US have imported more than 2.5 billion litres in 2006, EU about 690 million litres (Licht, 2007), while the imports of Japan were estimated as about 500 million litres. These three economic blocks represented about 80% of the net imports of ethanol in 2006.

Clearly, Brazil stands out as the largest exporter, covering more than 50% of the total volume traded. Except in 2006, when more than 50% was directly sold to US, ethanol exports from



Figure 2. Top 10 ethanol importers in 2006 (Licht, 2007).



Figure 3. Top 10 ethanol exporters in 2006 (Licht, 2007).

Brazil have been roughly well distributed among 10-12 countries. On the other hand, due to the Caribbean Basin Initiative (CBI) agreement<sup>10</sup>, most of the ethanol exported from Brazil to Central America and Caribbean countries reaches US. US importers from Caribbean and Central America countries have continuously grown since 2002.

Figure 4 shows Brazil's ethanol trade since 1970. Traditionally, Brazilian exports of ethanol have been oriented for beverage production and industrial purposes but, recently, trade for fuel purposes has enlarged. Halfway the 90-ies, a shortage of ethanol occurred, even requiring net imports. But after 2000 Brazilian exports of ethanol have risen steadily. In 2007 exports reached 3.5 billion litres and it is estimated that about 4 billion litres will be exported in 2008. It is expected that Brazil will maintain such an important position in the future. Outlooks on the future ethanol market are discussed in the next section.

 $<sup>^{10}</sup>$  CBI is an agreement between US and Central American and Caribbean countries that allows that up to 7% of the US ethanol demand may be imported duty-free, even if the production itself occurs in another country (Zarilli, 2006).



Figure 4. Trade in ethanol in Brazil 1970-2008 (estimates for 2008), including all end-uses (Brazil, 2008), (Kutas, 2008).

## 3. Drivers for ethanol demand

#### 3.1. Key drivers

When evaluating key drivers for ethanol demand, energy security and climate change are considered to be the most important objectives reported by nearly all countries that engage in bioenergy development activities. As illustrated in Table 1 no country highlights less than three key objectives. This renders successful bioenergy development a challenge as it tries to reach multiple goals, which are not always compatible. For instance, energy security considerations favour domestic feedstock production (or at least diversified suppliers), whereas climate change considerations and cost-effectiveness call for sourcing of feedstocks with low emissions and costs. This implies that imports are likely to grow in importance for various industrialized countries, but also a strong pressure on developing 2<sup>nd</sup> generation biofuels that are to be produced from lignocellulosic biomass. Not surprisingly, the latter is a key policy and RD&D priority in North America and the EU.

Country	Objectives								
	Climate change	Environment	Energy security	Rural development	Agricultural development	Technological progress	Cost effectivenness		
Brazil	Х	Х	х	Х	Х	Х			
China	Х	Х	Х	Х	Х				
India			Х	Х		Х	Х		
Mexico	Х	Х	Х	Х		Х			
South Africa	Х		Х	Х					
Canada	Х	Х	Х			Х			
France	Х		Х	Х	Х				
Germany	Х	Х		Х	Х	Х	Х		
Italy	Х		Х		Х				
Japan	Х	Х			Х	Х			
Russia	Х	Х	Х	Х	Х	Х			
UK	Х	Х	Х	Х			Х		
US	Х	Х	Х	Х	Х	Х			
EU	Х	Х	Х	Х	Х	Х			

Table 1. Main objectives of bioenergy development of G8 +5 countries (GBEP, 2008).

Overall there are few differences between the policy objectives of G8 Countries and the +5 countries (Mexico, South Africa, Brazil, India, China). Rural development is more central to the +5 countries' focus on bioenergy development, and this is often aligned with a poverty alleviation agenda. Bioenergy development is also seen as an opportunity to increase access to modern energy, including electrification, in rural areas. The rural development objectives of the wealthier G8 countries focus more on rural revitalization. Similarly, in the +5 countries, agricultural objectives envisage new opportunities not just for high-end commercialised energy crop production, but also for poorer small-scale suppliers. Very important is that in many countries (both industrialized and developing) sustainability concerns, e.g. on land-use, competition with food, net GHG balances, water use and social consequences, has become an overriding issue. Development and implementation of sustainability criteria is now seen in a variety of countries (including the EU) and for various commodities (such as palm oil, sugar and soy) (Van Dam *et al.*, 2008; Junginger *et al.*, 2008).

