Table 8. Agrochemical inputs consumption (per ha) and per ethanol production (m^3).

	Sugarcane		Maize	
	Cons./ha	**Cons./m^3**	**Cons./ha**	**Cons./m^3**
Ethanol production (m^3)	8.1	-	4.2	-
Quantity of N (kg)	25.0	3.1	140.0	33.7
Quantity of P (kg)	37.0	4.6	100.0	24.1
Quantity of K (kg)	60.0	7.4	110.0	26.5
Liming materials (kg)	600.0	74.5	500.0	120.5
Herbicide (liters)	2.6	0.3	13.0	3.1
Drying hormone (liters)	0.4	0.0	-	-
Insecticides (liters)	0.1	0.0	2.2	0.5
Formicide (kg)	-	-	0.5	0.1
Nematicide (liters)[a]	1.2	0.1	-	-
Total	726.2	90.2	865.7	208.5

Sources: Agrianual (2008); Fancelli and Dourado Neto (2006).

[a] Product used to control microscopic multicellular worms called nematodes.

are produced. Generally the vinasse has a high organic matter and potassium content, and relatively poor nitrogen, calcium, phosphorus and magnesium contents (Ferreira and Monteiro 1987). Advantages of using vinasse include increased pH and cation exchange capacity, improved soil structure, increased water retention, and development of the soil's micro flora and micro fauna. Many studies have been conducted involving specific aspects pertaining to leaching and underground water contamination possibilities at variable vinasse doses over periods of up to 15 years. The results obtained from tests so far indicate that there are no damaging impacts on the soil at doses lower than 300 m^3/ha, while higher doses may damage the sugarcane or, in specific cases (sandy or shallow soil), contaminate underground water (Souza, 2005).

Investments in infrastructure have enabled the use water from the industrial process and the ashes from boilers. Filter cake (a by product of the yeast fermentation process) recycling processes were also developed, thereby increasing the supply of nutrients to the field.

3.4. Management of diseases, insects and weeds[9]

Strategies for disease control involve the development of disease resistant varieties within large genetic improvement programs. This approach kept the major disease outbreak managed, i.e. the SCMV (sugarcane mosaic virus, 1920), the sugarcane smut, *Ustilago scitaminea*, and rust *Puccinia melanocephala* (1980's), and the SCYLV (sugarcane yellow leaf virus, 1990's) by replacing susceptible varieties.

The soil pest monitoring method in reform areas enabled a 70% reduction of chemical control (data provided by CTC), thereby reducing costs and risks to operators and the environment.

Sugarcane, as semi-permanent culture of annual cycle and vegetative propagation, forms a crop planted with a certain variety that is reformed only after 4 to 5 years of commercial use. These characteristics determine that the only economically feasible disease control option is to use varieties genetically resistant to the main crop diseases.

Insecticide consumption in sugarcane crops is lower than in citrus, maize, coffee and soybean crops; the use of insecticides is also low, and of fungicides is virtually null (Agrianual, 2008). Among the main sugarcane pests, the sugarcane beetle, *Migdolus fryanus* (the most important pest) and the cigarrinha, *Mahanarva fimbriolata*, are biologically controlled. The sugarcane beetle is the subject of the country's largest biological control program. Ants, beetles and termites are chemically controlled. It has been possible to substantially reduce the use of pesticides through selective application.

The control or management of weeds encompasses specific methods or combinations of mechanical, cultural, chemical and biological methods, making up an extremely dynamic process that is often reviewed. In Brazil, sugarcane uses more herbicides than coffee and maize crops, less herbicides than citrus and the same amount as soybean (Agrianual, 2008).

On these issues mentioned above related to use of agrochemicals, soil management and water uses, UNICA's (Brazilian Sugarcane Growers Association) associated mills are developing a set of goals, aiming at improving agricultural sustainability in the next few years (Table 9).

[9] This text was adapted from Arrigoni and Almeida (2005) and Ricci Junior (2005).

Table 9. Sugarcane agricultural sustainability.

Sugarcane		
Less agrochemicals	**Low soil loss**	**Minimal water use**
Low use of pesticides. No use of fungicides Biological control to mitigate pests. Advanced genetic enhancement programs that help idntify the most resistant varieties of sugarcane. Use of vinasse and filter cake as organic fertilizers.	Brazilian sugarcane fields have relatively low levels of soil loss, thanks to the semi-perennial nature of the sugarcane that is only replanted every 6 years. The trend will be for current losses, to decrease significantly in coming years through the use of sugarcane straw, some of which is left on the fields as organic matters after mechanical harvesting	Brazilian sugarcane fields require practically no irrigation because rainfall is abundant and reliable, particularly in the main South Central production region. Ferti-irrigation: applying vinasse (a water-based residue from sugar and ethanol production). Water use during industrial processing has decreased significantly over the years: from 5 m^3/t to 1 m^3/t.

Source: Unica (2008).

3.5. Conservation of biodiversity

Brazil is a biodiversity hotspot and contains more than 40% of all tropical rain forest of the World. Brazilian biodiversity conservation priorities were set mainly between 1995 and 2000, with the contribution of hundreds of experts; protected areas were established for the six major biomes in the National Conservation Unit System.

Steps for the implementation of the Convention on Biological Diversity includes the preparation of the biodiversity inventory and monitoring of important biodiversity resources, the creation of reserves, the creation of seed, germoplasm and zoological banks, and the conduct of Environmental Impact Assessments covering activities that could affect the biodiversity.

The percentage of forest cover represents a good indicator of conservation of biodiversity in agricultural landscapes. In São Paulo State for example the remaining forest covered is 11%, of which 8% being part of the original Atlantic Forest. Table 10 demonstrates that while the sugarcane area increased from 7 to 19% of the State territory, native forests also increased from 5 to 11%, showing that it is possible to recover biodiversity in intense agricultural systems.

Table 10. Sugarcane and vegetation area in São Paulo State.

Year	Sugarcane					Vegetation			% SP State	
	New lands (Kha)	Land in use (Kha)	Total area (Kha)	Production (Kton)	Productivity (ton/ha)	Woody-Cerradao (Kha)	Shrubby-Cerrado/ savana (Kha)	Native forests (Kha)	Sugarcane area	Native forests area
1983	345	1,421	1,765	107,987	76.0	196	489	1,139	7%	5%
1984	317	1,526	1,842	116,666	76.5	167	427	1,453	7%	6%
1985	326	1,626	1,952	121,335	74.6	221	438	1,545	8%	6%
1986	350	1,704	2,054	122,986	72.2	205	378	1,795	8%	7%
1987	311	1,753	2,064	132,322	75.5	211	348	1,870	8%	8%
1988	325	1,771	2,097	134,108	75.7	192	316	1,624	8%	7%
1989	322	1,757	2,078	130,795	74.5	198	325	1,487	8%	6%
1990	276	1,836	2,112	139,400	75.9	175	290	1,097	9%	4%
1991	301	1,864	2,165	144,581	77.6	198	301	1,601	9%	6%
1992	372	1,940	2,311	150,878	77.8	204	284	2,109	9%	8%
1993	371	1,989	2,360	156,623	78.7	238	259	2,120	10%	9%
1994	421	2,180	2,601	168,362	77.2	201	238	2,453	10%	10%
1995	449	2,260	2,709	175,073	77.5	189	220	2,434	11%	10%
1996	428	2,388	2,816	187,040	78.3	217	232	2,462	11%	10%
1997	422	2,451	2,872	194,801	79.5	215	244	2,478	12%	10%
1998	342	2,544	2,887	199,764	78.5	217	241	2,482	12%	10%
1999	281	2,475	2,756	193,374	78.1	218	244	2,468	11%	10%
2000	338	2,491	2,829	189,391	76.0	221	257	2,629	11%	11%
2001	440	2,569	3,009	201,683	78.5	223	262	2,622	12%	11%
2002	457	2,661	3,118	212,707	79.9	224	263	2,725	13%	11%
2003	495	2,818	3,313	227,981	80.9	225	264	2,720	13%	11%
2004	463	2,951	3,414	241,659	81.9	211	262	2,732	14%	11%
2005	553	3,121	3,673	254,810	81,7	217	254	2,648	15%	11%
2006	822	3,437	4,258	284,917	82,9	228	271	2,695	17%	11%
2007	935	3,897	4,832	327,684	84,1	233	277	2,716	19%	11%

Source: IEA/CATI-SAAESP (Annual statistics from 1983-2007).

3.6. Air quality

Burning sugarcane for harvesting is one of the most criticized issue of sugarcane production system, causing local air pollution and affecting air quality, despite of the benefits of using 100% ethanol running engines instead of gasoline (Figure 9), which decreases air pollution from 14 to 49%.

In order to eliminate gradually sugarcane burning, several attempts are being made. The São Paulo Green Protocol is being considered the most important one, setting an example for other regions and states in Brazil. Signed between the São Paulo state government (State Environment Secretariat) and the Sugarcane Growers Association (UNICA) in June 04, 2007, the Green Protocol aimed at:

- The anticipation of the legal deadline for the elimination of the practice of sugarcane straw burning to 2014.
- The protection of river side woods and recovering of those near water streams (permanent protected areas - APPs).
- The implementation of technical plans for conservation of soil and water resources.
- The adoption of measures to reduce air pollution.
- The use of machines instead of fire to harvest new sugarcane fields.

Voluntarily 141 of the total of 170 sugar mills from the state of São Paulo signed this Protocol, and recently 13 thousand sugarcane independent suppliers, members of the Organization of Sugarcane Farmers of the Center-South Region (Orplana), signed also this protocol. Therefore the entire production chain of sugar and ethanol of São Paulo participates

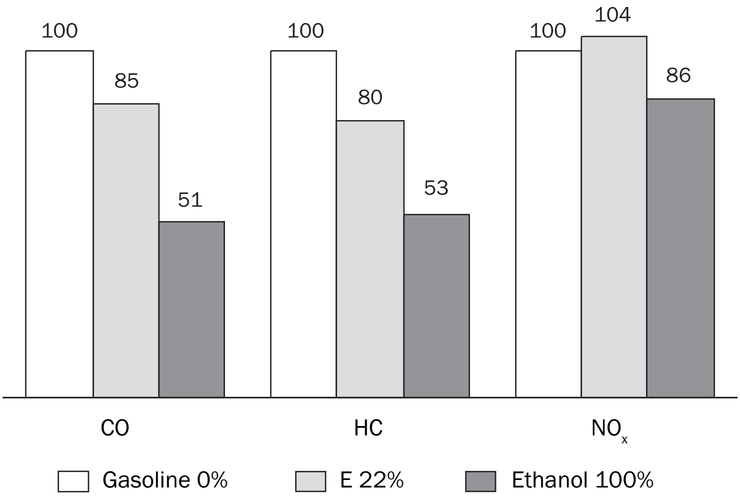

Figure 9. Air pollution by different blends of ethanol. Source: ANFAVEA (2006).

in the implementation of the Protocol. Maintaining the 2007 levels of mechanization, when 550 new harvest machines have begun to operate, it will be possible to complete the mechanization even prior to the deadline (2014) set by the Protocol.

4. Initiatives towards ethanol certification and compliance

The discussion on sustainable production of biofuels has fulfilled the scientific literature lately (see for example Hill *et al.*, 2006; Van Dam *et al.*, 2006; Goldemberg *et al.*, 2006; Smeets *et al.*, 2008; Macedo *et al.*, 2008). At the same time several initiatives are being developed in Europe and in the United States related to certification, traceability and definition of criteria and indicators for sustainable production of biofuels, mainly due to different supporting policies. For example in May 2003, the European Commission launched its Biofuels Directive 2003/30/EC, establishing legal basis for blending biofuels and fossil fuels. The EU member countries are urged to replace 2% of fossil fuels with biofuels by 2005 and 5.75% by 2010. From 2003 to 2005 the group of 25 countries members enhanced biofuel's market share of 0.6% to 1.4%. However, they have not yet achieved the first target yet. The EU Directive 2003/96/EC had also established tax incentives to encourage renewable energy use.

The government of Germany (GE), Netherlands (NL) and United Kingdom (UK) are supporting different assessment studies, while another one initiative is taking place from Switzerland, the Roundtable on Sustainable Biofuels (RTB), a multiple stakeholder initiative, hosted by the Ecole Polytechnique Federale de Lausanne. The main environmental issues addressed by these different initiatives are related to greenhouse gas reduction compared with fossil fuels; competition with other land uses, especially food competition; impacts on the biodiversity and on the environment (Table 11). Considering carbon and greenhouse gases balance current agricultural and industrial practices sugarcane ethanol from Brazil does comply with the targets of greenhouse reduction higher than 79% from existing brown fields, and from new green fields, when not replacing large areas of native vegetation. On food competition, there is no direct evidence that sugarcane is replacing the basic Brazilian staple foods (Nassar *et al.*, this book). On biodiversity conservation, data from São Paulo State show that sugarcane expansion did not reduce forest cover, but on the contrary (IEA/CATI – SAAESP). On the use of water, fertilizers and agrochemicals, sugarcane ethanol does perform well above any other current biofuel in the market (in this chapter).

In the USA, the Environmental Protection Agency (EPA) under the Energy Independence and Security Act of 2007 is responsible for revising and implementing regulations on the use of biofuels blended with gasoline. The Renewable Fuel Standard program will increase the volume of renewable fuel required to be blended into gasoline from 9 billion gallons in 2008 to 36 billion gallons by 2022. At the same time, EPA is conducting several studies on the direct and indirect impacts of the expansion of biofuels production and their carbon footprint and potential reduction of greenhouse gases.

Table 11. Main issues related to sustainable production of biofuels being considered under different certification regimes.

Criterion	NL	UK	GE	RTB	EU
1. Greenhouse gas balance	✓	✓	✓	✓	✓
a1) Net emission reduction compared with a fossil fuel reference is at least 50%. Variation in policy instruments could benefit the best performances.	✓				
a2) Life cycle GHG balance reduction of 67% compared with fossil fuels			✓		
a3) Processing of energy crops GHG reduction of 67% compared with fossil fuels			✓		
a4) GHG emissions savings from the use of biofuels at least 35% compared with fossil fuels		✓			✓
a5) GHG emissions will be reduced when compared to fossil fuels				✓	
b) Soil carbon and carbon sinks		✓		✓	✓
c) Emissions of N_2O from biofuels		✓			
2. Competition with other applications/ land use	✓	✓	✓	✓	✓
a) Availability of biomass for food, local energy supply, building materials or medicines should not decline	✓	✓	✓	✓	✓
b) Use of less productive land for biofuels		✓			
c) Increasing maximum use of crops for both food and fuel		✓			
d) Avoiding negative impacts from bioenergy-driven changes in land use			✓	✓	
3. Biodiversity	✓	✓	✓	✓	✓
a) No deterioration of protected area's or high quality eco-systems.	✓	✓	✓	✓	✓
b) Insight in the active protection of the local ecosystem.	✓				
c) Alteration of local habitats		✓			
d) Effect on local species		✓		✓	
e) Pest and disease resistance		✓			
f) Intellectual property and usage rights	✓		✓		
g) Social circumstances of the local residents	✓		✓		
h) Integrity	✓				
i) Standard on income distribution and poverty-reduction			✓		
j) Avoiding human health impacts			✓		
4. Environment	✓	✓	✓	✓	
a) No negative effects on the local environment					
b) Waste management	✓	✓			
c) Use of agro-chemicals, including artificial manure	✓	✓	✓		

Table 11. Continued.

Criterion	NL	UK	GE	RTB	EU
4. Environment (continued)	✓	✓	✓	✓	
d) Preventing erosion and deterioration of the soil to occur and maintaining the fertility of the soil	✓	✓	✓	✓	
e) Active improvement of quality and quantity of surface and groundwater	✓		✓	✓	
f) Water use efficiency of crop and production chain		✓	✓		
g) Emissions to the air	✓			✓	
h) Use of genetically modified organisms			✓	✓	

Source: adapted from Van Dam *et al.* (2006).
NL = the Netherlands; UK = United Kingdom; GE = Germany; RTB = Round table on sustainable biofuels; EU = European Union.

While the above concerns are well-justified, some criticism of biofuels and their impacts are motivated by protectionism and interest in agricultural subsidies and agribusiness production chains in several developing countries, especially from EU countries. Certification schemes suggested may become non-tariff barriers, rather than environmentally and socially sound schemes.

Scientific and technological assessments comparing different kinds of biofuels are needed to reduce the play of such interests and to establish the strengths of best potential of biofuels along with their dangers and limitations.

The OECD's latest report on biofuels illustrates how fears can be perpetuated without proper scientific basis. Suggestively titled: ('Biofuels: is the cure worse than the disease?'), the report stated: 'Even without taking into account carbon emissions through land-use change, among current technologies only sugarcane-to-ethanol in Brazil, ethanol produced as a by-product of cellulose production (as in Sweden and Switzerland), and manufacture of biodiesel from animal fats and used cooking oil, can substantially reduce [greenhouse gases] compared with gasoline and mineral diesel. The other conventional biofuel technologies typically deliver [greenhouse gas] reductions of less than 40% compared with their fossil-fuel alternatives'.

This report also recognized that while still trade barriers would persist to the international market, it will be difficult for the world to take advantage of the environmental qualities of the use of some biofuels, mainly the ethanol form sugarcane and so forth as international markets are not yet fully created for biofuels.

5. Future steps towards sustainable production of ethanol and the role of innovation

A huge challenge facing policy makers, businesses, scientists and societies as a whole is how to responsibly establish sustainable production systems and biofuel supplies in sufficient volume that meet current and future demands globally.

The examples and best practices found in Brazilian sugarcane ethanol provides a good framework and baseline of sustainability compared with other current biofuels available in large scale in the World, having the smallest impact on food inflation, high levels of productivity (on average 7,000 liters of ethanol/ha and 6.1 MWhr of energy/ha), with lower inputs of fertilizers and agrochemicals, while reducing significantly the emissions of greenhouse gases. The ending of sugarcane burning in 2014 is a good example of improving existing practices. The proper planning of sugarcane expansion into new areas will for another important step towards sustainable production of ethanol

In addition new technologies and innovation are taking place in Brazil and elsewhere in the world, aiming at optimizing the use of feedstocks: using lignocellulosic materials (the second generation of biofuels); reducing waste; adding value to ethanol co-products and moving towards ethanol chemistry and biorefinaries full deployment.

Different initiatives in Brazil from the State of São Paulo Research Foundation (FAPESP), Ministry of Science and Education (MC&T – FINEP) and investments from the private sector are contributing to the deployment of new opportunities provided by the sugarcane biomass, at the same time improving the environmental performances at the agriculture and at the industry.

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Chapter 6
Demand for bioethanol for transport

Andre Faaij, Alfred Szwarc and Arnaldo Walter

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, 2nd generation biofuels (including ethanol) produced from lignocellulosic 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

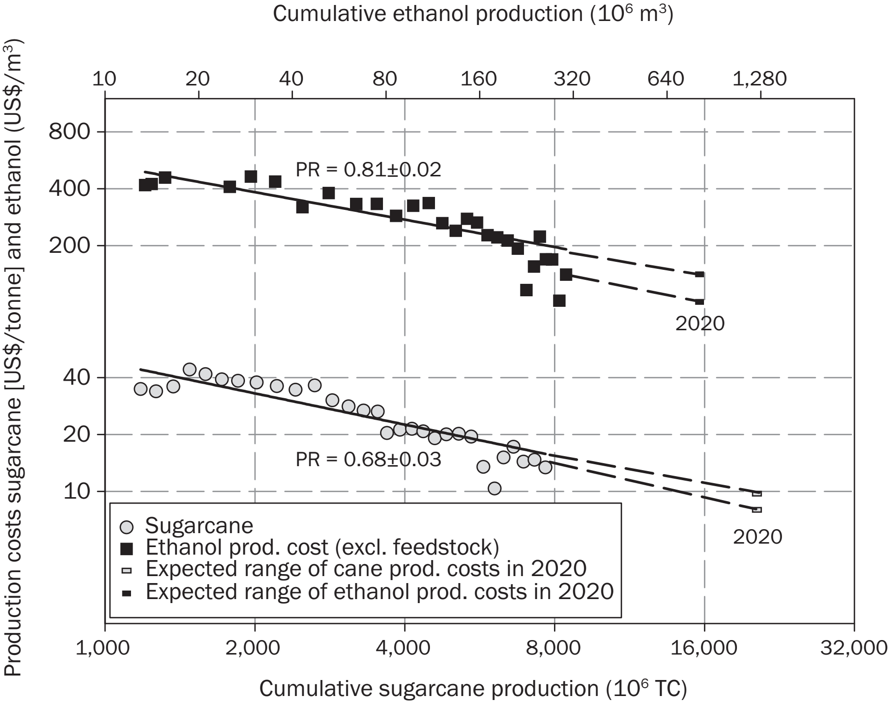

Figure 1. Learning curves and estimated future costs of sugarcane and ethanol production (excluding feedstock costs) assuming 8% annual growth of sugarcane and ethanol production (Wall-Bake *et al.*, 2008).