### 3.2. Developments in vehicle technology

Transport predominantly relies on a single fossil resource, petroleum that supplies 95% of the total energy used by world transport. In 2004, transport was responsible for 23% of world energy-related GHG emissions with about three quarters coming from road vehicles. (see also the breakdown of energy use of different modes of transport in Table 2). Over the past decade, transport's GHG emissions have increased at a faster rate than any other energy-using sector (Kahn Ribeiro *et al.*, 2007).

Figures 5a and 5b provide projections for the growth in energy use per mode of transport and per world region. Transport activity will continue to increase in the future as economic growth fuels transport demand and the availability of transport drives development, by

Mode	Energy use (EJ)	Share (%)
Light-duty vehicles	34.2	44.5
2-wheelers	1.2	1.6
Heavy freight trucks	12.48	16.2
Medium freight trucks	6.77	8.8
Buses	4.76	6.2
Rail	1.19	1.5
Air	8.95	11.6
Shipping	7.32	9.5
Total	76.87	100

Table 2. World transport energy use in 2000, by mode (Kahn Ribeiro *et al.*, 2007, based on WBCSD, 2004b).



Figure 5. Projection of transport energy consumption by mode (a) and region (b) (WBCSD, 2004a).

facilitating specialization and trade. The majority of the world's population still does not have access to personal vehicles and many do not have access to any form of motorized transport. However, this situation is rapidly changing.

Freight transport has been growing even more rapidly than passenger transport and is expected to continue to do so in the future. Urban freight movements are predominantly by truck, while international freight is dominated by ocean shipping.

Transport activity is expected to grow robustly over the next several decades. Unless there is a major shift away from current patterns of energy use, world transport energy use is projected to increase at the rate of about 2% per year, with the highest rates of growth in the emerging economies. Total transport energy use and carbon emissions are projected to be about 80% higher than current levels by 2030 (Kahn Ribeiro *et al.*, 2007).

There is an ongoing debate about whether the world is nearing a peak in conventional oil production that will require a significant and rapid transition to alternative energy resources. There is no shortage of alternative energy sources that could be used in the transport sector, including oil sands, shale oil, coal-to-liquids, gas-to-liquids, natural gas, biofuels, electricity and hydrogen produced from fossil fuels or renewable energy sources. Among these alternatives, unconventional fossil carbon resources could produce competitively priced fuels most compatible with the existing transport infrastructure, but these will lead to strongly increased carbon emissions (Kahn Ribeiro *et al.*, 2007).

## 3.2.1. The impact of existing technologies on fuel ethanol demand

In use vehicle technologies already enable large scale use of ethanol and therefore can be considered a key driver for its worldwide use. For instance, if E10 were to become globally used today, the global FFVs fleet (estimated at 15 million vehicles as of 2008) were to use the maximum level of ethanol and 50,000 buses were equipped with dedicated ethanol engines, fuel ethanol demand would jump from current 56 billion litres to 165 billion litres, almost a 200% increase over existing demand (Szwarc, A. personal communication). The largest consumption (75%) would come from ethanol blending with gasoline.

This estimate indicates the potential demand for ethanol without any technological breakthrough and although it would not be feasible to be achieved overnight because it requires a regulatory framework and ethanol logistics, it could be gradually developed until 2020. Projections of ethanol production for Brazil, the USA and the EU indicate that supply of 165 billion litres by 2020 could be achieved with the use of a combination of first and second generation ethanol production technologies.

However, a scenario where sugarcane ethanol production in Asia, Africa, Latin America and the Caribbean could fulfil these needs is also possible. Approximately 25 million hectares of sugarcane would be needed to produce this volume worldwide using only first generation technology. With cellulosic ethanol production technologies in place using sugarcane bagasse and straw and combination of these technologies with first generation technology, the need for land use would be reduced to 20 million hectares. A third scenario considering extensive use of second generation ethanol production from various non-conventional feedstocks, including industrial residues and municipal waste, could further reduce the need of land for ethanol production further (Walter *et al.*, 2008).

### 3.2.2. FFVs technology and the market

In 1992, the US market saw the first commercially produced FFVs. It was a concept that would allow the gradual structuring of an ethanol market. Drivers would be allowed to run on gasoline where ethanol would not be available, therefore resolving the question on 'what comes first: the car or the fuel infrastructure?' that inhibited the ethanol market growth. Pushed by alternative energy regulations and fiscal incentives, American car manufacturers began producing FFVs that in most part ended up in government fleets. Because the number of fuel stations marketing E85 is very limited, FFVs in the US have been fuelled with straight gasoline most of the time. General Motors has been championing the FFV concept in the USA and has recently engaged in the expansion of E85 sales locations. Other companies like Ford, Chrysler and Nissan have also FFVs in their sales portfolio. By December 2008 approximately 8 million FFVs (2.8% of vehicle fleet in the US) will be on American roads but still consuming mostly gasoline (Szwarc, A., personal communication).

Sweden was the first country in Europe to start using FFVs in 1994. At first only a few imported vehicles from the US composed a trial fleet, but in 2001 FFVs sales started. In 2005 local car manufacturers like Saab and Volvo developed E85 FFVs versions. In 2007, the market share of new FFVs in Sweden was 12% and the total fleet reached 80,000 vehicles (2% of the total vehicle fleet). Over 1,000 fuel stations are selling E85 in Sweden making possible the use of E85 in FFVs. A variety of policy measures have been provided incentives for FFVs in Sweden. These include exemption of biofuels from mineral oil tax, tax benefits for companies and private car owners, free parking in 16 cities and mandatory alternative fuel infrastructure and government vehicle purchases. This initiative is part of a set of measures taken by Sweden in order to achieve its ambitious goal to be at the forefront of the world's 'green' nations and achieve a completely oil-free economy by 2020.

E100-compatible FFVs were introduced in the Brazilian market in 2003 in a different context than observed in the US or Sweden, in order to fulfil consumers' desire to use a cheaper fuel. FFVs have become a sales phenomenon and presently sales correspond to nearly 90% of new light-duty vehicle sales. All car manufacturers in Brazil have developed FFVs that are being offered as standard versions for the domestic market (over 60 models in 2008). The success of FFVs can be explained by now excellent availability of E100 and E20/E25 (at more than 35,000 fuel stations nationwide), flexibility for consumers who can choose the fuel they want depending on fuel costs and/or engine performance. Since fuel ethanol has been in general less expensive than gasoline blends (straight gasoline is not available for sale in Brazil) and gives better performance, it became the fuel of choice. Furthermore FFV's have a 'greener' and more modern image and have higher resale value compared to conventional cars.

In 2008, the Brazilian fleet of FFVs will reach 7 million vehicles (25% of vehicle fleet) and in most cases the preferred fuel has been E100. The success of FFVs in Brazil has caught the attention of manufacturers of two wheel vehicles (motorcycles, scooters and mopeds) who are developing FFVs versions that are expected to reach the market soon.

### 3.2.3. The impact of new drive chain technologies

Compared to current average vehicle performance, considerable improvements are possible in drive chain technologies and their respective efficiencies and emission profiles. IEA does project that in a timeframe towards 2030, increased vehicle efficiency will play a significant role in slowing down the growth in demand for transport fuels. Such steps can be achieved with so-called hybrid vehicles which make use of combined power supply of internal combustion engine and an electric motor. Current models on the market, if optimised for ethanol use, could deliver a fuel economy of about *16 km/litre* of fuel. With further technology refinements, which could include direct injection and regenerative breaking, fuel ethanol economy of *24 km/litre* may be possible. Such operating conditions, can also deliver very low concentration of emissions.

The use of ethanol in heavy-duty diesel fuelled applications is not easy. But the well established experience with ethanol-fuelled buses in Sweden, which started in the mid-nineties, and recent research with dual-fuel use (diesel is used in combination with ethanol but each fuel is injected individually in the combustion chamber according to a preset electronically controlled engine map) indicate interesting possibilities with regard to reducing both diesel use and emissions.

Drive chain technologies that may make a considerable inroad in the coming decades, such as electric vehicles and serial hybrids, may however have a profound impact on vehicle efficiency and, to some extent, a dampening effect on the growth of transport fuel demand. Penetration of electric vehicles (cars, motorcycles and mopeds) or the use of plug-in hybrids that could be connected to the grid is still uncertain. Developments in battery technology are rapid though and electric storage capacity, charging time and power to weight ratios are continuously improved. When such improved technology is especially deployed in hybrid cars, the net effect will simply be a reduction of fuel demand. However, when deployed as plug-in hybrid, part of the fuel demand can be replaced by electricity. This could reduce the growth in demand for (liquid) transport fuels down more quickly than currently assumed in various studies.