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 agro-forestry). 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

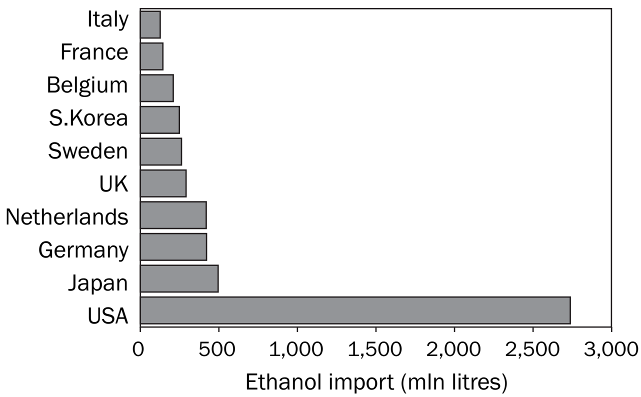

Figure 2. Top 10 ethanol importers in 2006 (Licht, 2007).

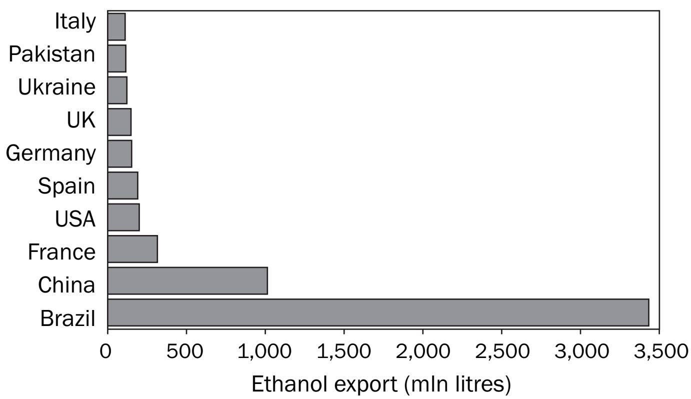

Figure 3. Top 10 ethanol exporters in 2006 (Licht, 2007).

Brazil have been roughly well distributed among 10-12 countries. On the other hand, due to the Caribbean Basin Initiative (CBI) agreement[10], 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.

[10] 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).

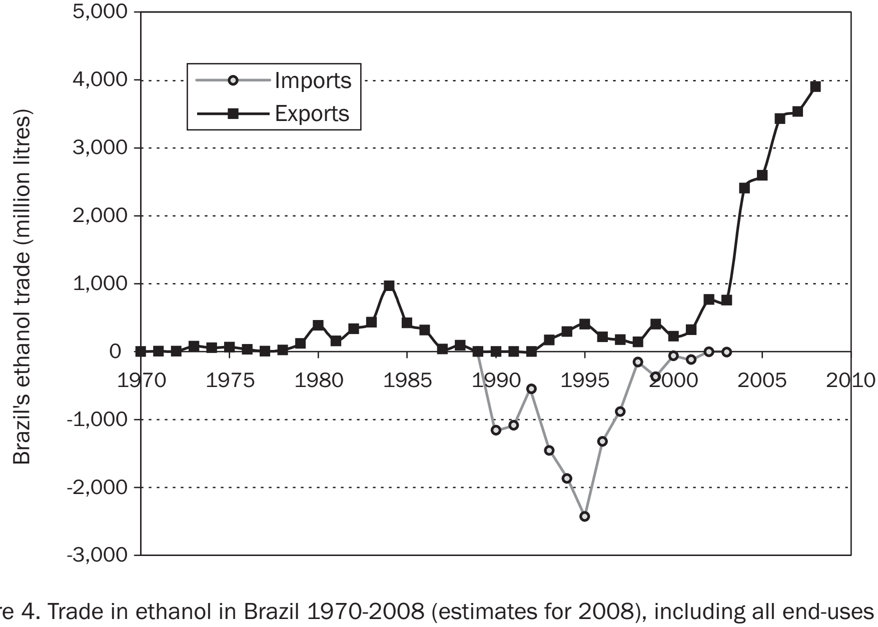

Figure 4. Trade in ethanol in Brazil 1970-2008 (estimates for 2008), including all end-uses (Brazil, 2008), (Kutas, 2008).

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 2nd 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.

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

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

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

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

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

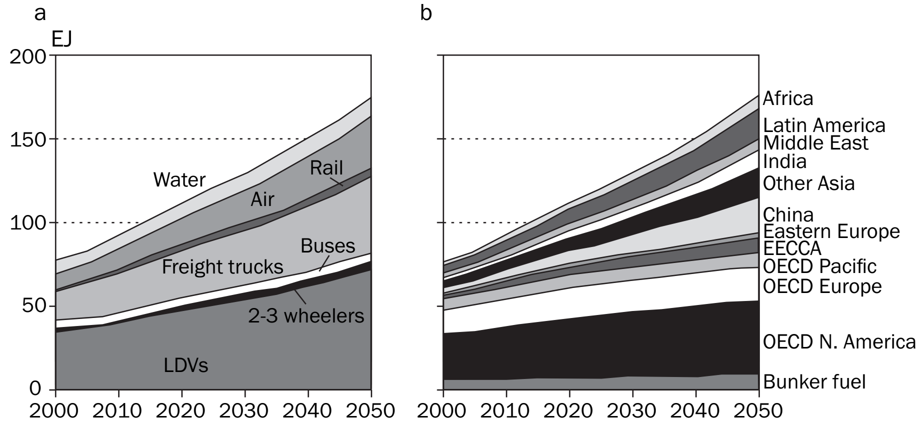

Figure 5. Projection of transport energy consumption by mode (a) and region (b) (WBCSD, 2004a).

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. Furhtermore 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^nd^ 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[11]. 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

[11] 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

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

Region/ country	Scenario 1	Gasoline displaced (%) [1]	Scenario 2	Gasoline displaced (%) [1]	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[3]	50.0	48.0[3]	62.0 [4]
ROW [5]	100.2	10.0	154.9	15.0	n.c.[6]

[1] Gasoline displaced in volume basis regarding the estimated gasoline consumption in 2030.
[2] 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.
[4] In this case production capacity is not the maximum, but the capacity that should be reached considering a certain path of growth.
[5] 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_2 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.

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Chapter 7
Biofuel conversion technologies

Andre Faaij

1. Introduction

In the current heated societal debate about the sustainability of biofuels, usually a distinction is made between so-called 'first' and 'second' generation biofuels. A large number of options to produce biomass from biofuel is used or are possible (a simplified overview of options is given in Figure 1). Although definitions differ between publications, first generation biofuels typically are produced from food crops as oilseeds (rapeseed, palm oil), starch crops (cereals, maize) or sugar crops (sugar beet and sugarcane). Conversion technologies are commercial and typically feedstock costs dominate the overall biofuel production costs. Furthermore,

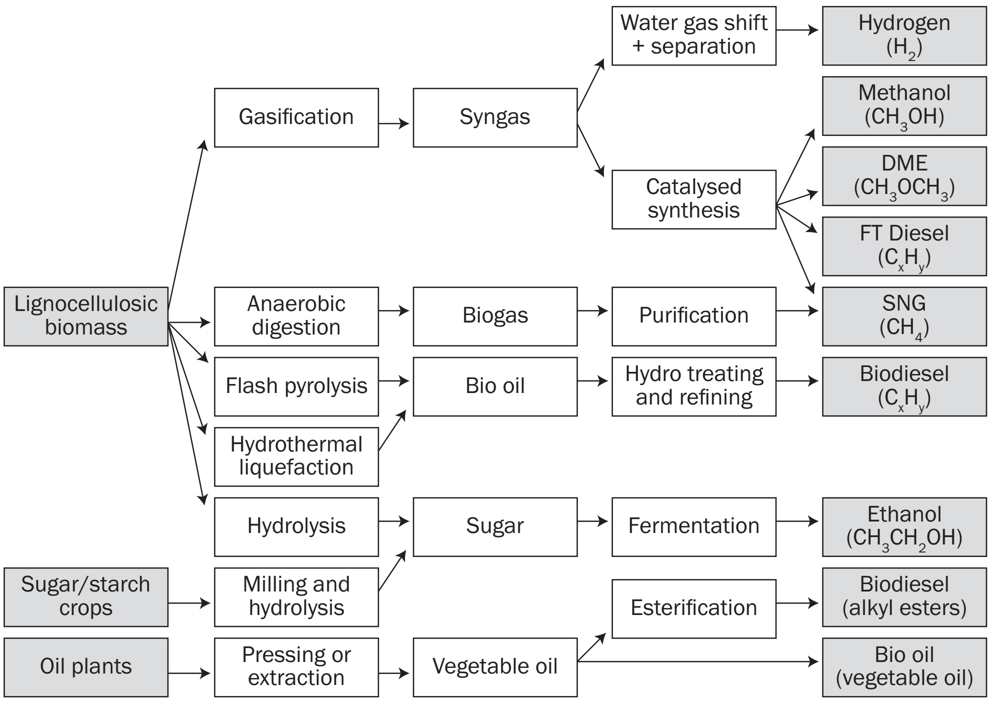

Figure 1. different existing and possible biofuel production routes (Hamelinck and Faaij, 2006). This is a simplified overview; other production chains are possible for example by combining conversion pathways, e.g. combined ethanol and biogas production, ethanol production and gasification of lignine for synfuels and integrated concepts with other industrial processes (pulp & paper plants) or bio refineries.

in particular when food crops are used grown in temperate climates (i.e. the US and the EU), costs are typically high due to high feedstock costs and the net overall avoided GHG emissions range between 20-50% compared to conventional gasoline or diesel (Fulton, 2004, Hunt *et al.*, 2007). Another constraint is that such food crops need to be produced on better quality land and increased demand directly competes with food markets. This has recently led to a wide range of estimates on the presumed impact of biofuel production on food prices (FAO, 2008), ranging between 3 up to 75%. However, sugarcane based ethanol production is a notable exception to these key concerns. Overall production costs as achieved in Brazil are competitive without subsidies, net GHG balance achieves 80-90% reduction and sugar prices have remained constant or have decreased slightly over the past years, despite strong increases in ethanol production from sugarcane.

Palm oil, in turn, although far less important as feedstock for biofuel production has been at the centre of the sustainability debate, because it's production is directly linked to loss of rainforest and peat lands in South-East Asia. Nevertheless, palm oil is an efficient and high yield crop to produce vegetal oil (Fulton, 2004). Recently, interest in Jatropha, a oil crop that can be grown in semi-arid conditions is growing, but commercial experience is very limited to date.

Second generation biofuels are not commercially produced at this stage, although in various countries demonstration projects are ongoing. 2nd generation biofuels are to be produced from lignocellulosic biomass. In lignocellulose, typically translated as biomass from woody crops or grasses and residue materials such as straw, sugars are chemically bound in chains and cannot be fermented by conventional micro-organisms used for production of ethanol from sugars and the type of sugars are different than from starch or sugar crops. In addition, woody biomass contains (variable) shares of lignine, that cannot be converted to sugars. Thus, more complex conversion technology is needed for ethanol production. Typical processes developed include advanced pre-treatment and enzymatic hydrolysis, to release individual sugars. Also fermentation of C5 instead of C6 sugars is required. The other key route being developed is gasification of lignocellulosic biomass, subsequent production of clean syngas that can be used to produce a range of synthetic biofuels, including methanol. DME and synthetic hydrocarbons (diesel). Because lignocellulosic biomass can origin from residue streams and organic wastes (that do in principle not lead to extra land-use when utilised), from trees and grasses that can also be grown on lower quality land (including degraded and marginal lands), it is thought that the overall potential of such routes is considerably larger on longer term than for 1st generation biofuels. Also, the inherently more extensive cultivation methods lead to very good net GHG balances (around 90% net avoided emissions) and ultimatly, they are thought to deliver competitive biofuels, due to lower feedstock costs, high overall chain efficiency, net energy yield per hectare, assuming large scale conversion.

This chapter gives an overview of the options to produce fuels from biomass, addressing current performance and the possible technologies and respective performance levels on longer term. It focuses on the main currently deployed routes to produce biofuels and on the key chains that are currently pursued for production of 2nd generation biofuels. Furthermore, an outlook on future biomass supplies is described in section 2, including a discussion of the impact of sustainability criteria and main determining factors and uncertainties. The chapter is finalized with a discussion of projections of the possible longer term role of biofuels on a global scale and the respective contribution of first and second generation biofuels.

2. Long term potential for biomass resources.

This section discusses a integral long term outlook on the potential global biomass resource base, including the recent sustainability debate and concerns. This assessment covered on global biomass potential estimates, focusing on the various factors affecting these potentials, such as food supplies, water use, biodiversity, energy demands and agro-economics (Dornburg *et al.*, 2008). The assessment focused on the relation between estimated biomass potentials and the availability and demand of water, the production and demand of food, the demand for energy and the influence on biodiversity and economic mechanisms.

The biomass potential, taken into account the various uncertainties as analysed in this study, consists of three main categories of biomass:

1. *Residues* from forestry and agriculture and organic waste, which in total represent between 40 - 170 EJ/yr, with a mean estimate of around 100 EJ/yr. This part of the potential biomass supplies is relatively certain, although competing applications may push the net availability for energy applications to the lower end of the range. The latter needs to be better understood, e.g. by means of improved models including economics of such applications.
2. *Surplus forestry*, i.e. apart from forestry residues an additional amount about 60-100 EJ/yr of surplus forest growth is likely to be available.
3. Biomass produced via *cropping systems*:
    a. A lower estimate for energy crop production *on possible surplus good quality agricultural and pasture lands*, including far reaching corrections for water scarcity, land degradation and new land claims for nature reserves represents an estimated 120 EJ/yr (‘*with exclusion of areas*’ in Figure 2).
    b. The potential contribution of *water scarce, marginal and degraded lands* for energy crop production, could amount up to an additional 70 EJ/yr. This would comprise a large area where water scarcity provides limitations and soil degradation is more severe and excludes current nature protection areas from biomass production (‘*no exclusion*’ in Figure 2).
    c. *Learning in agricultural technology* would add some 140 EJ/yr to the above mentioned potentials of energy cropping.

The three categories added together lead to a biomass supply potential of up to about 500 EJ.

Energy demand models calculating the amount of biomass used if energy demands are supplied cost-efficiently at different carbon tax regimes, estimate that in 2050 about 50-250 EJ/yr of biomass are used. At the same time, scenario analyses predict a global primary energy use of about 600 – 1040 EJ/yr in 2050 (the two right columns of Figure 2). Keep in mind that food demand of around 9 billion people in 2050 are basically met in those scenario's.

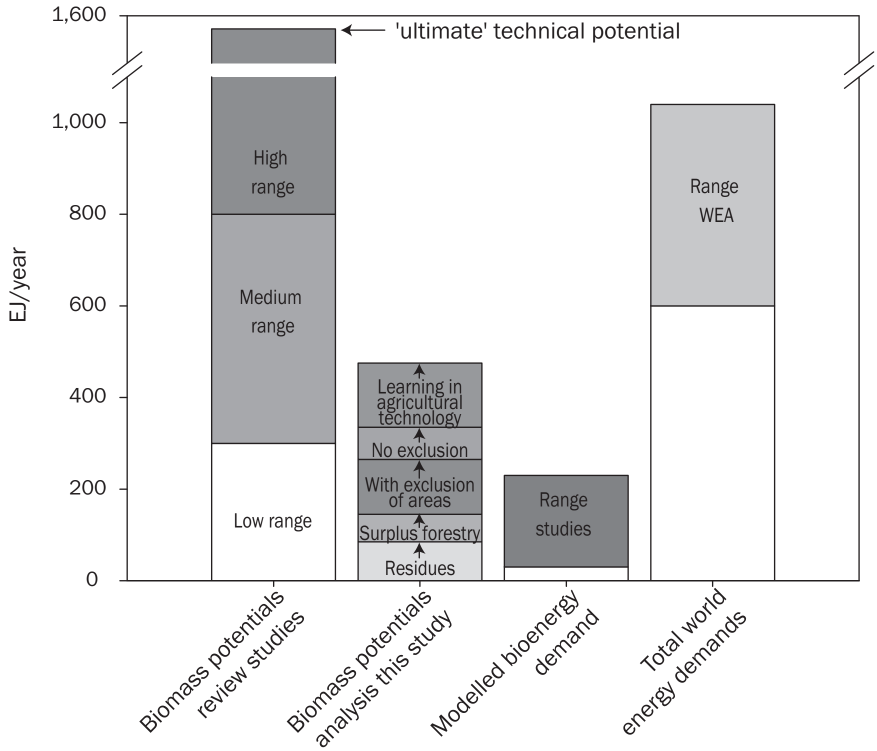

Figure 2. Comparison of biomass supply potentials in the review studies and in this study with the modelled demand for biomass and the total world energy demand, all for 2050 (Dornburg *et al.*, 2008). EJ = Exajoule (current global energy use amounts about 470 EJ at present). The first bar from the left represents the range of biomass energy potentials found in different studies, the second presents the results generated in (Dornburg *et al.*, 2008), taking a variety of sustainability criteria into account (such as water availability, biodiversity protection and soil quality), the third bar shows currently available estimates of biomass demand for energy from long term scenario studies and the fourth bar shows the range of projections of total global energy use in 2050.

In principle, biomass potentials are likely to be sufficient to allow biomass to play a significant role in the global energy supply system. Current understanding of the potential contribution of biomass to the future world energy supply is that the total technical biomass supplies could range from about 100 EJ using only residues up to an ultimate technical potential of 1500 EJ/yr potential per year. The medium range of estimates is between 300 and 800 EJ/yr (first column of Figure 2).

This study (Dornburg *et al.*, 2008) has confirmed that annual food crops may not be suited as a prime feedstock for bioenergy, both in size of potentials and in terms of meeting a wide array of sustainability criteria, even though annual crops can be a good alternative under certain circumstances. Perennial cropping systems, however, offer very different perspectives. These cannot only be grown on (surplus) agricultural and pasture lands, but also on more marginal and degraded lands, be it with lower productivity. At this stage there is still limited (commercial) experience with such systems for energy production, especially considering the more marginal and degraded lands and much more development, demonstration (supported by research) is needed to develop feasible and sustainable systems suited for very different settings around the globe. This is a prime priority for agricultural policy.

As summarized, the size of the biomass resource potentials and subsequent degree of utilisation depend on numerous factors. Part of those factors are (largely) beyond policy control. Examples are population growth and food demand. Factors that can be more strongly influenced by policy are development and commercialization of key technologies (e.g. conversion technology that makes production of fuels from lignocellulosic biomass and perennial cropping systems more competitive), e.g. by means of targeted RD&D strategies. Other areas are:

- Sustainability criteria, as currently defined by various governments and market parties.
- Regimes for trade of biomass and biofuels and adoption of sustainability criteria (typically to be addressed in the international arena, for example via the WTO).
- Infrastructure; investments in infrastructure (agriculture, transport and conversion) is still an important factor in further deployment of bioenergy.
- Modernization of agriculture; in particular in Europe, the Common Agricultural Policy and related subsidy instruments allow for targeted developments of both conventional agriculture and second generation bioenergy production. Such sustainable developments are however crucial for many developing countries and are a matter for national governments, international collaboration and various UN bodies.
- Nature conservation; policies and targets for biodiversity protection do determine to what extent nature reserves are protected and expanded and set standards for management of other lands.
- Regeneration of degraded lands (and required preconditions), is generally not attractive for market parties and requires government policies to be realized.

Current insights provide clear leads for further steps for doing so. In the criteria framework as defined currently by several governments, in roundtables and by NGO's, it is highlighted that a number of important criteria require further research and design of indicators and verification procedures. This is in particular the case for to the so-called 'macro-themes' (land-use change, biodiversity, macro-economic impacts) and some of the more complex environmental issues (such as water use and soil quality). Sustainability of biofuels and ongoing development around defining criteria and deployment of certification is discussed in Chapter 5 of this book by Neves do Amaral.

3. Technological developments in biofuel production

The previous section highlights the importance of lignocellulosic resources for achieving good environmental performance and reducing the risks of competition for land and with food production. This implies that different technologies are required to produce liquid fuels, compared to the currently dominant use of annual crops as maize and rapeseed. Sugarcane is however a notable exception given it's very high productivity, low production costs and good energy and GHG balance (Macedo *et al.*, 2004; Smeets *et al.*, 2008).

Three main routes can be distinguished to produce transportation fuels from biomass: gasification can be used to produce syngas from lignocellulosic biomass that can be converted to methanol, Fischer-Tropsch liquids, DiMethylEther (DME) and hydrogen. Production of ethanol can take place via direct fermentation of sugar and starch rich biomass, the most utilized route for production of biofuels to date, or this can be preceded by hydrolysis processes to convert lignocellulosic biomass to sugars first. Finally, biofuels can be produced via extraction from oil seeds (vegetal oil from e.g. rapeseed or palm oil), which can be esterified to produce biodiesel.