In case Fuel Cell Vehicles (FCVs) become commercially available, this may mean a boost for the use hydrogen as fuel. Although the projected overall 'well-to-wheel' potential efficiency of e.g. natural gas to hydrogen or biomass to hydrogen for use in a FCV is very good (Hamelinck and Faaij, 2006), it is highly uncertain to what extent the required hydrogen distribution infrastructure may be available in the coming decades. Important barriers are the currently high costs of FCVs and the high investment costs of hydrogen infrastructure. Most scenarios on the demand for transport fuels towards 2030 project only a marginal role for hydrogen.

Nevertheless, the speed of penetration of such more advanced drive chains in the market and the new infrastructure they require, is uncertain and the available projections for demand of liquid transport fuels indicate that we may be looking at a doubling of demand halfway this century. Also, the overall economic and environmental performance of the use of electricity and hydrogen for transport depends heavily on the primary energy source and overall chain efficiency.

Hybrid vehicles in the transport sector and urban services seem to be at present stage a more viable alternative than FCV for the same applications. Not only is this technology more advanced in terms of commercial use but also it has many practical advantages in terms of cost and fuel infrastructure (Kruithof, 2007). Sweden has been leading the development of hybrid buses and trucks equipped with electric motor and ethanol engine. Commercial use of this type of vehicles could occur by 2010 setting a new benchmark for sustainable ethanol use.

# 4. Future ethanol markets

Future ethanol markets could be characterized by a diverse set of supplying and producing regions. From the current fairly concentrated supply (and demand) of ethanol, a future international market could evolve into a truly global market, supplied by many producers, resulting in stable and reliable biofuel sources. This balancing role of an open market and trade is a crucial precondition for developing ethanol production capacities worldwide.

Paramount to a solution is an orderly and defined schedule for elimination of subsidies, tariffs, import quotas, export taxes and non-tariff barriers in parallel with the gradual implementation of sustainable ethanol mandates. These measures will provide the necessary conditions to reduce risks and to attract investment to develop and expand sustainable production. Several different efforts to reach these goals are ongoing including multilateral, regional, and bilateral negotiations, as well as unilateral action. Public and private instruments such as standards, product specifications, certification and improved distribution infrastructure are important for addressing technical and sustainability issues. In addition, the development of a global scheme for sustainable production combined with technical and financial support to facilitate compliance, could ensure that sustainability and trade agendas are complementary (Best *et al.*, 2008).

# 4.1. Outlook on 2<sup>nd</sup> generation biofuels

Projections that take explicitly second generation options into account are more rare, but studies that do so come to rather different outlooks, especially in the timeframe exceeding 2020. Providing an assessment of studies that deal with both supply and demand ofbiomass and bioenergy, IPCC highlights that biomass demand could lay between 70-130 EJ in total, subdivided between 28-43 EJ biomass input for electricity and 45-85 EJ for biofuels (Barker and Bashmakov, 2007). Heat and biomass demand for industry are excluded in these reviews. It should also be noted that around that timeframe biomass use for electricity has become a less attractive mitigation option due to the increased competitiveness of other renewables (e.g. wind energy) and e.g. carbon capture and storage. (Barker and Bashmakov, 2007).

In de Vries *et al.* (2007) (based on the analyses of Hoogwijk *et al.* (2005, 2008), it is indicated that the biofuel production potential around 2050 could lay between about 70 and 300 EJ fuel production capacity depending strongly on the development scenario, i.e. equivalent to 3,100 to 9,300 billion litres of ethanol<sup>11</sup>. Around that time, biofuel production costs would largely fall in the range up to 15 U\$/GJ, competitive with equivalent oil prices around 50-60 U\$/barrel (see also Hamelinck and Faaij, 2006). A recent assessment study confirms that such shares in the global energy supply are possible, to a large extent by using perennial

<sup>&</sup>lt;sup>11</sup> Based on the LHV of anhydrous ethanol (22.4 MJ/litre).

cropping systems that produced lignocellulosic biomass, partly from non-agricultural lands and the use of biomass residues and wastes. Large changes in land use and leakage effects could be avoided by keeping expanding biomass production in balance with increased productivity in agriculture and livestock management. Such a development would however require much more sophisticated policies and effective safeguards and criteria in the global market (Dornburg *et al.*, 2008).

#### 4.2. Scenario's on ethanol demand and production

Walter *et al.* (2008) evaluated market perspectives of fuel ethanol up to 2030, considering two alternative scenarios. The first scenario reflects constrains of ethanol production in US and Europe due to the hypothesis that large-scale production from cellulosic materials would be feasible only towards the end of the period. In this case world production would reach 272,4 billion litres in 2030 (6 EJ), being only 8 billion litres of second generation ethanol, amount that would displace almost 10% of the estimated demand of gasoline.

Scenario 2 is based on the ambitious targets of ethanol production defined by US government by early 2007, i.e. consumption of about 132 billion litres by 2017. This target can only be achieved if large-scale ethanol production from cellulosic materials becomes feasible in short- to mid-term. In Scenario 2 the consumption of fuel ethanol reaches 566 billion litres in 2030 (about 13 EJ), displacing more than 20% of the demand of gasoline; 203 billion litres would be second generation ethanol.

Tables 3 summarizes results of the two scenarios for different regions/countries of the world. In case of EU, the substitution of 28.5% of gasoline volume basis (Scenario 1) would correspond to the displacement of 20% energy basis. By 2030, the estimated ethanol consumption in EU (both scenarios) and US (scenario 2) would only be possible with FFVs or even neat ethanol vehicles.

Table 3 also presents estimates of production capacity of first generation ethanol. Production capacity by 2030 was evaluated by Walter *et al.* (2008) based on the capacity available in 2005 and on projections based on trends and plans. In some cases (e.g. EU) these results were adjusted to the estimates done by the IEA (2004) as well as Moreira (2006) taking into account constraints such as land availability. It is clear that without second generation ethanol the relatively modest target to displace 10% of the gasoline demand in 2030 (Scenario 1), at reasonable cost, can only be accomplished fostering fuel ethanol production in developing countries. Second generation of ethanol would be vital if 20% of the gasoline demand is to be replaced by biofuels in 2030 (Scenario 2), although a significant contribution would have to come from conventional feedstocks mainly from developing countries.

However, the combination of lignocellulosic resources (biomass residues on shorter term and cultivated biomass on medium term) and second generation conversion technology

Region/ country	Scenario 1	Gasoline displaced (%) <sup>1</sup>	Scenario 2	Gasoline displaced (%) <sup>1</sup>	Production capacity
US	55.3	7.4	263.7	35.0	63.0
EU	36.0	28.5	49.6	39.3	27.3
Japan	9.3	10.0	14.3	15.0	_ 2
China	21.6	10.0	33.5	15.0	18.2
Brazil	50.0	48.0 <sup>3</sup>	50.0	48.0 <sup>3</sup>	62.0 <sup>4</sup>
ROW <sup>5</sup>	100.2	10.0	154.9	15.0	n.c. <sup>6</sup>

Table 3. Ethanol consumption by 2030 in two different scenarios and production capacity based on conventional technologies (billion litres).

 $^{1}$  Gasoline displaced in volume basis regarding the estimated gasoline consumption in 2030.

<sup>2</sup> It was assumed that first generation ethanol would not be produced in Japan.

 $^{3}$  Estimates of gasoline displaced considering that the substitution ratio by 2030 would be 1 litre of gasoline = 1.25 litre of ethanol. In case of Brazil there is only one scenario.

<sup>4</sup> In this case production capacity is not the maximum, but the capacity that should be reached considering a certain path of growth.

<sup>5</sup> Rest of the World.

 $^{6}$  n.c. = not calculated.

offers a very strong perspective. Furthermore, sugarcane based ethanol has a key role to play at present and that role can be considerably expanded by improving the current operations further and by implementation cane based ethanol production to regions where considerably opportunities exist, especially to parts of Sub-Saharan Africa. For example, the efficient use bagasse and sugar can trash with advanced co-generation technology can increase electricity output of sugar mills considerably in various countries and thus deliver a significant contribution to (renewable) electricity production. Also, it seems realistic to assume that sugarcane based ethanol can meet the new and stringent sustainability criteria that are expected in the global market on short term (see e.g. Smeets *et al.*, 2008).