Other conversion routes and fuels are possible (such as production of butanol from sugar or starch crops) and production of biogas via fermentation. The above mentioned routes have however so far received most attention in studies and Research and Demonstration efforts.

3.1. Methanol, hydrogen and hydrocarbons via gasification

Methanol (MeOH), hydrogen (H_2) and Fischer Tropsch synthetic hydrocarbons (especially diesel), DME (DiMethylEther) and SNG (Synthetic Natural Gas) can be produced from biomass via gasification. All routes need very clean syngas before the secondary energy carrier is produced via relatively conventional gas processing methods. Here, focus lays on the first three fuels mentioned.

Several routes involving conventional, commercial, or advanced technologies under development, are possible. Figure 3 pictures a generic conversion flowsheet for this category of processes. A train of processes to convert biomass to required gas specifications precedes the methanol or FT reactor, or hydrogen separation. The gasifier produces syngas, a mixture of CO and H_2, and a few other compounds. The syngas then undergoes a series of chemical reactions. The equipment downstream of the gasifier for conversion to H_2, methanol or FT diesel is the same as that used to make these products from natural gas, except for the gas cleaning train. A gas turbine or boiler, and a steam turbine optionally employ the unconverted gas fractions for electricity co-production (Hamelinck *et al.*, 2004).

So far, commercial biofuels production via gasification does not take place, but interest is on the rise and development and demonstration efforts are ongoing in several OECD countries.

Overall energetic efficiencies of relatively 'conventional' production facilities, could be close to 60% (on a scale of about 400 MW_{th} input). Deployment on large scale (e.g over 1000 MW_{th}) is required to benefit maximally from economies of scale, which are inherent to this type of installations. Such capacities are typical for coal gasification. The use of coal gasifiers and feeding of pre-treated biomass (e.g. via torrefaction or pyrolysis oils) could prove one of the shorter term options to produce 2nd generation biofuels efficiently. This conversion route has a strong position from both efficiency and economic perspective (Hamelinck *et al.*, 2004; Hamelinck and Faaij, 2002; Tijmensen et al, 2002; Williams *et al.*, 1995). Generic performance ranges resulting from various pre-engineering studies are reported in Figure 3.

The findings of the previously published papers can be summarised as follows: gasification-based fuel production systems that apply pressurised gasifiers have higher joint fuel and electricity energy conversion efficiencies than atmospheric gasifier-based systems. The total efficiency is also higher for once-through configurations, than for recycling configurations that aim at maximising fuel output. This effect is strongest for FT production, where (costly) syngas recycling not only introduces temperature and pressure leaps, but also 'material leaps' by reforming part of the product back to syngas. For methanol and hydrogen, however,

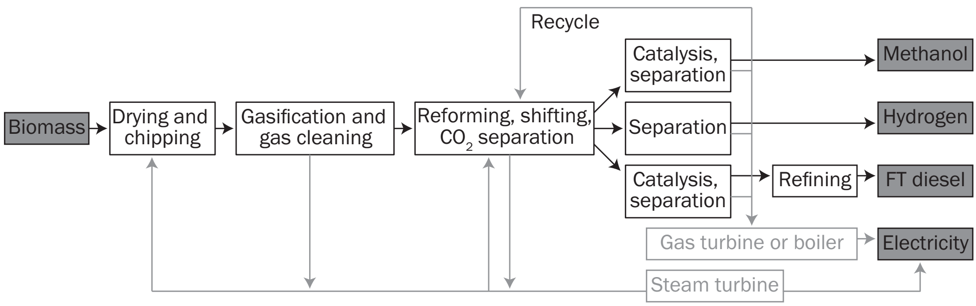

Figure 3. Generic process scheme for production of synthetic biofuels via gasification (Hamelinck and Faaij, 2006).

maximised fuel production, with little or no electricity co-production, generally performs economically somewhat better than once-through concepts.

Hot (dry) gas cleaning generally improves the total efficiency, but the economical effects are ambivalent, since the investments also increase. Similarly, CO_2 removal does increase the total efficiency (and in the FT reaction also the selectivity), but due to the accompanying increase in investment costs this does not decrease the product costs. The bulk of the capital investment is in the gasification and oxygen production system, syngas processing and power generation units. These parts of the investment especially profit from cost reductions at larger scales. Also, combinations with enriched air gasification (eliminating the expensive oxygen production assumed for some methanol and hydrogen concepts) may reduce costs further.

Several technologies considered here are not yet fully proven or commercially available. Pressurised (oxygen) gasifiers still need further development. At present, only a few pressurised gasifiers, operating at relatively small scale, have proved to be reliable. Consequently, the reliability of cost data for large-scale gasifiers is uncertain. A very critical step in all thermal systems is gas cleaning. It still has to be proven whether the (hot) gas cleaning section is able to meet the strict cleaning requirements for reforming, shift and synthesis. Liquid phase reactors (methanol and FT) are likely to have better economies of scale. The development of ceramic membrane technology is crucial to reach the projected hydrogen cost level. For FT diesel production, high CO conversion, either once through or after recycle of unconverted gas, and high C5+ selectivity are important for high overall energy efficiencies. Several units may be realised with higher efficiencies than considered in this paper: new catalysts and carrier liquids could improve liquid phase methanol single pass efficiency. At larger scales, conversion and power systems (especially the combined cycle) have higher efficiencies, further stressing the importance of achieving economies of scale for such concepts.

3.2. Production of ethanol from sugarcane

Ethanol production from sugarcane has established a strong position in Brazil and increasingly in other countries in tropical regions (such as India, China 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 (Wall-Bake *et al.*, 2008). As a result, bioethanol is no longer financially supported in Brazil and competes openly with gasoline.

Large scale production facilities, better use of bagasse and trash residues from sugarcane production e.g. with advanced (gasification based) power generation orhydrolysis techniques (see below) and further improvements in cropping systems, offer further perspectives for sugarcane based ethanol production.

Improvement options for sugarcane based ethanol production are plentiful (Damen, 2001; Groen, 1999). It is expected that the historic cost decreases and productivity increments will continue. An analysis of historic and potential future improvements in economic performance of ethanol production in Brazil (Wall Bake *et al.*, 2008) concludes that if improvements in sugarcane yield, logistics (e.g. green can harvesting techniques and utilisation of sugarcane trash), overall efficiency improvement in the sugar mills and ethanol production (e.g. by full electrification and advanced distillation technology) as well as the use of hydrolysis technology for conversion of bagasse and trash to ethanol, ethanol yields per hectare of land may even be tripled compared to current average production.

The key limitations for sugarcane production are climatic and the required availability of good quality soils with sufficient and the right rainfall patterns.

3.3. Ethanol from (ligno)-cellulosic biomass

Hydrolysis of cellulosic (e.g. straw) and lignocellulosic (woody) biomass can open the way towards low cost and efficient production of ethanol from these abundant types of biomass. The conversion is more difficult than for sugar and starch because from lignocellulosic materials, first sugars need to be produced via hydrolysis. Lignocellulosic biomass requires pretreatment by mechanical and physical actions (e.g. steam) to clean and size the biomass, and destroy its cell structure to make it more accessible to further chemical or biological treatment. Also, the lignin part of the biomass is removed, and the hemicellulose is hydrolysed (saccharified) to monomeric and oligomeric sugars. The cellulose can then be hydrolysed to glucose. Also C5 sugars are formed, which require different yeasts to be converted to ethanol. The sugars are fermented to ethanol, which is to be purified and dehydrated. Two pathways are possible towards future processes: a continuing consolidation of hydrolysis-fermentation reactions in fewer reactor vessels and with fewer micro organisms, or an optimisation of separate reactions. As only the cellulose and hemicellulose can be used in the process, the lignin is used for power production (Figure 4).

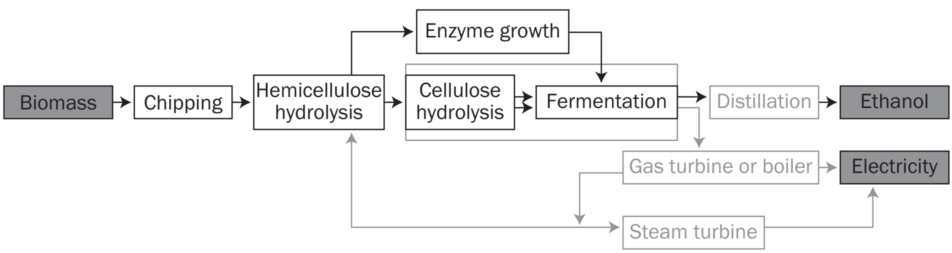

Figure 4. Generic process scheme for the production of ethanol from lignocellulosic biomass.

To date, acid treatment is an available process, which is so far relatively expensive and inefficient. Enzymatic treatment is commercially unproven but various test facilities have been built in North America and Sweden. The development of various hydrolysis techniques has gained major attention over the past 10 years or so, particularly in Sweden and the United States. Because breakthroughs seem to be necessary on a rather fundamental level, it is relatively uncertain how fast attractive performance levels can be achieved (Hamelinck *et al.*, 2005).

Assuming, however, that mentioned issues are resolved and ethanol production is combined with efficient electricity production from unconverted wood fractions (lignine in particular), ethanol costs could come close to current gasoline prices (Lynd *et al.*, 2005): as low as 12 Euroct/litre assuming biomass costs of about 2 Euro/GJ. Overall system efficiencies (fuel + power output) could go up to about 70% (LHV).

It should be noted though that the assumed conversion extent of (hemi)cellulose to ethanol by hydrolysis fermentation is close to the stoichiometric maximum. There is only little residual material (mainly lignin), while the steam demand for the chosen concepts is high. This makes the application of BIG/CC unattractive at 400MWHHV. Developments of pre-treatment methods and the gradual ongoing reactor integration are independent trends and it is plausible that at least some of the improved performance will be realised in the medium-term. The projected long-term performance depends on development of technologies that have not yet passed laboratory stage, and that may be commercially available earlier or later than 20 years from now. This would mean either a more attractive ethanol product cost in the medium-term, or a less attractive cost in the long-term. The investment costs for advanced hemicellulose hydrolysis methods is still uncertain. Continuing development of new micro-organisms is required to ensure fermentation of xylose and arabinose, and decrease the cellulase enzyme costs.

The hydrolysis technology can also boost the competitiveness of existing production facilities (e.g. by converting available crop and process residues), which provides an important market niche on short term.

Table 1. gives an overview of estimates for costs of various fuels that can be produced from biomass (Faaij, 2006). A distinction is made between performance levels on the short and on the longer term. Generally spoken, the economy of 'traditional' fuels like Rapeseed MethylEsther and ethanol from starch and sugar crops in moderate climate zones is poor at present and unlikely to reach competitive price levels in the longer term. Also, the environmental impacts of growing annual crops are not as good as perennials because per unit of product considerable higher inputs of fertilizers and agrochemicals are needed. In addition, annual crops on average need better quality land than perennials to achieve good productivities.

Production of methanol (and DME), hydrogen, Fischer-Tropsch liquids and ethanol produced from lignocellulosic biomass that offer good perspectives and competitive fuel prices in the longer term (e.g. around 2020). Partly, this is because of the inherent lower feedstock prices and versatility of producing lignocellulosic biomass under varying circumstances. Section 2 highlighted that a combination of biomass residues and perennial cropping systems on both marginal and better quality lands could supply a few hundred EJ by mid-century in a competitive cost range between 1-2 Euro/GJ (see also Hoogwijk *et al.*, 2005, 2008). Furthermore, as discussed in this paper, the (advanced) gasification and hydrolysis technologies under development have the inherent improvement potential for efficient and competitive production of fuels (sometimes combined with co-production of electricity).

Inherent to the advanced conversion concepts, it is relatively easy to capture (and subsequently store) a significant part of the CO_2 produced during conversion at relatively low additional costs. This is possible for ethanol production (where partially pure CO_2 is produced) and for gasification concepts. Production of syngas (both for power generation and for fuels) in general allows for CO_2 removal prior to further conversion. For FT production about half of the carbon in the original feedstock (coal, biomass) can be captured prior to the conversion of syngas to FT-fuels. This possibility allows for carbon neutral fuel production when mixtures of fossil fuels and biomass are used and negative emissions when biomass is the dominant or sole feedstock. Flexible new conversion capacity will allow for multiple feedstock and multiple output facilities, which can simultaneously achieve low, zero or even negative carbon emissions. Such flexibility may prove to be essential in a complex transition phase of shifting from large scale fossil fuel use to a major share of renewables and in particular biomass.

At the moment major efforts are ongoing to demonstrate various technology concepts discussed above. Especially in the US (but also in Europe), a number of large demonstration efforts is ongoing on production of ethanol from lignocellulosic biomass. IOGEN, a Canadian company working on enzymatic hydrolysis reported the production of 100,000 litres of ethanol from agricultural residues in September 2008. Also companies in India, China and Japan are investing substantially in this technology area.

Gasification for production of synfuels gets support in the US and more heavily in the EU. The development trajectory of the German company CHOREN (focusing on dedicated biomass gasification systems for production of FT liquids) is ongoing and stands in the international spotlights. Finland and Sweden have substantial development efforts ongoing, partly aiming for integration gasification technology for synfuels in the paper & pulp industry. Furthermore, co-gasification of biomass in (existing) coal gasifiers is an important possibility. This has for example been demonstrated in the Buggenum coal gasifiier in the Netherlands and currently production of synfuels is targeted.

Table 1. Performance levels for different biofuels production routes (Faaij, 2006).

Concept	Energy efficiency (HHV) + energy inputs	
	Short term	Long term
Hydrogen: via biomass gasification and subsequent syngas processing. Combined fuel and power production possible; for production of liquid hydrogen additional electricity use should be taken into account.	60% (fuel only) (+ 0.19 GJe/GJ H2 for liquid hydrogen)	55% (fuel) 6% (power) (+ 0.19 GJe/GJ H2 for liquid hydrogen)
Methanol: via biomass gasification and subsequent syngas processing. Combined fuel and power production possible	55% (fuel only)	48% (fuel) 12% (power)
Fischer-Tropsch liquids: via biomass gasification and subsequent syngas processing. Combined fuel and power production possible	45% (fuel only)	45% (fuel) 10% (power
Ethanol from wood: production takes place via hydrolysis techniques and subsequent fermentation and includes integrated electricity production of unprocessed components.	46% (fuel) 4% (power)	53% (fuel) 8% (power)
Ethanol from beet sugar: production via fermentation; some additional energy inputs are needed for distillation.	43% (fuel only) 0.065 GJe + 0.24 GJth/GJ EtOH	43% (fuel only) 0.035 GJe + 0.18 GJth/GJ EtOH
Ethanol from sugarcane: production via cane crushing and fermentation and power generation from the bagasse. Mill size, advanced power generation and optimised energy efficiency and distillation can reduce costs further on longer term.	85 litre EtOH per tonne of wet cane, generally energy neutral with respect to power and heat	95 litre EtOH per tonne of wet cane. Electricity surpluses depend on plant lay-out and power generation technology.
Biodiesel RME: takes places via extraction (pressing) and subsequent esterification. Methanol is an energy input. For the total system it is assumed that surpluses of straw are used for power production.	88%; 0.01 GJe + 0.04 GJ MeOH per GJ output Efficiency power generation on shorter term: 45%, on longer term: 55%	

Assumed biomass price of clean wood: 2 Euro/GJ. RME cost figures varied from 20 Euro/GJ (short term) to 12 Euro/GJ (longer term), for sugar beet a range of 12 to 8 Euro/GJ is assumed. All figures exclude distribution of the fuels to fueling stations.

For equipment costs, an interest rate of 10%, economic lifetime of 15 years is assumed. Capacities of conversion unit are normalized on 400 MWth input on shorter term and 1000 MWth input on longer term.

Investment costs (Euro/kWth input capacity)		O&M (% of inv.)	Estimated production costs (Euro/GJ fuel)	
Short term	**Long term**		**Shorter term**	**Longer term**
480 (+ 48 for liquefying)	360 (+ 33 for liquefying)	4	9-12	4-8
690	530	4	10-15	6-8
720	540	4	12-17	7-9
350	180	6	12-17	5-7
290	170	5	25-35	20-30
100 (wide range applied depending on scale and technology applied)	230 (higher costs due to more advanced equipment)	2	8-12	7-8
150 (+ 450 for power generation from straw)	110 (+ 250 for power generation from straw)	5 4	25-40	20-30

Industrial interest in those areas comes from the energy sector, biotechnology as well as chemical industry. Given the policy targets on (second generation) biofuels in North America and the EU, high oil prices and increased pressure to secure sustainable production of biofuels (e.g. avoiding conflicts with food production and achieve high reduction in GHG emissions), pressure on both the market and policy to commercialize those technologies is high. When turn-key processes are available is still uncertain, but such breakthroughs may be possible already around 2010.

4. Energy and greenhouse gas balances of biofuels

4.1. Energy yields

The energy yield per unit of land surfaces resources depends to a large extent on the crop choice and the efficiency of the entire energy conversion route from 'crop to drop'. This is illustrated by the figures in Table 2. It is important to stress that when lignocellulose is the feedstock of choice production is not constrained to arable land, but amounts to the sum of residues and production from degraded/marginal lands not used for current food production. Ultimately, this will be the preferred option in most cases.

Table 2. Indicative ranges for biomass yield and subsequent fuel production per hectare per year for different cropping systems in different settings. Starch and sugar crops assume conversion via fermentation to ethanol and oil crops to biodiesel via esterification (commercial technology at present). The woody and grass crops require either hydrolysis technology followed by ethanol or gasification to syngas to produce synthetic fuel (both not yet commercial conversion routes).

Crop	**Biomass yield (odt/ha/yr)**	**Energy yield in fuel (GJ/ha/yr)**
Wheat	4-5	~50
Maize	5-6	~60
Sugar beet	9-10	~110
Soy bean	1-2	~20
Sugarcane	5-20	~180
Palm oil	10-15	~160
Jathropha	5-6	~60
SRC temperate climate	10-15	100-180
SRC tropical climate	15-30	170-350
Energy grasses good conditions	10-20	170-230
Perennials marginal/degraded lands	3-10	30-120

4.2. Greenhouse gas balances

The net emissions over the full life cycle of biofuels – from changes in land use to combustion of fuels – that determine their impact on the climate. Research on net emissions is far from conclusive, and estimates vary widely. Calculations of net GHG emissions are highly sensitive to assumptions about system boundaries and key parameter values – for example, land use changes and their impacts, which inputs are included, such as energy embedded in agricultural machinery and how various factors are weighted.

The primary reasons for differing results are different assumptions made about cultivation, and conversion or valuation of co-products. (Larson, 2005), who reviewed multiple studies, found that the greatest variations in results arose from the allocation method chosen for co-products, and assumptions about N_2O emissions and soil carbon dynamics. In addition, GHG savings will vary from place to place – according to existing incentives for GHG reductions, for example. And the advantages of a few biofuels (e.g. sugarcane ethanol in Brazil) are location specific. As a result, it is difficult to compare across studies; however, despite these challenges, some of the more important studies point to several useful conclusions.

This analysis notwithstanding, the vast majority of studies have found that, even when all fossil fuel inputs throughout the life cycle are accounted for, producing and using biofuels made from current feedstock result in substantial reductions in GHG emissions relative to petroleum fuels.

In general, of all potential feedstock options, producing ethanol from maize results in the smallest decrease in overall emissions. The greatest benefit, meanwhile, comes from ethanol produced from sugarcane grown in Brazil (or from using cellulose or wood waste as feedstock). Several studies have assessed the net emissions reductions resulting from sugarcane ethanol in Brazil, and all have concluded that the benefits far exceed those from grain-based ethanol produced in Europe and the United States.

Fulton (2004) attributes the lower life-cycle climate impacts of Brazilian sugarcane ethanol to two major factors: First, cane yields are high and require relatively low inputs of fertilizer, since Brazil has better solar resources and high soil productivity. Second, almost all conversion plants use bagasse (the residue that remains after pressing the sugar juice from the cane stalk) for energy, and many recent plants use co-generation (heat and electricity), enabling them to feed electricity into the grid. As such, net fossil energy requirements are near zero, and in some cases could be below zero. (In addition, less energy is required for processing because there is no need for the extra step to break down starch into simple sugars. Because most process energy in Brazil is already renewable, this does not really play a role.)

According to Larson (2005), conventional grain- and oilseed-based biofuels can offer only modest reductions in GHG emissions. The primary reason for this is that they represent only a small portion of the above ground biomass. He estimates that, very broadly, biofuels from grains or seeds have the potential for a 20–30 percent reduction in GHG emissions per vehicle-kilometer, sugar beets can achieve reductions of 40–50 percent, and sugarcane (average in southeast Brazil) can achieve a reduction of 90 percent.

Other new technologies under development also offer the potential to dramatically increase yields per unit of land and fossil input, and further reducelife-cycle emissions. The cellulosic conversion processes for ethanol offers the greatest potential for reductions because feedstock can come from the waste of other products or from energy crops, and the remaining parts of the plant can be used for process energy.

Larson (2005) projects that future advanced cellulosic processes (to ethanol, F-T diesel, or DME) from perennial crops could bring reductions of 80–90 percent and higher. According to Fulton *et al.* (2004), net GHG emissions reductions can even exceed 100 percent if the feedstock takes up more CO_2 while it is growing than the CO_2-equivalent emissions released during its full life cycle (for example, if some of it is used as process energy to offset coal-fired power).

Typical estimates for reductions from cellulosic ethanol (most of which comes from engineering studies, as few large-scale production facilities exist to date) range from 70–90 percent relative to conventional gasoline, according to Fulton (2004), though the full range of estimates is far broader.

Figure 5 shows the range of estimated possible reductions in emissions from wastes and other next-generation feedstock relative to those from current-generation feedstock and technologies.

4.3. Chain efficiency of biofuels

When the use of such 'advanced' biofuels (especially hydrogen and methanol) in advanced hybrid or Fuel Cell Vehicles (FCV's) is considered, the overall chain ('tree - to – tyre') efficiency can drastically improve compared to current bio-diesel or maize or cereal derived ethanol powered Internal Combustion Engine Vehicles; the effective number of kilometres that can be driven per hectare of energy crops could go up with a factor of 5 (from a typical current 20,000 km/ha for a middle class vehicle run with RME up to over 100,000 km/ha for advanced ethanol in an advanced hybrid or FCV (Hamelinck and Faaij, 2002)). Note though, that the current exception to this performance is sugarcane based ethanol production; in Brazil the better plantations yield some 8,000 litre ethanol/ha*yr, or some 70,000 km/yr for a middle class vehicle at present. In the future, those figures can improve

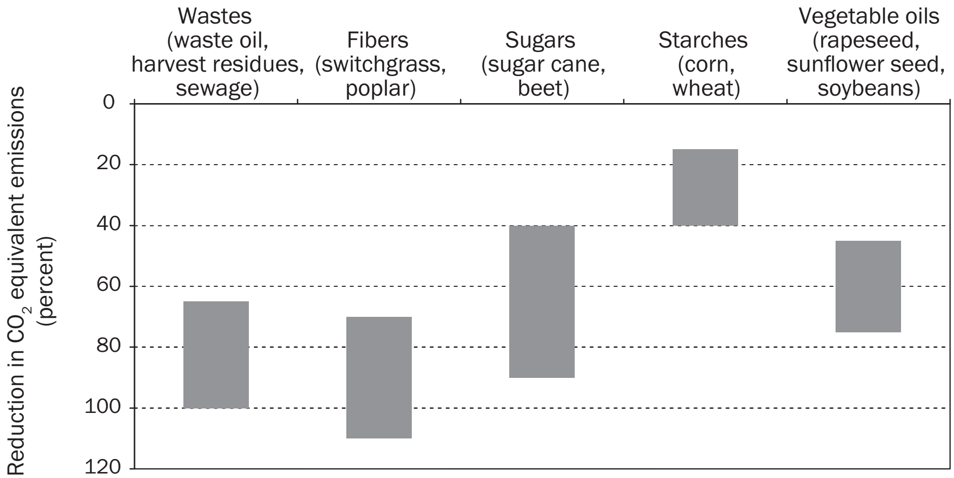

Figure 5. Reductions in greenhouse gas emissions per vehicle-kilometre, by feedstock and associated refining technology (taken from Fulton, 2004).

further due to better cane varieties, crop management and efficiency improvement in the ethanol production facilities (Damen, 2001).

Furthermore, FCV's (and to a somewhat lesser extent advanced hybrids) offer the additional and important benefits of zero or near zero emission of compounds like NO_x, CO, sulphur dioxide, hydrocarbons and small dust particulates, which are to a large extent responsible for poor air quality in many urban zones in the world. Table 3 provides a quantification of the range of kilometres that can be driven with different biofuel-vehicle combinations expressed per hectare. The ranges are caused by different yield levels for different land-types and variability and uncertainties in conversion and vehicle efficiencies. However, overall, there are profound differences between first and second generation biofuels I favour of the latter.

4.4. Future expectations on biofuels

The future biofuels and specifically the bioethanol market is uncertain. There are fundamental drivers (climate, oil prices and availability, rural development) that push for further development of biofuels. On the one hand, recent developments and public debate point towards conflicts with land use, food markets, poor GHG performance (especially when indirect land-use changes are assumed caused by biofuel production) and, even with high oil prices, high levels of subsidy for biofuels in e.g. Europe and the United States. Recently, policy targets (as discussed in chapter 5 of this book) set for biofuels are rediscussed in the EU, as well as in China. In most key markets (EU, US, China), the role of biofuels is increasingly connected to rapid deployment of 2nd generation technologies. The bulk of the growth beyond 2015 or so should be realized via such routes.

Table 3. Distance that can be driven per hectare of feedstock for several combinations of fuels and engines, derived from the net energy yield and vehicle efficiency as reported in (Hamelinck and Faaij, 2006). ICEV = Internal Combustion Engine Vehicle, FCV = Fuel Cell Vehicle.

Feedstock	Fuel	Engine	Distance (thousands km/ha)	
			Short term	Long term
Lignocellulose	Hydrogen	ICEV	26-37	80-97
		FCV	44-140	189-321
	Methanol	ICEV	34-49	75-287
		FCV	68-83	113-252
	FT	ICEV	22-38	56-167
		FCV	50-67	97-211
	Ethanol	ICEV	29-30	82-238
		FCV	38-72	129-240
Sugar beet	Ethanol	ICEV	15-37	57-88
		FCV	19-93	58-138
Rapeseed	RME	ICEV	5-28	15-79
		FCV	6-84	19-137

Some projections as published by the International Energy Agency (World Energy Outlook) and the OECD (Agricultural Outlook) focus on first generation biofuels only (even for projections to 2030 in the IEA-WEO). Biofuels meet 2.7% of world road-transport fuel demand by the end of the projection period in the Reference Scenario, up from 1% today. In the Alternative Scenario, the share reaches 4.6%, thanks to higher demand for biofuels but lower demand for road-transport fuels in total. The share remains highest in Brazil, though the pace of market penetration will be fastest in the European Union in both scenarios. The contribution of liquid biofuels to transport energy, and even more so to global energy supply, will remain limited. By 2030, liquid biofuels are projected to still supply only 3.0-3.5 percent of global transport energy demand. This is however also due to the key assumption that 2nd generation biofuel technology is not expected to become available to the market (IEA, 2006).

In the Agricultural Outlook, similar reasoning is followed be it for a shorter time frame (up to the year 2016), focusing on 1st generation biofuels. The outlook focuses in this respect on the implications of biofuel production on demand for food crops. In general, a slowdown in growth is expected (OECD, 2007).

Projections that take explicitly 2nd generation options into account are more rare, but studies that do so, come to rather different outlooks, especially in the timeframe exceeding 2020.

The IPCC, providing an assessment of studies that deal with both supply and demand of biomass and bioenergy. It is highlighted 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; Kahn Ribeiro et al., 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. [and storage. At the same time, carbon intensity of conventional fossil transport fuels increases due to the increased use lower quality oils, tar sands and coal gasification.

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. 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. This is confirmed by other by the information compiled in this chapter: it was concluded that the, sustainable, biomass resource base, without conflicting with food supplies, nature preservation and water use, could indeed be developed to a level of over 300 EJ in the first half of this century.

5. Final remarks

Biomass cannot realistically cover the whole world's future energy demand. On the other hand, the versatility of biomass with the diverse portfolio of conversion options, makes it possible to meet the demand for secondary energy carriers, as well as bio-materials. Currently, production of heat and electricity still dominate biomass use for energy. The question is therefore what the most relevant future market for biomass may be.

For avoiding CO_2 emissions, replacing coal is at present a very effective way of using biomass. For example, co-firing biomass in coal-fired power stations has a higher avoided emission per unit of biomass than when displacing diesel or gasoline with ethanol or biodiesel. However, replacing natural gas for power generation by biomass, results in levels of CO_2 mitigation similar to second generation biofuels. Net avoided GHG emissions therefore depend on the reference system and the efficiency of the biomass production and utilisation chain. In the future, using biomass for transport fuels will gradually become more attractive from a CO_2 mitigation perspective because of the lower GHG emissions for producing second generation biofuels and because electricity production on average is expected to become less carbon-intensive due to increased use of wind energy, PV and other solar-based power generation, carbon capture and storage technology, nuclear energy and fuel shift from coal to natural gas. In the shorter term however, careful strategies and policies are needed to avoid brisk allocation of biomass resources away from efficient and effective utilisation in power and heat production or in other markets, e.g. food. How this is to be done optimally will differ from country to country.

First generation biofuels in temperate regions (EU, North America) do not offer a sustainable possibility in the long term: they remain expensive compared to gasoline and diesel (even at high oil prices), are often inefficient in terms of net energy and GHG gains and have a less desirable environmental impact. Furthermore, they can only be produced on higher quality farmland in direct competition with food production. Sugarcane based ethanol production and to a certain extent palm oil and Jatropha oilseeds are notable exceptions to this given their high production efficiencies and low(er) costs.

Especially promising are the production via advanced conversion concepts biomass-derived fuels such as methanol, hydrogen, and ethanol from lignocellulosic biomass. Ethanol produced from sugarcane is already a competitive biofuel in tropical regions and further improvements are possible. Both hydrolysis-based ethanol production and production of synfuels via advanced gasification from biomass of around 2 Euro/GJ can deliver high quality fuels at a competitive price with oil down to US$55/ barrel. Net energy yields for unit of land surface are high and up to a 90% reduction in GHG emissions can be achieved. This requires a development and commercialization pathway of 10-20 years, depending very much on targeted and stable policy support and frameworks.

However, commercial deployment of these technologies does not have to be postponed for such time periods. The two key technological concepts that have shorter term opportunities (that could be seen as niches) for commercialization are:

1. Ethanol: 2nd generation can build on the 1st generation infrastructure by being built as 'add-ons' to existing factories for utilisation of crop residues. One of the best examples is the use of bagasse and trash at sugar mills that could strongly increase the ethanol output from sugarcane
2. Synfuels via gasification of biomass: can be combined with coal gasification as currently deployed for producing synfuels (such as DME, Fischer-Tropsch and Methanol) to obtain economies of scale and fuel flexibility. Carbon capture and storage can easily be deployed with minimal additional costs and energy penalties as an add-on technology.

The biomass resource base can become large enough to supply 1/3 of the total world's energy needs during this century. Although the actual role of bioenergy will depend on its competitiveness with fossil fuels and on agricultural policies worldwide, it seems realistic to expect that the current contribution of bioenergy of 40-55 EJ per year will increase considerably. A range from 200 to 400 EJ may be observed looking well into this century, making biomass a more important energy supply option than mineral oil today. Considering lignocellulosic biomass, about half of the supplies could originate from residues and biomass production from marginal/degrade lands. The other half could be produced on good quality agricultural and pasture lands without jeopardizing the worlds food supply, forests and biodiversity. The key pre-condition to achieve this goal is increased agricultural land-use efficiency, including livestock production, especially in developing regions. Improvement potentials of agriculture and livestock are substantial, but exploiting such potentials is a challenge.

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Chapter 8
The global impacts of US and EU biofuels policies

Wallace E. Tyner

1. Introduction

The major biofuels producers in the world are the US, EU, and Brazil. Figure 1 shows the global breakdown of biofuels production for 2006. The US and Brazil combine to produce three-fourths of global ethanol, and the EU produces three-fourths of global biodiesel. The US overtook Brazil in ethanol production, and global production now exceeds 50 billion liters. Biodiesel total production is much smaller.

In the US, Brazil, and the EU, the biofuels industries were launched with some combination of subsidies and mandates plus border protection. As production levels have grown and as oil prices have risen, all three are now switching in different degrees from reliance on subsidies to reliance on mandates. One reason is the government budget cost of subsidies, which increase as production increases. Mandates also have a cost, but it is paid by consumers at the pump assuming the biofuel is more expensive to produce than the petroleum based fuel it replaces. The consumer cost of a mandate is directly related to oil price. At low oil prices, a mandate can be expensive for consumers because high cost renewable fuel is mandated in lieu of a certain fraction of relatively lower cost petroleum. At high oil prices, the renewable fuel may even be less expensive than petroleum based fuels, so the cost can be much lower or zero.

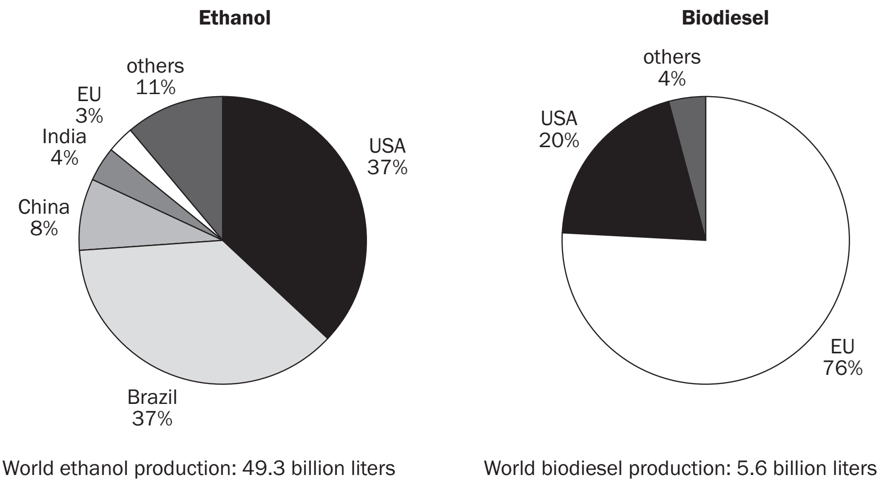
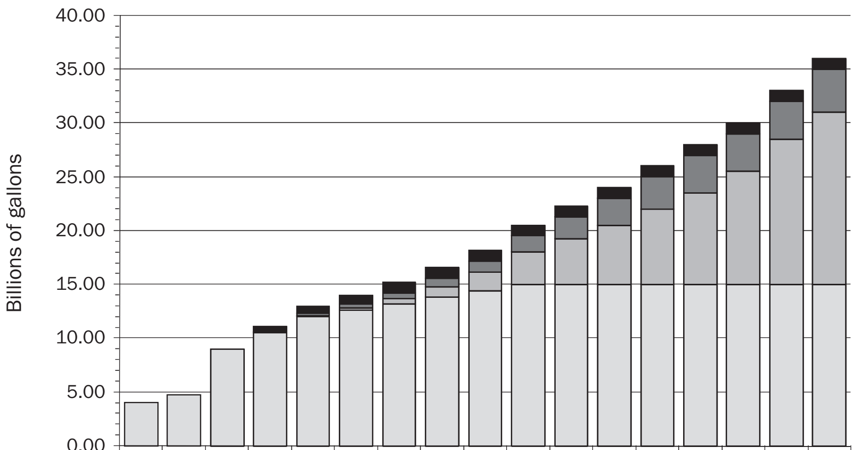


Figure 1. Global biofuels production, 2006. Data sources: Earth Policy Institute (2006), Renewable Fuels Association (2007), European Biodiesel Board (2007).

In Brazil, subsidies have been completely replaced with mandates. In the EU, subsidies are determined by each country. In essence, the EU sets a target level of renewable fuels, and each country decides how best to achieve that target. The original target was 5.75 percent renewable fuels by 2010. Most countries were well behind the pace needed to achieve that target. More recently a target of 10 percent by 2020 has been proposed. Given the recent food price and greenhouse gas controversies (more later), it appears the EU is backing away from that target. Germany has had relatively high levels of subsidies for biodiesel, but these have now ended. At present, the future directions for biofuels policies in the EU are uncertain.

In the US, ethanol has been subsidized for 30 years (Tyner, 2008). The subsidy has ranged from 10.6 to 15.9 cents per liter, and is currently 13.5 cents per liter. The subsidy on maize ethanol will be reduced to 11.9 cents per liter on 1 January 2009, but a new subsidy of 26.7 cents per liter of cellulosic ethanol will be introduced (US Congress, 2008). In addition to the subsidy, in December 2007, the US introduced biofuel mandates in the Energy Independence and Security Act (US Congress, 2007). Figure 2 portrays the timing of the US mandate, called a Renewable Fuel Standard (RFS). The Renewable Fuel Standard (RFS) as amended in the 2007 Energy Independence and Security Act calls for 36 billion gallons of renewable fuels by 2022. The RFS is divided into four categories of biofuels: conventional, advanced, cellulosic, and biodiesel. The advanced category reaches 21 billion gallons by 2022 and includes cellulosic ethanol, ethanol from sugar, ethanol from waste material, biodiesel, and other non-maize sources. In other words, the advanced category encompasses both the cellulosic and biodiesel categories. Cellulosic ethanol as a sub-set of advanced reaches 16



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Biomass-based diesel				0.50	0.65	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Non-celulosic advanced				0.10	0.20	0.30	0.50	0.75	1.00	1.50	2.00	2.50	3.00	3.50	3.50	3.50	4.00
Celulosic advanced					0.10	0.25	0.50	1.00	1.75	3.00	4.25	5.50	7.00	8.50	10.5	13.5	16.0
Conventional biofuels	4.00	4.70	9.00	10.5	12.0	12.6	13.2	13.8	14.4	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0

Figure 2. US Renewable Fuel Standard (2007-2022). Source: Joel Valasco (pers. comm.).

billion by 2022, and biodiesel reaches 1 billion. The residual, likely to be sugarcane ethanol, amounts to 4 billion gallons by 2022. The way the standard is written, there is the total RFS requirement and the advanced requirement (with its sub-components specified separately) with the difference being presumed to be maize based ethanol. However, there is no specific RFS for maize ethanol. This residual, labeled conventional biofuels, reaches 15 billion gallons by 2015 and stays at that level. The residual is the only category that permits maize ethanol. However, it could also include any of the other categories of biofuels.

Associated with all the biofuel categories is a GHG reduction requirement. For maize based ethanol, the reduction must be at least 20 percent. For all advanced biofuels except cellulosic ethanol, the reduction required is 50 percent, and for cellulosic ethanol, it is 60 percent. Ethanol plants that were under construction or in operation as of the data of enactment of the legislation are exempt from the GHG requirement (grandfathered). The GHG requirements are to be developed and implemented by EPA. The EPA administrator has flexibility to modify to some extent the GHG percentages. S/he also has authority to reduce or waive the RFS levels.

In addition to the subsidy and RFS, the US also has a tariff on imported ethanol (Abbott *et al.*, 2008). The tariff is 2.5 percent *ad valorem* plus a specific tariff of 14.3 cents per liter of ethanol. With an ethanol CIF price of 52.9 cents per liter, the total tariff becomes 15.6 cents per liter. The rationale for the tariff was that the US ethanol subsidy applies to both domestic and imported ethanol. Congress clearly wanted to subsidize only domestically produced ethanol, so the tariff was established to offset the domestic subsidy. At the time the tariff was created, the domestic subsidy was also about 14.3 cents per liter (Tyner, 2008). However, the domestic subsidy was reduced to 13.5 and has now been reduced further to 11.9 cents per liter. Thus, today, the import tariff, as a trade barrier, goes far beyond the subsidy offset. The EU and Brazil also have import tariffs on ethanol. For Brazil, it is largely irrelevant since Brazil is one of the world's lowest cost producers of ethanol, so it is unlikely to import ethanol.

2. Ethanol economics and policy

The lowest cost ethanol source is ethanol from sugarcane. It is also the most advantageous from a net energy perspective. Brazil is the global leader in sugarcane based ethanol production, and has ample land resources to expand production. The US uses maize to produce ethanol. The cost of producing ethanol from maize varies with the price of maize. The value of the ethanol produced is a function of the price of crude oil since ethanol substitutes for gasoline. Figure 3 provides a breakeven analysis for maize ethanol at varying prices of crude oil and maize. The top line is the breakeven values with no government intervention and ethanol valued on an energy basis. The second line includes the 13.5 cent per liter subsidy. Prior to 2005, maize often ranged between \$80 and \$90 per mt. Without a subsidy oil would have had to be over \$60 for maize ethanol to be economic. However,

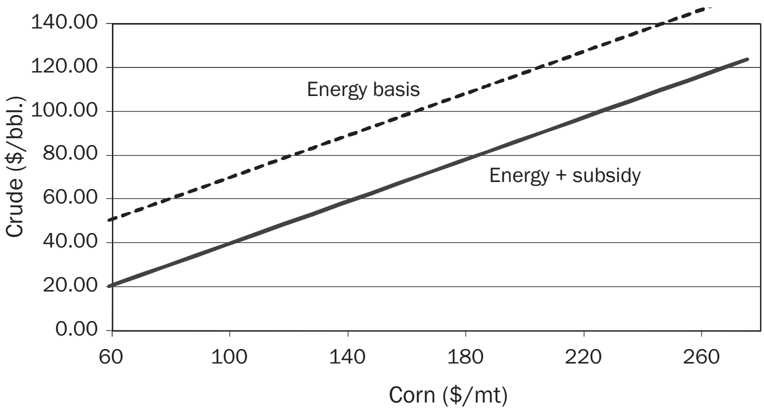


Figure 3. Breakeven ethanol prices with and without federal subsidy.

with the federal subsidy, maize ethanol was economic at around $30 crude. In addition to the federal subsidy, many US states also offered subsidies, so ethanol was attractive in the two decades prior to 2005 even though oil averaged $20/bbl. During that period It was not hugely profitable, but enough so to see the industry grow slowly over the entire period. Today with maize around $240/mt, the breakeven oil price is about $135 with no subsidy and $105 with a subsidy. The nature of a fixed subsidy is such that regardless of the maize price, the breakeven oil price difference with and without the subsidy is about $30/bbl. Or conversely, at $120 oil, the maize breakeven prices with and without subsidy are $270 and $207 per metric tonne, respectively.