### 5. Discussion and final remarks

#### 5.1. Key issues for the future markets

Biofuels in 2008 is at a crossroad: the public perception and debate have to a considerable amount pushed biofuels in a corner as being expensive, not effective as GHG mitigation option, to have insignificant potential compared to global energy use, a threat for food production and environmentally dangerous. But that basic rationale for the production and use of biofuels still stands and is stronger than ever. Climate change is accepted as a certainty, the supply of oil in relation to growing demand has developed into a strategic and economic risk, with oil prices hoovering around 130 US\$/barrel at the moment of writing. Furthermore, the recent food crisis has made clear how important it is that investment and capacity building reach the rural regions to improve food production capacity and make this simultaneously more sustainable. Biofuels produced today in various OECD countries have a mediocre economic and environmental performance and many objections raised are understandable, be it overrated.

However, distinguishing those biofuels from sugarcane based ethanol production and the possibilities offered by further improvement of that production system, as well as second generation biofuels (including ethanol production from lignocellulosic resources produced via hydrolysis) is very important. It is clear though, that future growth of the biofuel market will take place with much more emphasis on meeting multiple goals, especially avoiding conflicts on land-use, water, biodiversity and at the same time achieving good GHG performance and socio-economic benefits (see e.g. Hunt *et al.*, 2007).

### 5.2. Future outlook

Projections for the production and use of biofuels differ between various institutions. Clearly, demand for transport fuels will continue to rise over the coming decades, also with the introduction of new drive chain technology. In fact, there could be an important synergy between new drive chains (such as serial hybrid technology) and high quality biofuels with narrow specifications (such as ethanol), because such fuels allow for optimised performance and further decreased emissions of dust and soot, sulphur dioxide and nitrous oxides.

Projections that highlight a possibly marginal role for biofuels in the future usually presume that biomass resource availability is a key constraint and that biofuel production will remain based on current technologies and crops and stay expensive (e.g. IEA, 2006, OECD/FAO, 2007). Clearly, the information compiled in this chapter shows that a combination of further improved and new conversion technologies and conversion concepts (such as hydrolysis for producing sugars of ligno cellulosic materials) and use of ligno cellulosic biomass offers a different perspective: the biomass resource basis consisting of biomass residues from forestry and agriculture, organic wastes, use of marginal and degraded lands and the possible improvement in agricultural and livestock efficiency that can release lands for additional biomass production could become large enough to cover up to one third of the global energy demand, without conflicting with food production or additional use of agricultural land. Also, the economic perspectives for such second generation concepts are very strong, offering competitiveness with oil prices equivalent to some 55 US\$/barrel around 2020. Further improved ethanol production (i.e. with improved cane varieties, more efficient factories and efficiently use of bagasse and trash for power generation or more ethanol using hydrolysis processes) from sugarcane holds a similar strong position for the future.

#### 5.3. Policy requirements and ways forward

It is very likely ethanol has a major role to play in the future worlds' energy markets. There are uncertainties though, such as dwindling public support for biofuels and possible failure to commercialise second generation technologies on foreseeable term. In case biofuels can be developed and managed to be the large and sustainable energy carriers they can in principle become (which largely depends on the above mentioned governance issues). It is also clear that sugarcane based ethanol production is one of the key systems now with a very good future outlook. In addition, ethanol is a fuel that can easily absorbed by the market. Key preconditions for achieving the sketched desirable future outlook are:

- To build on the success of current sugarcane based ethanol production and develop and implement further optimised production chains.
- Remove market barriers to allow for open trade for biofuels across the globe, while at the same time securing sustainable production by adoption of broad criteria.
- To enhance strong Research Development, Demonstration and Deployment efforts with respect to advanced, second generation conversion technologies. This concerns new, commercial stand-alone processes, but also improvements of existing infrastructure and even combinations with fossil fuels (such as co-gasification of biomass with coal for production of synfuel, combined with CO<sub>2</sub> capture and storage).
- To develop and broaden the biomass resources base by expanding (commercial) experience with production of woody and grassy crops. Also the enhanced use of agricultural and forestry residues can play an important role, in particular on the shorter term.
- To further develop, demonstrate and implement the deployment of broad sustainability criteria for biomass production, in general, and biofuels, in particular. This can be done by means of certification. Global collaboration and linking efforts around the globe is important now to avoid a 'proliferation of standards' and the creation of different, possible conflicting schemes.