2.1. Impacts of alternative US ethanol policies

This breakeven analysis is from the perspective of a representative firm. We can use a partial equilibrium economic model to examine the fixed subsidy, a variable subsidy, and the RFS over a range of oil prices (Tyner and Taheripour, 2008a,b). The model includes, maize, ethanol, gasoline, crude oil, and distillers dried grains with solubles (DDGS). The supply side of the maize market consists of identical maize producers. They produce maize using constant returns to scale Cobb-Douglas production functions and sell their product in a competitive market. Under these assumptions, we can define an aggregated Cobb-Douglas production function for the whole market. In the short-run the variable input of maize producers is a composite input which covers all inputs such as seed, fertilizers, chemicals, fuel, electricity, and so on. In short run capital and land are fixed. The demand side of the maize market consists of three users: domestic users who use maize for feed and food purposes; foreign users, and ethanol producers. We model the domestic and foreign demands with constant price elasticity functions. The foreign demand for maize is more elastic than the domestic demand. The demand of the ethanol industry for maize is a function of the demand for ethanol.

The gasoline market has two groups of producers: gasoline and ethanol producers. It is assumed that ethanol is a substitute for gasoline with no additive value. The gasoline and ethanol producers produce according to short run Cobb-Douglas production functions. The variable input of gasoline producers is crude oil and the variable input of ethanol producers is maize. Both groups of producers are price takers in product and input markets. We model the demand side with a constant price elasticity demand. The constant parameter of this function can change due to changes in income and population. We assume that thegasoline industry is well established and operates at long run equilibrium, but the ethanol industry is expanding. The new ethanol producers opt in when there are profits. There is assumed to be no physical or technical limit on ethanol production – only economic limits.

The model is calibrated to 2006 data and then solved for several scenarios. Elasticities are taken from the existing literature. Endogenous variables are gasoline supply, demand, and price: ethanol supply, demand, and price; maize price and production; maize use for ethanol, domestic use, and exports; DDGS supply and price; land used for maize; and the price of the composite input for maize. Exogenous variables include crude oil price, maize yield, ethanol conversion rate, ethanol subsidy level and policy mechanism, and gasoline demand shock (due to non-price variables such as population and income). The model is driven and solved by market clearing conditions that maize supply equal the sum of maize demands and that ethanol production expands to the point of zero profit. The model is simulated over a range of oil prices between $40 and $140.

Figure 4 provides the results from this model simulation for maize price and Figure 5 for ethanol production. In each figure, the far left bar is the 13.5 cent fixed subsidy, the second is no subsidy, the third a subsidy that varies with the price of crude oil, the fourth the RFS alone, and the fifth the RFS in combination with the fixed subsidy (current policy). The variable subsidy is in effect only for crude oil prices below $70. The first thing to note from Figure 4 is that, just as was evident from the perspective of the firm, there is now a tight linkage between crude oil price and maize price. The basic mechanism is that gasoline price is driven by crude price. Ethanol is a close substitute for gasoline, so a higher gasoline price means larger ethanol demand. That demand stimulates investment in ethanol plants. More ethanol plants means greater demand for maize, and that increased demand means higher maize price. This is a huge change, as historically, there was very little correlation between energy and agricultural prices.

The $40 oil price represents the approximate price in 2004. The model accurately ‘predicts’ the ethanol production and maize price corresponding to $40 oil. That is, the 2004 model results are very close to the actual 2004 values. The ethanol production under no subsidy also accurately shows ethanol production beginning only when oil reaches $60 and then at a very low level. Of course, the RFS case has the ethanol production level at 56.7 bil. l., which is the level of the RFS in 2015, and the level modeled in this analysis. The numbers above the RFS bar in Figure 5 represent the implicit subsidy on ethanol ($/gal. ethanol) due to the

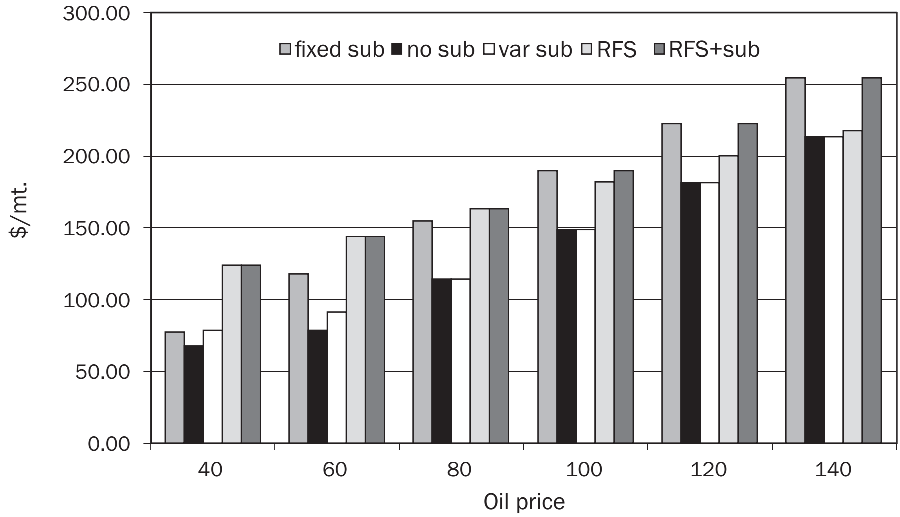


Figure 4. Maize price under alternative policies and oil prices.

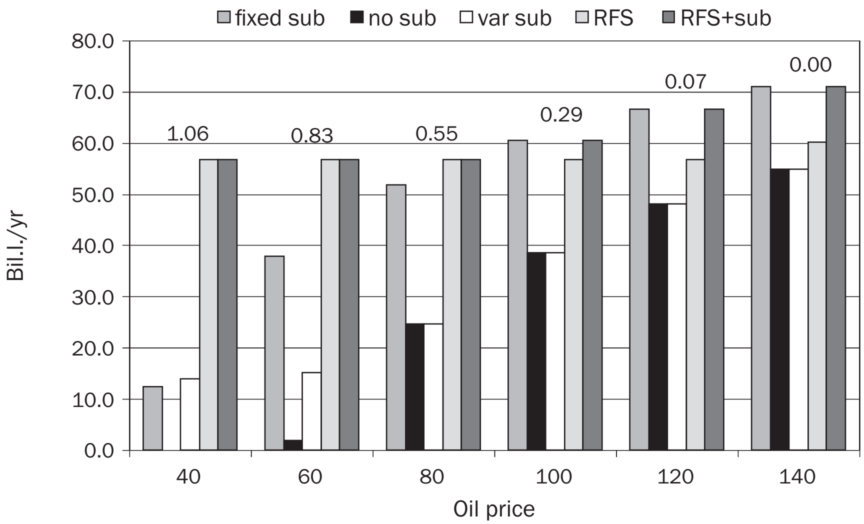


Figure 5. Ethanol production under alternative policies and oil prices.

RFS. It is also an implicit tax on consumers. The model follows the RFS rule, and 'requires' that the stipulated level of ethanol be produced. To the extent that the cost of ethanol is higher than the cost of gasoline, this higher cost gets passed on to consumers in the form of an implicit tax on consumers. Thus, a RFS functions very differently from a subsidy. The subsidy is on the government budget, whereas the mandate cost is paid by consumers directly at the pump. When oil is very inexpensive, the ethanol costs considerably more than petroleum. So the requirement to blend ethanol means consumers pay more at the pump than they would without the mandate. For $40 oil, the implicit subsidy/tax is $1.06/gal. or 28 cents per liter. The subsidy/tax falls to zero at $140 oil. At $140 oil, the mandate is no longer binding, and the amount of ethanol demanded is market driven – not determined by the mandate. Thus the RFS is a form of variable subsidy for the ethanol producer and variable tax for the consumer depending on the price of crude oil. Ethanol production stays at the RFS level of 56.7 bil. l. until oil reaches $120. At that oil price and beyond the market demands more than 56.7 bil. l., and the RFS becomes non-binding.

The final bar is the current policy of RFS plus subsidy. Note that at low oil prices, the RFS production level is higher than that induced by the subsidy, and at high oil prices, the subsidy induces higher production than the RFS. If the RFS represents the intent of Congress with respect to level of ethanol production, the subsidy takes production well beyond that level at high oil prices.

Another important question that can be addressed using these model results is what proportion of the maize price increase is due to the oil price increase, and what proportion to the subsidy. If we start at the no subsidy case with $40 oil, we have a maize price of $67, which increases to $181 when oil triples to $120. If we add on the subsidy at $120 oil, the maize price goes up to $222. The total maize price increase is $155, of which $41 is due to the subsidy, and $113 to the oil price increase. So roughly ¾ of the maize price increase has been due to higher oil prices, and ¼ to the US subsidy on maize ethanol. Even if the subsidy went away, maize prices would not return to their historic levels because of the new link between energy and agriculture. And if oil price went down, we would expect to see the maize price fall as well. As the oil price fell, gasoline would fall as would the price of ethanol. With lower ethanol prices, some plants could not produce profitably, so maize demand would fall and also the maize price.

Figure 6 displays the annual costs of the various policy options. Recall that the method of paying the costs is very different between the government subsidy and the RFS. The RFS is paid by the consumer at the pump, and the fixed and variable subsidies are paid through the government budget. The variable subsidy has no cost for oil above $70 by design, and its cost at low oil prices is quite low. The cost of the fixed subsidy increases almost linearly with oil price. The higher the oil price, the higher the government subsidy cost. The RFS is exactly opposite. It has a high cost when oil price is low, and a very low or zero cost at high oil prices.

The US tariff on imported ethanol introduces a potentially greater distortion than does the subsidy or mandate. Since high oil prices directly lead to higher maize prices, maize ethanol becomes much more expensive. Sugarcane-based ethanol is less expensive to produce than maize ethanol at any oil price, but the gap widens at higher oil prices. So removal

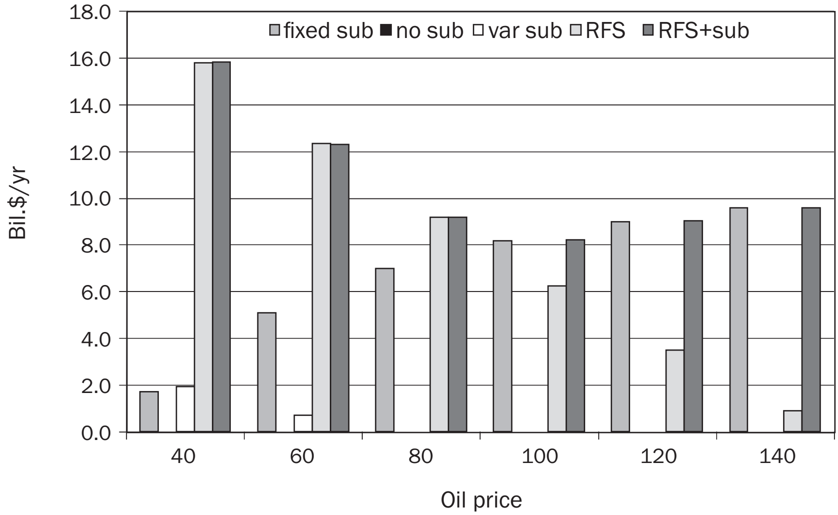


Figure 6. Costs of the policy alternatives.

of the tariff on imported ethanol would lead to the biofuel coming from the lowest cost source–sugarcane–which would reduce some pressure on maize prices and provide the United States with lower cost ethanol. Brazil has the potential to expand ethanol production substantially without increasing world sugar prices substantially, so imports down the road could be quite high.

However, the question is more complicated because it depends on the extent to which imported ethanol adds to total consumption and the extent to which it displaces maize ethanol. For the portion that displaced maize ethanol, each billion gallons of imports would displace about 358 million bushels of maize used for ethanol (Tyner and Taheripour, 2007). So you would get price impacts as the ethanol industry demanded less maize. The problem is figuring out how much would go to increase total consumption and how much to displace maize ethanol. In the United States, the limit of how much ethanol can be blended is called the blending wall (Tyner *et al.*, 2008). The blending wall is the maximum amount of ethanol that can be blended at the regulatory maximum of 10%. Currently, we consume about 140 billion gallons of gasoline (Energy Information Administration, 2008), so the max level for the blending wall would be 14 billion gallons of ethanol. However, for logistical reasons, the practical level is likely to be much lower, perhaps around 12 billion gallons. See Tyner *et al.* (2008) for a more complete analysis of this issue.

We already have in place or under construction 13 billion gallons of ethanol capacity. At present E85 is tiny, and it would take quite a while to build that market. There are only about 1,700 E85 pumps in the nation and few flex-fuel vehicles that are required to consume the fuel. It would require a massive investment to make E85 pumps readily available for all consumers, and a huge switch to flex-fuel vehicle manufacture and sale to grow this market. Without strong government intervention, it will not happen.

What options exist? The most popular among the ethanol industry is switching to E15 or E20 instead of E10. The major problem is that automobile manufacturers believe the existing fleet is not suitable for anything over E10. Switching to a higher blend would void warranties on the existing fleet and potentially pose problems for older vehicles not under warranty. In the US, the automobile fleet turns over in about 14 years, so it is a long term process. We could not add yet another pump for E15 or E20. The costs would be huge. So the blending wall in the near term is an effective barrier to growth of the ethanol industry. If a switch is made to an E15 or E20 limit for standard cars, some agreement would have to be reached on who pays for any vehicle repair or performance issues.

On the technical side, two options could emerge. One would be using cellulose through a thermochemical conversion process to produce gasoline or diesel fuel directly. Today this process is quite expensive, but the cost might be reduced over the next few years. A second option is to convert cellulose to butanol instead of ethanol, which is much more similar to gasoline. Without such a breakthrough, the EPA administrator likely will be forced to cap the RFS far below the planned levels.

Until we hit the blending wall, most of the imports likely would increase total consumption and not displace maize ethanol. However, we will probably reach the blending wall in 2009/10, at which point imports would likely displace domestic maize ethanol and thereby lower maize price.

3. Impacts of US and EU policies on the rest of the world

Our analysis of global impacts is done using the Global Trade Analysis Project (GTAP) model and data base. This work is based on Hertel *et al.* (2008). We begin with an analysis of the origins of the recent bio-fuel boom, using the historical period from 2001-2006 for purposes of model calibration and validation. This was a period of rapidly rising oil prices, increased subsidies in the EU, and, in the US, there was a ban on the major competitor to ethanol for gasoline additives (MTBE) (Tyner, 2008). Our analysis of this historical period permits us to evaluate the relative contribution of each of these factors to the global biofuel boom. We also use this historical simulation to establish a 2006 benchmark biofuel economy from which we conduct our analysis of future mandates.

We then can do a forward-looking analysis of EU and US biofuel programs. The US Energy Policy and Security Act of 2007 calls for 15 billion gallons of ethanol use by 2015, most of which is expected to come from maize. In the EU, the target is 5.75% of renewable fuel use in 2010 and 10% by 2020. However, there are significant doubts as to whether these goals are attainable. For this analysis, we adopt the conservative mandate of 6.25% by 2015 in the EU.

The starting point for our prospective simulations is the updated, 2006 fuel economy which results from the foregoing historical analysis. Thus, we analyze the impact of a continued intensification of the use of biofuels in the economy treating the mandates as exogenous shocks.[12] Ethanol exports from Brazil to the US grow in this simulation as well.

Table 1 reports the percentage changes in output for biofuels and the land-using sectors in the USA, EU and Brazil. The first column in each block corresponds to the combined impact of EU and US policies on a given sector's output (USEU-2015). The second column in each block reports the component of this attributable to the US policies (US-2015), and the third reports the component of the total due to the EU policies (EU-2015) using the decomposition technique of Harrison *et al.* (2000). This decomposition method is a more sophisticated approach to the idea of first simulating the global impacts of a US program, then simulating the impact of an EU biofuels program, and finally, simulating the impact of the two combined. The problem with that (rather intuitive) approach is that the impacts of the individual programs will not sum to the total, due to interactions. By adopting this numerical integration approach to decomposition, the combined impacts of the two programs are fully attributed to each one individually.

In the case of the US impacts (columns labeled Output in US), most of the impacts on the land-using sectors are due to US policies. Coarse grains output rises by more than 16%, while output of other crops and livestock falls when only US policies are considered. However, oilseeds are a major exception. Here, the production impact is reversed when EU mandates are introduced. In order to meet the 6.25% renewable fuel share target, the EU requires a massive amount of oilseeds. Even though production in the EU rises by 52%, additional imports of oilseeds and vegetable oils are required, and this serves to stimulate production worldwide, including in the US. Thus, while US oilseeds output falls by 5.6% in the presence of US-only programs, due to the dominance of ethanol in the US biofuel mix, when the EU policies are added to the mix, US oilseed production actually rises.

In the case of the EU production impacts (Output in EU: the second group of columns in Table 1), the impact of US policies is quite modest, with the main interaction again through the oilseeds market. However, when it comes to third markets – in particular Brazil (Output in Brazil), the US and EU both have important impacts. US policies drive sugarcane production, through the ethanol sector, while the EU policies drive oilseeds production in Brazil. Other crops, livestock, and forestry give up land to these sectors.

[12] Technically, we endogenize the subsidy on biofuel use and exogenize the renewable fuel share, then shock the latter. For simplicity, all components of the renewable fuels bundle are assumed to grow in the same proportion.

Table 1. Change in output due to EU and US biofuel mandates: 2006-2015 (%).

Sector	Output in US			Output in EU			Output in Brazil		
	USEU-2015	US-2015	EU-2015	USEU-2015	US-2015	EU-2015	USEU-2015	US-2015	EU-2015
Ethanol	177.5	177.4	0.1	430.9	1.3	429.7	18.1	17.9	0.2
Biodiesel	176.9	176.8	0.1	428.8	1.2	427.6	-	-	-
Coarse grains	16.6	16.4	0.2	2.5	0.8	1.7	-0.3	1.1	-1.4
Oilseeds	6.8	-5.6	12.4	51.9	1.2	50.7	21.1	0.6	20.5
Sugarcane	-1.8	-1.9	0.1	-3.7	0.0	-3.7	8.4	9.3	-0.9
Other grains	-7.6	-8.7	1.2	-12.2	0.1	-12.3	-8.7	-2.0	-6.8
Other agri	-1.6	-1.7	0.2	-4.5	0.0	-4.5	-3.8	-1.5	-2.4
Livestock	-1.2	-1.2	0.0	-1.7	0.1	-1.8	-1.4	-0.6	-0.7
Forestry	-1.2	-1.4	0.1	-5.4	-0.3	-5.1	-2.7	-1.0	-1.8

Note: Ethanol in the US and EU is from grains, and it is sugarcane-based in Brazil.

Table 2 reports changes in crop harvested area as a result of the biofuel mandates in the US and EU for all regions in the model. The simulation includes only the biofuels shock, and does not include population growth, income growth, trend yield increases, or anyother 'baseline' factors. It is designed just to isolate the biofuels impacts. Coarse grains acreage in the US is up by about 10%, while sugar, other grains, and other crops are all down. The productivity-weighted rise in coarse grains acreage is 10% (Table 3). This increase in maize acreage in the US comes from contribution of land from other land-using sectors such as other grains (Table 3) as well as pasture land and commercial forest land – to which we will turn momentarily.

From Table 2, we see that US oilseeds acreage is up slightly due to the influence of EU policies on the global oilseeds market. However, this marginal increase is dwarfed by the increased acreage devoted to oilseeds in other regions, where the percentage increases range from 11 to 16% in Latin America, and 14% in Southeast Asia and Africa, to 40% in the EU. If the EU really intends to implement its 2015 renewable fuels target, there will surely be a global boom in oilseeds. Coarse grains acreage in most other regions is also up, but by much smaller percentages. Clearly the US-led ethanol boom is not as significant a factor as the EU oilseeds boom. Sugarcane area rises in Brazil, but declines elsewhere, and other grains and crops are somewhat of a mixed bag, with acreage rising in some regions to make up for diminished production in the US and EU and declines elsewhere.

From an environmental point of view, the big issue is not which crops are grown, but how much cropland is demanded overall, and how much (and where) grazing and forestlands are converted to cropland. These results are very sensitive to the productivity of land in the pasture and forest categories compared to cropland. We recognize that more work needs to be done on certain land categories such as idled land and cropland pasture in the US and the savannah in Brazil. Therefore the numerical results reported here must be taken as only illustrative of the results that will be available once the land data base is improved. Table 3 reports the percentage changes in different land cover areas as a result of the EU and US mandates. Furthermore, as with the output changes in Table 1, we decompose this total into the portion due to each region's biofuels programs. From the first group of columns, we see that crop cover is up in nearly all regions. Here we also see quite a bit of interaction between the two sets of programs. For example, in the US, about one-third of the rise in crop cover is due to the EU programs. In the EU, the US programs account for a small fraction of the rise in crop cover. In other regions, the EU programs play the largest role in increasing crop cover. For example, in Brazil, the EU programs account for nearly 11% of the 14.2% rise in crop cover.

Where does this crop land come from? In our framework it is restricted to come from pastureland and commercial forest lands, since we do not take into account idle lands, nor do we consider the possibility of accessing currently inaccessible forests. The largest percentage reductions tend to be in pasturelands (Table 3, final set of columns). For example, in Brazil,

Table 2. Change in crop harvested area by region, due to EU and US biofuel mandates: 2006-2015 (%).

Region	**Crops**				
	Coarse grains	**Oilseeds**	**Sugarcane**	**Other grains**	**Other agri**
USA	9.8	1.6	-5.7	-10	-2.7
Canada	3.5	16.9	-3.2	-2.6	-1.6
EU-27	-2.3	40	-7.4	-15.1	-6.1
Brazil	-3.2	16	3.8	-10.9	-5.1
Japan	10.7	7.6	-0.7	0.8	-0.1
China-Hong Kong	1.2	8.2	-0.6	-0.5	-0.5
India	-0.7	0.9	-0.7	0.5	-0.2
Latin American energy exporters	1.8	11.3	-2.3	-0.2	-0.8
Rest of Latin America & Caribbean	1.7	11.5	-1.6	-0.6	-0.3
EE & FSU energy exporters	0.5	18.1	-0.6	0.4	-0.5
Rest of Europe	2.3	10.5	0	1.8	0.4
Middle Eastern North Africa energy exporters	4	8.6	-0.9	2.5	-0.4
Sub Saharan energy exporters	-0.8	13.7	0	2.3	1.2
Rest of North Africa & SSA	1.5	14.2	-0.4	1.1	1.1
South Asian energy exporters	-0.5	3.7	-0.9	-0.6	-0.1
Rest of high income Asia	3.7	6.1	-0.1	-0.2	0
Rest of Southeast & South Asia	-0.2	2.9	-0.8	0	-0.1
Oceania countries	3.9	17.2	-0.6	-1.3	0.3

Note: These results are solely illustrative of the kinds of numerical results that are produced by the analysis. They are not definitive results.

we estimate that pasturelands could decline by nearly 11% as a result of this global push for biofuels, of which 8% decline is from EU mandates alone. The largest percentage declines in commercial forestry cover are in the EU and Canada, followed by Africa. In most other regions, the percentage decline in forest cover is much smaller.

Our prospective analysis of the impacts of the biofuels boom on commodity markets focused on the 2006-2015 time period, during which existing investments and new mandates in the US and EU are expected to substantially increase the share of agricultural products (e.g. maize in the US, oilseeds in the EU, and sugar in Brazil) utilized by the biofuels sector. In

Table 3. Decomposition of change land cover by EU and US biofuel mandates (with Sensitivity Analysis): 2006-2015 (% change).

	Crop cover				
	USEU 2015	US 2015	EU 2015	Confidence interval (95%)	
				Lower	Upper
US	7	4.7	2.3	3.5	10.8
Canada	11.3	2.9	8.4	4.7	18.0
EU-27	14.3	0.9	13.4	8.0	20.7
Brazil	14.2	3.5	10.7	7.0	21.5
Japan	1.3	0.5	0.8	-0.1	2.7
China-Hong Kong	1.9	0.5	1.4	-0.5	4.3
India	1	0.1	0.9	-0.6	2.7
Latin American EEx.	6.2	2.1	4.1	1.6	10.9
Rest of Latin Am.	5.5	1.5	4.1	1.3	9.9
EE & FSU EEx.	4.6	0.9	3.7	0.1	9.1
Rest of Europe	6.8	1.3	5.5	2.1	11.5
Middle Eastern N Africa EEx.	1.7	0.4	1.2	0.2	3.2
Sub Saharan EEx.	6.9	1.6	5.3	1.7	12.1
Rest of North Africa & SSA	9.9	2.1	7.8	3.3	16.6
South Asian EEx.	-0.2	0	-0.2	-0.9	0.5
Rest of high income Asia	0.1	0	0	-0.1	0.2
Rest of Southeast & South Asia	1.2	0.2	1	-0.3	2.7
Oceania countries	6.6	1.5	5.1	1.6	11.7

the US, this share could more than double from 2006 levels, while the share of oilseeds going to biodiesel in the EU could triple. In analyzing the biofuel policies in these regions, we decompose the contribution of each set of regional policies to the global changes in output and land use. The most dramatic interaction between the two sets of policies is for oilseed production in the US, where the sign of the output change is reversed in the presence of EU mandates (rising rather than falling). The other area where they have important interactions is in the aggregate demand for crop land. About one-third of the growth in US crop cover is attributed to the EU mandates. When it comes to the assessing the impacts of these mandates on third economies, the combined policies have a much greater impact than just the US or just the EU policies alone, with crop cover rising sharply in Latin America, Africa

Forest cover					Pasture cover				
USEU 2015	US 2015	EU 2015	Confidence interval (95%)		USEU 2015	US 2015	EU 2015	Confidence interval (95%)	
			Lower	Upper				Lower	Upper
-1.7	-1.3	-0.5	-2.6	-0.9	-4.9	-3.2	-1.7	-7.3	-2.6
-6	-1.6	-4.4	-9.2	-2.8	-4.4	-1.1	-3.4	-6.9	-2.1
-7.3	-0.5	-6.8	-10.4	-4.3	-5.6	-0.4	-5.3	-7.8	-3.5
-1.7	-0.5	-1.2	-2.5	-0.9	-10.9	-2.7	-8.3	-15.8	-6.1
-0.8	-0.3	-0.5	-1.8	0.2	-0.4	-0.2	-0.3	-0.8	-0.1
0.1	0	0.2	-0.2	0.5	-2	-0.4	-1.6	-4.1	0.1
0	0	0	-0.4	0.4	-1	-0.1	-0.9	-2.4	0.3
-2	-0.8	-1.2	-3.3	-0.6	-4	-1.3	-2.7	-6.8	-1.2
-0.3	-0.3	0	-1.5	0.9	-5	-1.1	-3.9	-8.3	-1.7
-0.8	-0.2	-0.5	-3.6	2.0	-3.6	-0.6	-3	-6.0	-1.2
-0.7	-0.3	-0.4	-2.0	0.7	-5.7	-0.9	-4.8	-9.2	-2.3
-0.9	-0.2	-0.6	-1.7	0.0	-0.8	-0.2	-0.6	-1.4	-0.2
-3.4	-0.8	-2.6	-6.3	-0.5	-3.2	-0.7	-2.5	-5.1	-1.2
-3.4	-0.8	-2.6	-5.8	-1.1	-5.8	-1.1	-4.6	-9.2	-2.4
0.5	0.1	0.4	-0.2	1.2	-0.3	-0.1	-0.2	-0.5	0.0
0.1	0	0.1	0.0	0.2	-0.1	0	-0.1	-0.3	0.0
0	0	0	-0.3	0.2	-1.1	-0.2	-0.9	-2.5	0.2
-2.4	-0.6	-1.8	-4.0	-0.8	-3.9	-0.8	-3.1	-6.8	-1.0

and Oceania as a result of the biofuel mandates. These increases in crop cover come at the expense of pasturelands (first and foremost) as well as commercial forests. It is these land use changes that have attracted great attention in the literature (e.g. Searchinger *et al.*, 2008) and a logical next step would be to combine this global analysis of land use with estimates of the associated greenhouse gas emissions.

4. Conclusions

This paper examines US ethanol policy options using a partial equilibrium model and US and EU options using a global general equilibrium model. The partial equilibrium results clearly illustrate the new linkage between energy and agricultural markets. Prices of agricultural commodities in the future will be driven not only by demand and supply relationships for the agricultural commodities themselves, but also by the price of crude oil. Ethanol from maize and sugarcane can be produced economically at high crude oil prices. The US policy interventions have enabled the ethanol industry to exist and grow over the past 30 years. Today the government interventions continue to be important, but the new added driver is high oil prices.

When one examines the US and EU policies together, one sees clearly that the impacts are felt around the world. Trade and production patterns are affected in every region. The results presented here are very preliminary, but they serve to illustrate how the analysis can be used to estimate global production, trade, and land use impacts of US and EU policies.

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Chapter 9
Impacts of sugarcane bioethanol towards the Millennium Development Goals

Annie Dufey

1. Introduction

At the Millennium Summit in September 2000 the largest gathering of world leaders in history adopted the United Nations Millennium Declaration. They committed to a new global partnership to reduce extreme poverty by 2015 in line with a series of targets that have become known as the Millennium Development Goals (MDGs). The MDGs are crafted around eight themes to promote sustainable development addressing extreme poverty in its different dimensions including hunger, health, education, the promotion of gender quality and environmental sustainability (see Box 1).

At the same time, during the last five years or so, the world has witnessed the global emergence of a new sector – the biofuels sector. Biofuels potential for achieving simultaneously economic, poverty reduction and environmental goals have combined and placed biofuels at the top of today's most pressing policy agendas.

This chapter argues that sugarcane bioethanol can be supportive of sustainable development and poverty reduction, thus contributing to the achievement of the MDGs. In some contexts there might be synergies between the pursue of different goals but there may be

Box 1. The Millennium Development Goals.

The eight Millennium Development Goals were agreed at the United Nations Millennium Summit in September 2000. The eight Millennium Development Goals are:

- Eradicate extreme poverty and hunger
- Achieve universal primary education
- Promote gender equality and empower women
- Reduce child mortality
- Improve maternal health
- Combat HIV and AIDS, malaria and other diseases
- Ensure environmental sustainability
- Develop a global partnership for development

Source: http://www.un.org/millenniumgoals/

also risks and serious trade-offs over food security, small farmers inclusion, environment and the economy.

Much of the available evidence comes from Brazil, which has the main longstanding experience with the launching of the PROALCOOL Programme in 1975 to replace imported gasoline with bioethanol produced from locally grown sugarcane. Today Brazil is the second bioethanol producer after the United States and the main exporter. In addition, there have been other smaller initiatives with different rate of success. These include African and East Asian countries such as Zimbabwe, Malawi, Kenya, Pakistan and India that have promoted bioethanol from sugarcane molasses, some of them since the early eighties. More widely, at present, many countries around the world, in their search for development and poverty reduction opportunities are trying to replicate the Brazilian experience with sugarcane bioethanol. Their vast majority are developing countries in tropical and semitropical areas in the Caribbean, Africa, Latin America and East Asia in which sugarcane is traditionally grown.

The chapter is organized as follows. After this brief introduction, Section 2 argues that sugarcane bioethanol may offer some genuine opportunities for sustainable development and poverty reduction and identify the key potential benefits. Section 3 points out that benefits are not straightforward and identifies several challenges and trade-offs that need to be confronted in order to realize their full potential for achieving sustainable development and poverty reduction. Finally, section 4 concludes and provides some recommendations.

2. Opportunities for sugarcane bioethanol in achieving sustainable development and the Millennium Development Goals

Sugarcane bioethanol can contribute to sustainable development and poverty reduction through a varied range of environmental, social and economic advantages over fossil fuels. These include: (a) enhanced energy security both at national and local level; (b) improved social well-being through better energy services especially among the poorest; (c) improved trade balance by reducing oil imports; (d) rural development and better livelihoods; (e) product diversification leaving countries better-off to deal with market fluctuations; (f) creation of new exports opportunities; (g) potential to help tackling climate change through reduced emissions of greenhouse gases (h) reduced emissions of other air contaminants; and (i) opportunities for investment attraction through the carbon finance markets. This section briefly addresses each of these aspects.

2.1. Enhanced energy security

Enhanced energy security has become a universal geopolitical policy concern and it was a key policy driver behind the first attempts to introduce sugarcane bioethanol at a massive scale in the mid-1970s in Brazil (Dufey *et al.*, 2007b). Current increasing energy costs and uncertainty regarding future energy supply are giving many governments incentive to encourage the production of petroleum substitutes from agricultural commodities. Indeed, the volatility of world oil prices, uneven global distribution of oil supplies, uncompetitive structures governing the oil supply and heavy dependence on imported fuels are all factors that leave many countries vulnerable to disruption of supply, imposing serious energy security risks which can result in physical hardships and economic burden (Dufey, 2006). For instance, crude oil imports to African, Caribbean and Pacific countries were expected to increase to 72 percent of their requirements in 2005 (Coelho, 2005).

Energy diversification makes countries less vulnerable to oil price shocks, compromising macro-stability affecting variables such as the exchange rate, inflation and debt levels (Cloin, 2007). Sugarcane bioethanol is a rational choice in countries where sugarcane can be produced at reasonable cost without adverse social and environmental impacts (Dufey *et al.*, 2007b). For remote places, locally produced sugarcane bioethanol can offer a highly competitive alternative to other fuels. This might be the case of several sugarcane producing countries in Pacific island nations and land-locked countries in Africa where the high costs of fossil fuel transportation and the related logistics make them prohibitive.

2.2. Benefits at the household level - improved social well-being

A large part of the poor, mostly in rural areas, do not have access to affordable energy services which affects their chances of benefiting from economic development and improved living standards. In this context the use of bioethanol and other renewable sources can directly or indirectly lead to several MDGs including gender equality, reduction of child mortality, poverty reduction, improvement of maternal health and environmental sustainability. Firstly, they can reduce the time spent by women and children on basic survival activities (gathering firewood, fetching water, cooking, etc.). Women in least developed countries may spend more than one third of their productive life collecting and transporting wood. Additional help needed from children often prevents them from attending school (FAO, 2007). Secondly, the use of bioethanol (and other liquid biofuels) for household cooking and heating could help to reduce respiratory disease and death associated with burning of other traditional forms of fuels usually used in the poorest countries (e.g charcoal, fuelwood and paraffin solid biomass fuels indoors), to which women and children are especially vulnerable (UN-Energy, 2007; Woods and Read, 2005). In some African countries charcoal and woodfuel account for over 95 percent of household fuel (Johnson and Rosillo-Calle, 2007). As Box 2 suggests, experiences promoting the use of sugarcane bioethanol in stoves at the household level are expected to report important socio-economic and environmental benefits. Finally, the use of biofuels can improve access to pumped drinkingwater, which can reduce hunger by allowing for cooked food (95% of food needs cooking) (Gonsalves, 2006a). However, adaptation of bioethanol for domestic uses would of course require a cultural shift away from the traditional hearth, plus attention to safety in fuel storage, as liquid biofuels are highly flammable (Dufey *et al.*, 2007b). Overall, electricity through transmission lines to

Box 2. Bioethanol stoves to condominium residents in Addis Ababa in Ethiopia

In Ethiopia the Municipality of Addis Ababa EPA (Environmental Protection Authority) and a Sub-City district are working closely with Gaia Association, Dometic AB, Makobu Enterprises, and Finchaa Sugar Factory to develop a project whereby initially 2000 CleanCook (CC) stoves will be installed in newly built condominium apartments. Wood and charcoal stoves are not permitted in these condominium buildings.

The CC stove is financed within the condominium unit price. Financing is provided by the condominium association with the assistance of the Municipal EPA, the Sub-City Administration and a financing entity. The finance rate is regulated by the government and is kept low. The bioethanol used in the project is produced at one of three state-owned sugar factories at a contractual price by Makobu Enterprises and delivered to the condominium. The fuel storage and distribution infrastructure will be financed by the condominium association. The Ethiopian EPA will work with one Sub-City Administration to package the stove financing into the condominium financing through the national bank. As a result, 2000 CC stoves will be financed in 2008 and approximately 360,000 liters of domestically produced bioethanol will supplant kerosene, charcoal and firewood use. The other nine Sub-City administrations could replicate the model.

Since the CC stove is clean burning, its introduction will improve indoor air quality and, consequently, household health. Another advantage of this model lies in the potential for Clean Development Mechanism (CDM) financing. It is important to note the government has had a central role for the development of a domestic bioethanol industry in Ethiopia, as well as for building a local market for bioethanol as a household cooking fuel. Indeed, after considering allocating bioethanol for fuel blending in the transport sector in 2006, the Government got convinced that the most significant socioeconomic and environmental benefits would stem from prioritizing the use in the domestic household sector.

Source: adapted from Lambe (2008).

many rural areas is unlikely to happen in the near future, so access to modern decentralized small-scale energy technologies, particularly renewables are an important element for effective poverty alleviation policies (Gonsalves, 2006a). In this context, bioethanol can be directed towards high value added uses such as lighting or motors, which can lead to income generating activities.

But the effectiveness of using sugarcane bioethanol for these uses would need to be assessed against those of other energy crops or renewable sources such as small hydropower.

2.3. Improved trade balance

Heavy reliance on foreign energy sources means countries have to spend a large proportion of their foreign currency reserves on oil imports. Oil import dependency is especially acute in Sub-Saharan and East Asian countries, where 98 percent and 85 percent of their oil needs are met by imports, respectively (ESMAP, 2005a). Changes in oil prices have devastating effects in these countries. For instance, the 2005 oil price surge reduced Gross Domestic Product growth of net oil importing countries from 6.4 percent to 3.7 percent, and, as a consequence, the number of people in poverty rose by as much as 4-6 percent, with nearly 20 countries experiencing increases of more than 2 percent (ESMAP, 2006).

Domestically produced bioethanol offers oil importing countries an opportunity to improve their trade balance. In Brazil, for instance, the replacement of imported gasoline by sugarcane bioethanol saved the country some US$ 61 billion in avoided oil imports during the last eight years – equating the total amount of the Brazilian external public debt (FAO, 2007). In Colombia, the implementation of the bioethanol programme would result in foreign exchange savings of US$ 150 million a year (Echeverri-Campuzano, 2000).

2.4. Rural development and creation of sustainable livelihoods

Biofuels provide new economic opportunities and employment in the agricultural sector, key aspects for poverty reduction. They generate a new demand for agricultural products that goes beyond traditional food, feed and fibre uses, expanding domestic markets for agricultural produce and paving the way for more value-added produce. All of these aspects enhance rural development, especially in developing countries where most of the population live in rural areas. For instance, Echeverri-Campuzano (2002) estimates that every Colombian farming family engaged in bioethanol production will earn two to three times the minimum salary (US$ 4,000/year). In South Africa meeting targets of E8 and B2 would contribute 0.11 percent to the country's Gross Domestic Product. Most of the positive effect would take place in rural areas characterized by unemployment and rising poverty (Cartwright, 2007).

Compared to other sources of energy, biofuels are labour intensive. Their production is expected to generate more employment per unit of energy than conventional fuels and more employment per unit investment than in the industrial, petrochemical or hydropower sector (UN-Energy, 2007). Creation of rural employment and the related livelihoods are all key aspects for rural development and poverty reduction. In Brazil estimations of direct employment associated with sugarcane bioethanol production ranges from 500,000 and 1 million (Worldwatch Institute, 2006; FAO, 2007) with indirect employment in the order of 6 million. Although most of them are filled by the lower-skilled, poorest workers in rural areas (Macedo, 2005), average earnings are considered better than in other sectors as the average family income of the employees ranks in the upper 50 percentile (FAO, 2007). In India, country that houses 22 percent of the world's poor, the sugarcane industry including bioethanol production is the biggest agroindustry in the country and the source of livelihood of 7.5 percent of the rural population. Half a million people are employed as skilled or semi-skilled labourers in sugarcane cultivation (Gonsalves, 2006a).

The highest impact on poverty reduction is likely to occur where sugarcane bioethanol focuses on local consumption, involving the participation and ownership of small farmers in the production and processing (FAO, 2007; Dufey *et al.*, 2007b) and where processing facilities are near to the cultivation fields.

2.5. Product diversification and value added

International sugarcane market is one of the most distorted markets. It is highly protected, in general countries manage to negotiate quotas, a limited access to different markets, and because it is a commodity, it has important price fluctuations (Murillo, 2007). In this context, sugarcane bioethanol is an opportunity to promote agricultural diversification leaving producers in a more favourable situation to deal with changes in prices and other market fluctuations. In Brazil, for instance, besides the pursue of enhanced energy security, the government promoted the PROALCOOL programme in order to deal with the fall in international sugar prices preventing thus the industry of having idle capacity (FAO, 2007). Moreover, the production of both sugar and bioethanol gives the Brazilian industry flexibility in responding to the changing profitability of sugar and bioethanol production worldwide. In most cases, sugar and bioethanol are produced in the same mills (Bolling and Suarez, 2001).