## References

- Barker, T. and I. Bashmakov, 2007. Mitigation from a cross-sectoral perspective, In: B. Metz, O.R. Davidson, P.R. Bosch, R. Dave and L.A. Meyer (eds.), Climate Change 2007: Mitigation contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge United Kingdom and New York, USA.
- Best, G.J.C. Earley, A. Faaij, U. Fritsche, A. Hester, S. Hunt, T. Iida, F. Johnson, P.M. Nastari, D.E. Newman, C.A. Opal, M. Otto, P. Read, R.E.H. Sims, S.C. Trindade, J. Bernard Tschirley and S. Zarilli, 2008. Sustainable Biofuels Consensus, Bellagio Declaration, prepared with support from the Rockefeller Foundation, April 2008, pp. 8.
- Damen, K., 2001. Future prospects for biofuels in Brazil a chain analysis comparison between production of ethanol from sugarcane and methanol from eucalyptus on short and longer term in Sao Paulo State-, Department of Science, Technology & Society Utrecht University, November 2001, 70 pp.

- De Vries, B.J.M., D.P. van Vuuren and M.M. Hoogwijk, 2007. Renewable energy sources: Their global potential for the first-half of the 21st century at a global level: An integrated approach. Energy Policy 35: 2590-2610.
- Dornburg, V., A. Faaij, H. Langeveld, G. van de Ven, F. Wester, H. van Keulen, K. van Diepen, J. Ros, D. van Vuuren, G.J. van den Born, M. van Oorschot, F. Smout, H. Aiking, M. Londo, H. Mozaffarian, K. Smekens, M. Meeusen, M. Banse, E. Lysen and S. van Egmond, 2008. Biomass Assessment: Assessment of global biomass potentials and their links to food, water, biodiversity, energy demand and economy Main Report, Study performed by Copernicus Institute Utrecht University, MNP, LEI, WUR-PPS, ECN, IVM and the Utrecht Centre for Energy Research, within the framework of the Netherlands Research Programme on Scientific Assessment and Policy Analysis for Climate Change. Reportno: WAB 500102012, January 2008. 85 pp. + Appendices.
- Faaij, A.P.C., 2006. Modern biomass conversion technologies. Mitigation and Adaptation Strategies for Global Change 11: 335-367.
- FAO, 2008. State of Food and Agriculture Biofuels: prospects, risks and opportunities, Food and Agriculture Organisation of the United Nations, Rome, Italy.
- GBEP, 2008. A Review of the Current State of Bioenergy Development in G8 +5 Countries, Global Bioenergy Partnership, Rome, Italy.
- Goldemberg, J., S. Teixeira Coelho, P. Mário Nastari and O. Lucon, 2004. Ethanol learning curve the Brazilian experience, Biomass and Bioenergy 26: 301-304.
- Hamelinck, C. and A. Faaij, 2006. Outlook for advanced biofuels. Energy Policy 34: 3268-3283.
- Hamelinck, C.N., G. van Hooijdonk and A.P.C. Faaij, 2005. Future prospects for the production of ethanol from ligno-cellulosic biomass. Biomass & Bioenergy 28: 384-410.
- Hettinga, W.G., H.M. Junginger, S.C. Dekker, M. Hoogwijk, A.J. McAloon and K.B. Hicks, 2008. Understanding the Reductions in U.S. Corn Ethanol Production Costs: An Experience Curve Approach, Energy Policy, in press.
- Hoogwijk, M., A. Faaij, B. de Vries and W. Turkenburg, 2008. Global potential of biomass for energy from energy crops under four GHG emission scenarios Part B: the economic potential. Biomass & Bioenergy, in press.
- Hoogwijk, M., A. Faaij, B. Eickhout, B. de Vries and W. Turkenburg, 2005. Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios, Biomass & Bioenergy 29: 225-257.
- Hunt, S., J. Easterly, A. Faaij, C. Flavin, L. Freimuth, U. Fritsche, M. Laser, L. Lynd, J. Moreira, S. Pacca, J.L. Sawin, L. Sorkin, P. Stair, A. Szwarc and S. Trindade, 2007. Biofuels for Transport: Global Potential and Implications for Energy and Agriculture prepared by Worldwatch Institute, for the German Ministry of Food, Agriculture and Consumer Protection (BMELV) in coordination with the German Agency for Technical Cooperation (GTZ) and the German Agency of Renewable Resources (FNR), ISBN: 1844074226, Published by EarthScan/James & James, April 2007336 pp.
- International Energy Agency, 2004. Biofuels for transport an international perspective, Office of Energy Efficiency, Technology and R&D, OECD/IEA, Paris, France.

International Energy Agency, 2006. World Energy Outlook 2006, IEA Paris, France.

- Junginger, M., T. Bolkesjø, D. Bradley, P. Dolzan, A. Faaij, J. Heinimö, B. Hektor, Ø. Leistad, E. Ling, M. Perry, E. Piacente, F. Rosillo-Calle, Y. Ryckmans, P.-P. Schouwenberg, B. Solberg, E. Trømborg, A. da Silva Walter and M. de Wit, 2008. Developments in international bioenergy trade. Biomass & Bioenergy 2: 717-729.
- Kahn Ribeiro, S., S. Kobayashi, M. Beuthe, J. Gasca, D. Greene, D.S. Lee, Y. Muromachi, P.J. Newton, S. Plotkin, D. Sperling, R. Wit and P.J. Zhou, 2007: Transport and its infrastructure. In: B. Metz, O.R. Davidson, P.R. Bosch, R. Dave and L.A. Meyer (eds.), Climate Change 2007: Mitigation contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge United Kingdom and New York, USA.
- Kruithof, T., 2007. Drive the future, techno-economic comparison of fuel cell, serial hybrid and internal combustion engine drivechains for light duty vehicles. Copernicus Institute – Utrecht University, department of Science, Technology & Society. Report no.: NWS-I-2007-25, November 2007. 81 pp.
- Kutas, G., 2008. Brazil's Sugar and Ethanol Industry: Endless Growth?. Presentation in Brussels, June 2008. Available at: www.unica.com.br.
- Licht, F.O., 2007. World Bioethanol and Biofuels Report 5: 17.
- Macedo, I.d.C., J.E.A. Seabra and J.E.A.R. Da Silva, 2008. Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and a prediction for 2020. Biomass & Bioenergy 32: 582-595.
- Moreira, J.R., 2006. Global biomass energy potential. Mitigation and Adaptation Strategies for Global Change 11: 313-342.
- OECD/FAO, 2007. Agricultural Outlook 2007-2016, Paris-France.
- RFA, 2008. Changing the Climate Ethanol Industry Outlook 2008. Renewable Fuels Association, page 16.
- Rosillo-Calle, F. and L.A.B. Cortez, 1998. Towards Pro-Alcool II a review of the Brazilian bioethanol programme, Biomass & Bioenergy 14: 115-124.
- Smeets, E., M. Junginger, A. Faaij, A. Walter, P. Dolzan and W. Turkenburg, 2008. The sustainability of Brazilian Ethanol; an assessment of the possibilities of certified production. Biomass & Bioenergy 32: 781-813.
- Valdes, C., 2007. Ethanol demand driving the expansion of Brazil's sugar industry. Sugar and Sweeteners Outlook/SSS-249: 31-38.
- Van Dam, J., M. Junginger, A. Faaij, I. Jürgens, G. Best and U. Fritsche, 2008. Overview of recent developments in sustainable biomass certification. Biomass & Bioenergy 32: 749-780.
- Wall-Bake, J.D., M. Junginger, A, Faaij, T. Poot and A. da Silva Walter, 2008. Explaining the experience curve: Cost reductions of Brazilian ethanol from sugarcane. Biomass & Bioenergy, in press.
- Walter, A., F. Rosillo-Calle, P. Dolzan, E. Piacente and K. Borges da Cunha, 2008. Perspectives on fuel ethanol consumption and trade. Biomass & Bioenergy 32: 730-748.
- WBCSD, 2004a. Mobility 2030: Meeting the Challenges to Sustainability. Available at: http://www.wbcsd.ch/
- WBCSD, 2004b. IEA/SMP Model Documentation and Reference Projection. Fulton, L. and G. Eadsn (eds.). Available at: http://www.wbcsd.org/web/publications/mobility/smp-model-document.pdf.
- Zarrilli. S., 2006. The emerging biofuels market: regulatory, trade and development implications. Geneva: United NationsConference on Trade and Development (UNCTAD); 2006. Available at: /www.unctad. org/en/docs/ditcted20064\_en.pdfS.