Sugarcane bioethanol can also reduce vulnerability through diversification. The changes in the European Union's sugar regime will imply that many African, Caribbean and Pacific countries will see their market access preferences eroded generating negative impacts on poverty levels. In the Caribbean, for instance, the associated possible loss of export revenues is expected to be 40 percent with a heavy contraction in the industry. The resulting sugar surpluses therefore could be accommodated for biofuels production thus helping the industry to diversify, avoiding or mitigating the expected contraction (E4Tech, 2006).

Another element to consider is the fact that sugarcane bioethanol production provides value added to sugarcane production. For instance, Murillo (2007) notes for Costa Rica that if the molasses and sugar producers substitute their production by those of bioethanol the price received would be much more than what they would get if they were to continue producing molasses or sugar for the surplus market.

2.6. Export opportunities

Although at present very little bioethanol enter the international market (about 10%), international trade is expected to expand rapidly, as the global increase in consumption (especially countries in the North) will not coincide geographically with the scaling up of production (countries in the South) (Dufey, 2006). The geographical mismatch between global supply and demand represents an opportunity for countries with significant cost advantages in sugarcane production to develop new export markets and to increase their export revenues. These are invariably developing countries in tropical and semitropical areas.

Brazil, the main global bioethanol exporter, increased its exports considerably over the last few years and today supplies about 50 percent of international demand. (Dufey *et al.*, 2007b). The Brazilian government expects that by 2015 about 20 percent of the national production to be exported (Ministerio da Agricultura *et al.*, 2006). Countries from the Caribbean Basin Initiative are developing export-oriented sugarcane bioethanol industries taking advantage of preferential market access provided by the trade agreement with the United States. Other exporters include Peru, Zimbabwe and China. As them other Latin American, African and East Asian countries are exploring the benefits of export-oriented sugarcane bioethanol sectors.

In absence of trade distorting policies and where effective distributional and social policies are supportive, the development of a successful sugarcane bioethanol export-oriented industry could effectively reduce poverty.

2.7. Reduced greenhouse gas emissions

At present global warming is considered one of the key global threats facing the humanity (Stern, 2006). Biofuels alleged reduced greenhouse gas emissions compared to fossil fuels are one of the main policy rationales for their promotion especially in Northern countries. There are two ways in which biofuels can reduce carbon emissions. First, over their life cycle, biofuels absorb and release carbon from the atmospheric pool without adding to the overall pool (in contrast to fossil fuels). Second, they displace use of fossil fuels (Kartha, 2006). However, biofuels production does, in most cases, involve consumption of fossil fuels.

Compared to other types of liquid biofuels and under certain circumstances, Brazilian sugarcane bioethanol and second generation biofuels show the higher reductions in greenhouse gas emissions relative to standard fuels. IEA (2004) estimates that greenhouse emissions from sugarcane bioethanol in Brazil are 92 percent lower than standard fuel, while wheat bioethanol points to reductions ranging from 19 percent to 47 percent and reductions from sugar beet bioethanol vary between 35 percent and 53 percent. In addition to Brazil's exceptional natural conditions in terms of high soil productivity and that most sugarcane crops are rain fed, a key factor behind its great greenhouse emissions performance is that nearly all conversion plants' processing energy is provided by 'bagasse' (the remains of the crushed cane after the juice has been extracted). This means energy needs from fossil fuel are zero and the surplus bagasse is even used for electricity co-generation. In 2003, Brazil avoided 5.7 million tonnes CO_2 equivalent due to the use of bagasse in sugar production (Macedo, 2005). Moreover, new developments in the sector such as the commercial application of lignocelulosic technology that will allow the use of bagasse for bioethanol production and the increased generation of electricity from bagasse will improve their greenhouse emissions balance (Dufey *et al.*, 2007a).

However the Brazilian experience is not necessarily replicable in other contexts. For example, efficiency gains and the greenhouse emissions reductions associated with co-generation are an option for those countries whose electricity sectors regulation allows power sale to the grid (E4Tech, 2006).

Finally, these estimations do not include the emissions resulting from changes in land use and land cover induced by sugarcane plantations for bioethanol production. For example, the evaluation of greenhouse emissions from Brazil for the 1990-1994 period points out the change in land use and forests as the factor accounting for most of the emissions (75%), followed by energy (23%). This implies that if additional land use for sugarcane production leads (directly or indirectly) to conversion of pastures or forests as suggested later in this chapter, the greenhouse emissions may be severe and could have a major impact on the overall greenhouse emission balance (Smeets *et al.*, 2006). Overall, the land use issue requires further attention and is addressed in another chapter of this book.

2.8. Outdoor air quality

Road transport is a growing contributor to urban air pollution in many developing country cities. One of the greatest costs of air pollution is the increased incidence of illness and premature death that result from human exposure to elevated levels of harmful pollutants. The most important urban air pollutants to control in developing countries are lead, fine particulate matter, and, in some cities, ozone. Sugarcane bioethanol, when used neat, is a clean fuel (aside from increased acetaldehyde emissions). More typical use of bioethanol is in low blends. Bioethanol also has the advantage of having a high blending octane number, thereby reducing the need for other high-octane blending components such as lead that cause adverse environmental effects. Venezuela, for instance, began importing Brazilian bioethanol as part of the effort to eliminate lead from gasoline. Bioethanol can be effective for cutting carbon monoxide emissions in winter in old technology vehicles as well as hydrocarbons emissions. The latter are ozone-precursors, in old technology vehicles (ESMAP, 2005b).

On the other hand, there is air pollution associated with the slush and burn of sugarcane and the burning of the straw, a common practice in developing countries to facilitate the harvesting. This issue is further addressed in Section 3.b on Environmental Impacts.

2.9. Opportunities for investment attraction – including the Clean Development Mechanism

Developing countries can make use of the carbon finance markets for attracting investment into biofuels projects using the market value of expected greenhouse emission reductions. The Clean Development Mechanism (CDM) under the Kyoto Protocol is the most important example of the carbon market for developing countries. The CDM allows developed countries (or their nationals) to implement project activities that reduce emissions in developing countries in return for certified emission reductions (CERs). Developed countries can use the CERs generated by such project activities to help meet their emissions targets under the Kyoto Protocol. For instance, it is calculated the Colombian Programme on bioethanol would reduce CO_2 emissions by six million tons, offering opportunities to obtain financial resources for the project trough the CDM (Echeverri-Campuzano, 2000). For Costa Rica, Horta (2006) estimates that considering an avoided ton of carbon at a conservative price of US$ 5, in the scope of the Kyoto Protocol and the valid mechanisms of carbon trade, US$ 320,000/year can be obtained using a 10 percent of sugarcane bioethanol in the gasoline blend.

Although the CDM is a potential source of financing for biofuels projects, taking advantage of it can present a number of challenges for the developing country host. Firstly, so far there is no liquid-biofuels baseline and monitoring methodology approved. Calculation of greenhouse gases emissions is not straightforward and for many countries biofuels are still a relatively expensive means of reducing these emissions relative to other mitigation measures. An additional challenge is that the existing experience with CDM projects shows that approved projects are strongly concentrated in a handful of large developing countries, with over 60 percent of all CDM projects distributed across China, India and Brazil alone. While there are simplified procedures for small-scale projects, the current structure of the CDM tends to select for large-scale projects. The transaction costs associated with registering a CDM project are often prohibitively expensive for smaller developing countries, which imply that economies of scale are relevant (Bakker, 2006). For bioenergy projects specifically, the exclusion of all land use activities from the CDM except for afforestation and reforestation is another significant limiting factor, since in the poorest developing countries, land-use related emissions make up the bulk of greenhouse gases emissions from biomass energy systems (Schlamadinger and Jürgens, 2004). Overall, as FAO (2007) concludes, while carbon credits might be influential in the future, currently the carbon market does not have a large influence over the economics of bioenergy production.

3. Risks and challenges

Section 2 analysed a diverse range of benefits associated with sugarcane bioethanol in terms of its potential to support poverty reduction and environmental sustainability. However, as this section argues, these benefits are not straightforward. There is a range of challenges and trade-offs that need to be confronted in order to realize the full potential that sugarcane bioethanol offers to support the MDGs, which include: (a) impacts on food security; (b) environmental pressure; (c) small farmer inclusion and fair distribution of the value chain benefits; (d) land impacts; (e) employment quality; (f) need of government support; (g) existence of market access and market entry barriers and; (h) issues related to improved efficiency, access to technology, credit and infrastructure. These issues are addressed in the following.

3.1. The food versus fuel debate

Current food prices increases, the role that biofuels play on such rises and their related impacts on food security are, probably, one of the most controversial debates being held both at national and international fora. Indeed, food prices increased by 83 percent during the last three years (World Bank, 2008). The Food and Agriculture Organization of the United Nations (FAO) food index price rose by nearly 40 percent in 2007, from a 9 percent increase in 2006 (IFPRI, 2008). World prices rose much more strongly in 2006 than anticipated for cereals, and to a lesser extent for oilseeds, but weakened for sugar (OECD-FAO, 2007).

The understanding of biofuels impacts on food security is a wider and complex. It requires considering that the link between food prices increases and food security is not unique and necessarily negative. It needs to be analysed in the context that changes in food prices not only impact food *availability* but also its *accessibility* through changes in incomes for farmers and rural areas (Schmidhuber, 2007).

3.1.1. Impacts on food availability

The key question at the national level is whether the savings and gains from biofuels will outweigh additional food costs. Biofuels compete with food crops for land and water, potentially reducing food production where new agricultural land or water for irrigation are scarce (Dufey *et al.*, 2007b). For biofuels that are manufactured from food crops, there is also direct competition for end-use. To what extent sugarcane bioethanol creates competition for land and crowd out food crops is an issue that is not very clear. The limited available evidence would suggest a lesser impact compared to other feedstocks. Zarrilli (2006), for example, points out that sugarcane producing regions in Brazil stimulate rather than compete with food crops, which is done by two means. Firstly, through the additional income generated by sugarcane related agro-industrial activities which 'capitalises' agriculture and improves the general conditions for producing other crops. This is also noted by Murillo (2007) for Costa Rica, where under current weather conditions and land use, sugarcane bioethanol production is seen as a complement in income generation rather than a competition for basic products and vegetables. Secondly, the high productivity of cane per unit of land compared to other feedstocks enables a significant production of cane, with a relatively small land occupation (Zarrilli, 2006). Sugarcane's minimal land requirements but in the context of sub-Saharan Africa is noted by Johnson *et al.* (2006), but needs to be proven (Dufey *et al.*, 2007b). Moreover, in those countries where bioethanol is produced from sugarcane molasses there is no displacement of food crops (Rafi Khan *et al.*, 2007). In addition, in many African countries, cassava and maize are grown for subsistence purposes while cane is often grown for sugar export. Diversion to fuel production is therefore more likely to adversely affect food availability in the case of cassava (Johnson and Rosillo-Calle, 2007)

At the international level, the growing international demand for biofuels is expected to reverse the long-term downward trend in global prices of agricultural commodities. Several studies have been conducted linking increased global biofuels production with rising agricultural commodity prices. Estimations vary widely with most credible ones going up to 30 percent. Other contributing factors to price increases are the weather-related shortfalls in many key producing countries, reduced global stocks, increased demand from new emerging economies in Asia (OECD-FAO, 2007) and speculation (IFPRI, 2008). In that sense, the higher demand for biofuel feedstocks is viewed as increasing pressure on an already tight supply.

However, it is one issue trying to isolate how much biofuels, in overall, are responsible for the sector's inflationary pressure and, a different one, understanding to what extent sugarcane bioethanol is responsible for the price increase. Although the available evidence in this sense is also scant, it would suggest that, compared to other feedstocks, sugarcane bioethanol would have a slighter impact on food security. A key reason behind this is that sugarcane is not a principal food crop. Staple grains like maize and rice are often the main food source for the poorest people, accounting for 63 percent of the calories consumed in low-income Asian countries, nearly 50 percent in Sub-Saharan Africa, and 43 percent in lower-income Latin American countries (IFPRI, 2008). Rosegrant (2008) in an exercise in which biofuel production was frozen at 2007 levels for all countries and for all crops used as feedstocks, shows the smaller price reductions for sugarcane followed by wheat while the higher reductions are for maize (Figure 1). Another reason been argued is that sugarcane price would be relatively uncorrelated with other food crops (Oxfam, 2008).

3.1.2. Impacts on accessibility

The issue of how the gains and costs of biofuels to food security are distributed across society has been less explored in the literature. FAO and other commentators agree that hunger is largely a matter of access rather than supply, so that a focus on rural development and livelihoods makes more sense that trying to maximise global food supply, which for now at least is adequate for global needs (Murphy, 2007).

Higher agricultural commodity prices are good news for agricultural producers, but they have an adverse impact on poorer consumers, who spends a much larger share of their income on food (IFPRI, 2008). There are also differences depending on whether households are net food producers or buyers. For small farmers that are net food producers, overall gains in welfare and food security are expected due to rising revenues from biofuel crops and

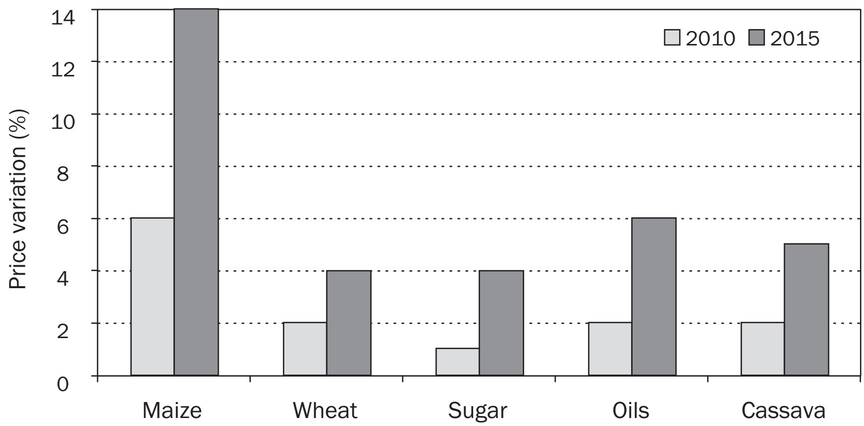

Figure 1. Change in selected crop prices if biofuel demand was fixed at 2007 levels. Source: Rosegrant (2008).

food crops (Peskett *et al.*, 2007). In overall, poor consumers in urban areas who purchase all their food are expected to be worst off. From this perspective and compared to other feedstocks, sugarcane bioethanol is likely to provide more limited opportunities to meet food security for small farmers. In Brazil, for example, sugarcane is a crop mainly grown under large-scale schemes, with limited participation of small farmers. In regions such as Asia, although small farmers participation in sugarcane cultivation is important, the need to use irrigation makes more unlikely to involve poorest farmers (ICRISAT, 2007). More widely, it is agreed that despite being producers of agricultural crops, most poor farming households in rural areas are net buyers of food (Dufey *et al.*, 2007b; IFPRI, 2008).

Finally, it should be noted that, historically, domestic food prices have not been tightly linked to international food or energy prices, as price transmission mechanisms are not straightforward (Hazell *et al.*, 2005). For instance, agricultural pricing policies such as price fixation, the remoteness of some rural areas, trade distortions and power structures governing agricultural commodity markets are key factors preventing world prices from reaching domestic markets. This may imply that farmers may not see the incentives to change feedstock production in tandem with changes in international prices.

3.2. Environmental pressure

Traditional environmental impacts associated with sugarcane appear when it comes to managing soil, water, agrochemicals, agricultural frontier expansion and the related biodiversity impacts. Among them, impacts on agricultural frontier and on water deserve especial attention. Regarding the former, it should be noted that the bulk of the sugarcane expansion in the last thirty years in Brazil has been concentrated in the central southern region of the country. Between 1992 and 2003, 94 percent of the expansion occurred in existing areas of agriculture or pastureland and only a small proportion of new agricultural borders were involved (Macedo, 2005). Often the sugarcane crop replaced cattle grazing and other agricultural activities (e.g. citrus crops), which in turn moved to the central region of Brazil where the land is cheaper (Smeets *et al.*, 2006). Land converted to agriculture in the sensitive area of the Cerrado savanna (which accounts for 25% of the national territory) has been used for cattle grazing and/or planted to soya, with only a small proportion for sugarcane. However, given the new phase of expansion experiencing the sector for bioethanol production, new areas are expected to be converted to sugarcane, including the Cerrado of Mato Grosso do Sul, Goiás and Minas Gerais (Dufey *et al.*, 2007a). This could further increase the pressure on the already affected biodiversity and produce greenhouse emissions. There is concern in this sense on the impacts that the substitution effect - sugarcane taking over existing pastureland or other crops that become less profitable which in turn advance into protected or marginal areas – may have on biodiversity. Indeed, in Brazil, substitution effect related impacts are considered more significant than the direct effects of sugarcane expansion (Dufey, 2007). In Africa, on the other hand, land constraints appear unlikely in any near-term scenario, and resources such as water, as explained in the next paragraph, may turn out to be the key limiting factor (Johnson and Rosillo-Calle, 2007).

Regarding water, sugarcane requires large amounts of water, both at the farming and processing level. Even in Brazil where most sugarcane is rain fed, irrigation is increasing. Energy cane, which is especially bred for energy production, requires more water and fertiliser than conventional sugarcane (Cloin, 2007). Water is likely to be a key limiting factor especially in dry and semi-dry areas in Africa and Asia. Bioethanol impact on water quality is another issue and not only at the farming level due to the use of agrochemicals but also at the processing level. Vinasse, - a black residue resulting from the distillation of cane syrup - is hot and requires cooling. In the mountainous areas of north-eastern Brazil, for instance, the costs of pumping storing vinasse were prohibitive, and it was therefore released into rivers, resulting in the pollution of rivers causing eutrophication and fish kills. Currently, vinasse is used for ferti-irrigation of cane crops, together with wastewaters. Moreover, legislation has been implemented in Brazil to avoid the negative impacts of vinasse applications, although its coverage is incomplete and its enforcement is rather weak (Smeets *et al.*, 2006). All in all, while steps have been taken in Brazil order to manage vinasse disposal, in countries such as Malawi it is still a major concern (Johnson and Rosillo-Calle, 2007).

Furthermore, the air pollution associated with the slush and burn of sugarcane and the burning of the straw, a common practice in developing countries to facilitate the harvesting, is an additional issue. Sugarcane burning emits several gases including CO, CH_2, ozone, non-methane organic compounds and particle matter that are potentially damaging for human health. Several studies were conducted in São Paulo in Brazil during the 1980s and 1990s to identify the impacts of sugarcane burning on human health. Although some studies did not found a link, others studies did confirm the relationship (Smeets *et al.*, 2006;

Dufey *et al.*, 2007a). Legislation has been passed in Brazil by which sugarcane burning is to be completely phased out in the São Paulo State by 2031. In Southern Africa efforts to reduce sugarcane burning pre-harvesting have also been reported (Jackson, 2004), but in other countries it still remain a major practice.

Overall, sugarcane bioethanol production poses some specific environmental challenges that need to be carefully identified and managed using a life cycle approach in order to achieve the MDG on environmental sustainability.

3.3. Small farmers inclusion and fair distribution of the value chain benefits

Addressing poverty means that biofuels should benefit poor and small farmers overall. An emphasis on small farmers would provide livelihoods across the greatest section of the populations (Johnson and Rosillo-Calle, 2007). But the competitiveness of a biofuels industry is highly dependent on gaining economies of scale. Often large-scale systems are more globally competitive and export oriented, while small-scale systems offer greater opportunities for employment generation and poverty alleviation (Dufey *et al.*, 2007b). In Brazil, the sugarcane business model is characterised by enormous concentration of land and capital, which highlights the need for a better inclusion of small-scale producers (Dufey *et al.*, 2007a). Increasing economies of scale and land concentration have meant that benefits of sugarcane bioethanol production for small land owners have so far been limited and large farmers and industrialists have benefited more from the expansion of the industry (Peskett *et al.*, 2007). In contrast, in countries such as India and South Africa small farmers are key players in the sugarcane sector. In India, they represent between 60 and 70 percent of the cane growers (Johnson and Rosillo-Calle, 2007). In Costa Rica, the proportion of small producers in the sugarcane sector increased by 97 percent between 2000 and 2005 (Murillo, 2007).

Small farmers face several obstacles in trying to access supply chains. They trade-off high transportation costs getting crops to processing plants with selling through middlemen (Peskett *et al.*, 2007; Rafi Khan *et al.*, 2007). In India, farmers must access to irrigation to be competitive, which is increasingly difficult and expensive due to growing water scarcity and cost (ICRISAT, 2007). At processing plants they have to time delivery to fit daily plant capacity and meet plant standards. Either way, small producers are price-takers (Peskett *et al.*, 2007). Box 3 highlights some of the challenges faced by sugarcane small farmers in Pakistan.

However, large-scale and small-scale systems are not mutually exclusive and can interact successfully in a number of different ways (Dufey *et al.*, 2007b). Some of the models for partnership between large-scale and small-scale enterprises include outgrower schemes, cooperatives, marketing associations, service contracts, joint ventures and share-holding by small-scale producers (Mayers and Vermeulen, 2002). Concerning sugarcane, in Brazil co-operatives operate in certain areas (Oxfam, 2008). In India some of the sugar mills are

Box 3. Unfair distribution of benefits against small farmers - middleman in Pakistan.

In Pakistan, where bioethanol is produced from sugarcane molasses, middlemen play a key role in sugarcane procurement and often end up exploiting small-scale farmers forcing them to sell at distress prices. In collusion with mill owners, they orchestrate delays at the mill gate; the problem becomes exacerbated during surplus years. The farmer has no option but to accept the price offered (lower than the support price) or face further delays. Large farmers are better placed as their crop represents a large proportion of the mill intake and they also have greater political clout. Small farmers are indebted to middlemen for their consumption and input needs, which also leads to under pricing. Further, a report by the Agricultural Prices Commission of Pakistan indicates that the scales installed to weigh sugarcane do not provide correct readings. However, given the high level of illiteracy among small-scale growers, such practices go undetected. Moreover, mills are also known to make undue deductions contending that sugarcane quality is low and contains high trash content.

Source: adapted from Rafi Khan *et al.* (2007).

cooperatives in which farmers also hold ownership shares in the factory (ICRISAT, 2007). The South African sugar industry distinguishes itself by operating a successful small-scale outgrower scheme, which supplies 11 percent of the country's sugarcane under contract farming arrangements to one of the three major mills (Cartwright, 2007).

The need for economies of scale to increase competitiveness constitutes a pressure to reduce costs. The main mechanisms for doing this – introduction of improved varieties, switch away from diversified production systems to monocropping, move to larger land holdings, and shift to increasingly capitalised production - are difficult or risky for small producers. For example, in Brazil, selection of improved cane varieties (e.g. energy cane) and investment in irrigation have helped to improve yields but the benefits of these have mostly been felt on plantations. Other mechanisms, such as increasing labour productivity without increasing wages, are likely to be detrimental to poor households (Peskett *et al.*, 2007). This presents a serious challenge to identifying pro-poor biofuels production systems.

Analysis by a UN consortium suggests that efficient clusters of small and medium-scale enterprises could participate effectively in different stages of the value chain (UN-Energy, 2007). The main challenge is how to provide appropriate policy conditions to promote value-sharing and prevent monopolisation along the chain (Dufey *et al.*, 2007b). Controlling value-added parts of the production chain 'is critical for realising the rural development benefits and full economic multiplier effects associated with bioenergy' (UN-Energy, 2007). In countries such as Thailand policy interventions are addressing the sharing of the earning between sugarcane growers and producers (70% and 30%, respectively). However, for bioethanol manufactured directly from sugarcane juice, producers argue the Government has to come with a better agreement as they have to invest on bioethanol plants (Gonsalves, 2006b).

At the international level this implies that the biofuels value chain must shift to the countries that produce the feedstock.

Overall, economies of scale are important and small-farmers will need to adapt and get organised towards that direction. Challenges and difficulties will be confronted and more research is needed to understand the role partnership schemes (Dufey *et al.*, 2007b).

3.4. Landlessness and land rights

The strength and nature of land rights are key determinants of patterns of land ownership under biofuel production. As the above point suggests, the need of costs reduction offers considerable incentives for large-scale, mechanised agribusiness and concentrated land ownership. This is turn can displace small farmers and other people living from the forests and depriving them from its main source of livelihoods. This may have devastating effects on rural poverty. Indeed, the primary threat associated with biofuels is landlessness and resultant deprivation and social upheaval, as has been seen for example with the expansion of the sugarcane industry in Brazil (Worldwatch Institute, 2006; Dufey *et al.*, 2007b) which is summarised in Box 4. Johnson and Rosillo-Calle (2007) also highlight land related problems in the African context, where the high proportion of subsistence farming and complexities of land ownership under traditional land regimes make large acquisition of land, for large-scale sugarcane operations, a highly controversial issue.

Box 4. Access, ownership and use of land in Brazil.

Biothanol production in Brazil has inherited problems faced by the sugar industry over the last 50 years, including violent conflict over land between indigenous groups and large farmers. Problems stem from weak legal structures governing land ownership and use which have increased land concentration, monoculture cropping and minimisation of production costs. Land occupation planning is carried out at municipal level, but not all municipalities have developed guidelines governing monocultures. Land concentration in Brazil is very high, with only 1.7% of real estate covering 43.8% of the area registered. Land concentration and subsequent inequality is increasing with expansion of monocropping areas, reduction of sugar mill numbers, growth in foreign investment and land acquisition. The need of economies of scale for efficient sugarcane production in part drives these effects.

Source: adapted from Peskett *et al.* (2007).

Rossi and Lambrou (2008) note some gender-differentiated risks. Marginal lands are particularly important for women. The conversion of these lands to energy crops might cause displacement of women's agricultural activities towards increasingly marginal lands, with negative effects in their ability to meet household obligations. This highlights the urgent need of a careful analysis of what the concept of 'marginal', 'idle' or 'unproductive' lands really entails. It is in these lands where most government are mandating biofuels to be grown.

3.5. Quality of the employment

Sugarcane bioethanol will generate a range of employment opportunities, mostly in rural areas, which is certainly good for poverty reduction. However there are limitations and trade-offs. Firstly, there is concern about the quality of employment, whether self-employment (small-scale farmers) or employment within large-scale operations (Worldwatch Institute, 2006; UN-Energy, 2007). Sugarcane harvesting is extreme physically demanding. Production is highly seasonal and, in Brazil, for example, the ratio between temporary and permanent workers is increasing. Low skilled labour dominates the industry and a high rate of migrant labour is employed. In southern Africa the sudden influx of seasonal workers has had negative effects on community cohesion, causing ethnic tension and disintegration of traditional structures of authorities. Migrants behaviour is also linked with higher rates of HIV infection around sugarcane plantations (Johnson and Rosillo-Calle, 2007).

Whilst over the latest years in some plantations in Brazil improvements in working conditions have been done, in other plantations, sugarcane cutters continue to work in appalling conditions. Cases of forced labour and poor working conditions within the sector are still reported (Oxfam, 2008). Other problems include a lack of agreed or enforceable working standards in many countries, and lack of labour representation (Dufey *et al.*, 2007b).

Moreover, compared to other feedstocks (e.g. palm oil, castor oil, sweet sorghum) sugarcane is less labour-intensive and thus provide less on-farm and off-farm employment (Dufey *et al.*, 2007b). The industry greater mechanisation in turn reduces labour demands. One harvester can replace 80 cutters and thus facilitate the whole harvesting process (Johnson and Rosillo-Calle, 2007). In Brazil mechanization of sugarcane harvesting has been driven by increasing labour costs and more recently by legislation to eliminate sugarcane burning. Total employment in the industry decreased by a third between 1992 and 2003 (ESMAP, 2005b). Indeed sugarcane related unemployment is expected to become the key social challenge faced by the sugarcane industry in Brazil (Dufey *et al.*, 2007a). This can have devastating effects on poverty levels as it is unemployment among the lower-skilled workers.

In order to balance trade-offs between environmental needs, mechanisation and unemployment, Johnson and Rosillo-Calle (2007) propose the use of half-mechanisation which was successfully used in Brazil as a transition towards full mechanisation. It consists in mechanical aid for the harvesting, in which a machine is used for cutting the cane and workers are used to gather the crops. As the cutting of the cane is the hardest part physically, the authors argue this system would also contribute to opening up the labour force for women.

All in all, although recognising that many of the above mentioned issues are not exclusive for sugarcane bioethanol, employment generation that leads to effective poverty reduction requires addressing these problems.

3.6. Government support

Experience suggests the biofuels sector requires some form of policy support, at the very least in the initial phases development. Even Brazil, the most efficient biofuel producing country, still maintains a significant tax differential between gasoline and hydrous ethanol to promote the sector (ESMAP, 2005b) and fixes a mandatory blend (between 20% to 25%). More generally, the PROALCOOL programme in the past required heavy support. Between 1975 and 1987 it produced savings for US$ 10.4 billion but it costs were US$ 9 billion (World Watch Institute, 2006). Moreover, with falling oil prices, rising sugar prices, and a national economic crisis the programme simply became too expensive and collapsed by end of 1980s.

In many countries, the main rationale behind biofuels production is to decrease the costs associated with imported fossil fuels. Among the costs of such a policy that need to be accounted is the foregone duty on fuel imports, which results in a decline in government revenues. For instance, in Brazil, the forgone tax revenue in the state of São Paulo, which accounts for more than one-half of the total hydrous ethanol consumption in the country, was about US$ 0.6 billion in 2005 (ESMAP, 2005b). In many developing countries a substantial portion of public revenues are derived from import duties. In addition, the diversion of sugar exports for bioethanol production for domestic markets means that countries may suffer reductions in their export earnings. All these pose significant challenges in poorest countries, where there are a multitude of urgent needs competing for scarce fiscal resources.

Another issue is that once granted and the biofuel industry has been launched, subsidies are difficult to withdraw. A major challenge to reduce policy support is the vested interests created in the domestic industry (Henniges and Zeddies, 2006).

On the other hand, the existence of contentious domestic policies and practices can undermine industry development. For instance, Rafi Khan *et al.* (2007) and Gonsalves (2006a) report the negative effects on bioethanol development of policy measures such as a high central excise duty and sales tax on alcohol that exist in Pakistan and India, respectively. The lack of policy provenance - reflected by the fact that the Pakistani government directed the Petroleum Ministry (who houses the oil lobby) to develop the bioethanol conversion plan also constitutes an additional policy constraint. Pricing issues - whether to use bioethanol international price or its cost of production - can also affect industry development (Rafi Khan *et al.*, 2007).

All the above suggest the promotion of a sugarcane bioethanol industry can become very expensive, not only due to the high up front investments that are required but also due to the financial resources that are needed to make it viable in the long term.

From a poverty reduction strategy point of view this means that governments should design their sugarcane bioethanol policies so as to reach the desired target group. As ESMAP (2005b) notes, resources that flow to agriculture all too often benefit politically powerful, large producers and modern enterprises disproportionately at the expense not only of the society as a whole, but of those that are supposed to be the main beneficiary group: smallholder farmers and landless workers. Examples include untargeted producer subsidies and distortionary subsidies for privately used inputs such as water and electricity. According to the same source, promoting biofuels for energy diversification can make sense if large government subsidies are not required. However, UN-Energy (2007) holds the view that if the large subsidies are targeting small producers this may be money well spent. Governments tend to get higher returns on their public spending by fostering small-scale production due to the lowered demand for social welfare spending and greater economic multiplier effects.

Overall, governments need to conduct a careful assessment of the pros and cons of promoting sugarcane bioethanol to support poor rural communities versus those of other alternatives. Similarly, from a climate change mitigation strategy, although sugarcane bioethanol may show the greatest greenhouse reductions compared to other first generation feedstocks, these should be assessed against the costs of other policy instruments to achieve the same goal.

3.7. Market access and market entry barriers

The strategic nature of bioethanol implies the existence of some degree of protectionism in almost any producing country. Protectionism is especially acute where energy security is equated with self-sufficiency or where biofuels are promoted to help domestic farmers in high-cost producing countries (Dufey *et al.*, 2007b). The use of tariffs to protect domestic biofuel industries is a common practice and, as Table 1 shows, these can be very high. However, these tariffs are only indicative as their actual level applied vary widely as both the European Union and the United States have trade agreements providing preferential market access to several developing countries. In particular, the extra US$ 0.14 to each litre (US$ 0.54 per gallon) of imported bioethanol on top of the 2.5 percent tariff applied by the United States, it is said to be targeting Brazilian imports as it brings the cost of Brazilian bioethanol in line with that produced domestically (Severinghaus, 2005). Tariff escalation, which discriminates against the final product, can also be an issue, for example, where there are differentiated tariffs on bioethanol and feedstock such as raw molasses (Dufey, 2006).

Table 1. Import tariffs on bioethanol[1].

Country	Import tariff
US	2.5% + extra US$ 14 cents/litre (46% *ad valorem*)
EU	€ 19.2/hl (63% *ad valorem*)
Canada	4.92 US$ cent/litre
Brazil[2]	20%
Argentina	20%
China	30%
Thailand	30%
India	186% on undenatureated alcohol

Source: adapted from Dufey *et al.* (2007b)
[1] Undenaturated alcohol.
[2] Temporarily lifted in February 2006.

On the other hand, the planning of an export-oriented bioethanol industry based on the rationale of preferential market access is a risky strategy. As Box 5 suggests for Pakistan, trade preferences can be withdrawn at any time with devastating effects on the industry.

Subsidies is another key concern. In industrialised countries, government support for the domestic production of energy crops, the processing or commercialisation of biofuels seems to be the rule (Dufey, 2006). Amounts involved are enormous. In the United States, Koplow (2006) estimated that subsidies to the biofuels industry to be between US$ 5.5 billion and US$ 7.3 billion a year. In the European Union, Kutas and Lindberg (2007) estimated that total support to bioethanol amounted € 0.52/litre.

The impacts these policies have on the developing countries competitiveness and on their potential for poverty reduction needs to be understood as domestic support in these countries is likely to be very limited. Moreover, subsidies impacts on environmental sustainability are also questionable as they promote bioethanol industries based on the less efficient energy crops and with the least greenhouse gases reductions such as maize and wheat (Dufey, 2006).

The proliferation of different technical, environmental and social standards and regulations for biofuels – without a system for mutual recognition – cause additional difficulties. For instance, at present not all biofuels are perceived as 'sustainable' especially those coming from overseas. As a consequence, several initiatives towards the development of sustainability certification for both bioethanol and biodiesel have started. Some of them are led by governments (e.g. the United Kingdom, Netherlands and the European Union); others by

Box 5. The elimination of Pakistan from the EU GSP.

Until recently, Pakistan was the second largest industrial alcohol exporter to the EU after Brazil, under the General System of Preferences (GSP). In May 2005, the Commission of Industrial Ethanol Producers of the EU (CIEP) accused Pakistan and Guatemala (the largest duty free exporters for the period 2002-2004) of dumping ethyl alcohol in the EU market, causing material harm to domestic producers. The Commission dropped proceedings a year later when full custom tariffs were restored on Pakistani imports. Later, following a complaint lodged by India at the World Trade Organization (WTO), a panel concluded that by granting tariff preferences to 12 countries under this special arrangement the EU was violating GATT/WTO preferential treatment obligations. The EU consequently removed Pakistan from the GSP. In the revised GSP regime, the anti-drug system has been replaced by GSP Plus, for which Pakistan does not qualify.
Elimination of Pakistan from the GSP had devastating effects on the local industry. Distilleries begun to suffer important losses and some had no option but to cease operations. Whilst between 2002 and 2003, the number of distilleries in the country increased from 6 to 21, the more stringent EU tariff measures together with a rise in molasses exports, the distilleries were soon running idle capacities. Currently, at least 2 distilleries have shut down, with another 5 contemplating that option.

Source: adapted from Rafi Khan *et al.* (2007).

NGOs (e.g. WWF); and also by Universities (e.g. Lausanne University). These schemes tend to focus on traditional environmental and social aspects of feedstocks production, with several of them including greenhouse emission issues and with some few of them expanding to food security concerns. Although environmental and social assurance is needed in the industry, where these schemes are developed by importing nations, with little participation by producing country stakeholders, insufficient reflection of the producing countries' environmental and social priorities and without mutual recognition between them, they are bound to constitute significant trade barriers. Moreover, the experience with assurance schemes in the agriculture and forestry sector indicates that the complex procedures and high costs usually associated with them have regressive effects in detriment of small and poorest producers in developing countries. All in all, sustainability standards for bioethanol trade are to become more and more important. Countries wanting to benefit from bioethanol exports need to invest in the development of robust and credible certification systems that satisfy importing countries requirements.

Overall, it is widely agreed that developing countries would benefit from enhanced bioethanol trade and therefore the need to eliminate trade barriers.

3.8. Improving efficiency, access to technology, credit and channelling investment

The development of a successful bioethanol sector goes beyond having available land, cheap labour and good climate. It crucially depends on countries' domestic capacity to expand production efficiently, accessing the technology and assuring best practice. Indeed, Brazil's success in developing an efficient bioethanol industry is in a large extent explained by the enormous endogenous efforts devoted to R&D, capacities building and infrastructure (Dufey *et al.*, 2007a). This implies that having a number of technical skills for research, technology transfer as well as access to credit are critical issues. Moreover, those countries wanting to develop an export oriented sector also need to be in compliance with the relevant technical standards in importing markets and to invest in suitable transport infrastructure (roads, water ways and ports) to reach exports markets. Countries also need to have sufficient capacity in policy implementation and project management to run biofuels production and processing effectively (Dufey *et al.*, 2007b).

At present, many countries foresee a major participation of the sugar industry in bioenergy production. However, the current low efficiency and productivity of the sector in many of them implies that major changes to the industry's structure will be needed to make sugarcane an important feedstock (FAO, 2007). In countries where bioethanol is produced from molasses and wanting a significant scale of production, efforts will need to be made to produce from sugarcane juice, which is a relatively more efficient source of bioethanol and capable of supplying larger volumes (Woods and Read, 2005). Other specific needs include adaptive agricultural research and extension development for enhanced transfer of bioethanol technologies. Investment is also important to bring agricultural practices up to the required level of technical capacity, scale of operations, and intensity of production (Johnson and Rosillo-Calle, 2007)

4. Conclusions

Sugarcane bioethanol can contribute to the achievement of several Millennium Development Goals through a varied range of environmental, social and economic advantages over fossil fuels. The highest impact on poverty reduction is likely to occur where sugarcane bioethanol production focuses on local consumption, involving the participation and ownership of small farmers and where processing facilities are near to the cultivation fields.

Realising the greatest potential of sugarcane bioethanol on poverty reduction implies that several challenges will need to be confronted and dealing with serious trade-offs. Especially tough will be those related to efficiency gains through large-scale operations, mechanisation and land concentration versus small farmers inclusion. Economies of scale are important and small farmers will need to adapt and get organised towards that direction. Likewise, the resulting unemployment among the lower-skilled workers is a key aspect to be addressed. Whilst the domestic use of sugarcane bioethanol may imply opportunities in terms of general well-being, the increasing use of marginal land for biofuels cultivation may imply negative impacts among the most vulnerable such as women. From a poverty reduction strategy this means that governments should explicitly design their sugarcane bioethanol policies to provide the right environment to promote business models that maximises rural development, small farmer inclusion and equitable access to ownership and value along the chain. One example in that direction can be the use of tax-breaks for companies that include small producers among their suppliers, which is already being used in the context of biodiesel in Brazil through the PROBIODIESEL programme.

The impacts of sugarcane bioethanol on food security are less clear. Regarding food availability and compared to other feedstocks, sugarcane bioethanol would provide better opportunities to meet food security as long as it creates less competition for land and crowd out other crops. However, from an accessibility point of view, it would provide more limited opportunities to the extent that its production is less likely to involve small or poorest farmers. Overall, more research is needed to understand these linkages.

From an environmental sustainability perspective, compared to other first generation biofuels, sugarcane bioethanol offers opportunities to achieve one of the greatest reductions in greenhouse emissions under certain circumstances. However, available estimations need to be revised to include the emissions directly and indirectly associated with changes in land use and cover. Similarly, biodiversity impacts linked to changes in land use and cover especially those associated with the substitution effect appear as crucial environmental aspects to be addressed and more research to understand them is needed. Likewise, impacts on water, especially in the context of dry and semi-dry lands, are other key aspects that deserve better analysis. Only the adequate understanding and management of these impacts, using a life cycle approach, will help to improve the environmental sustainability of sugarcane bioethanol and thus achieving the Millennium Development Goal on environmental sustainability.

In some contexts, the promotion of a sugarcane bioethanol industry can be a very expensive means of achieving poverty reduction and promoting environmental sustainability. Governments need to conduct a careful assessment of the pros and cons of promoting sugarcane bioethanol to support poor rural communities versus those of other policy choices. Similarly, from a climate change mitigation strategy, although under certain circumstances sugarcane bioethanol shows the greatest greenhouse reductions compared to other first generation feedstocks, these should be assessed against the costs and benefits of other policy instruments for achieving the same goal.

Another crucial issue involved in realising the full potential of sugarcane bioethanol is the building of an adequate set of national capabilities on technical skills, policy implementation, project management and development of R&D programmes. These should come hand in hand with promoting access to technology, credit and finance as well as the provision of some minimum transport infrastructure. For those countries wanting to take advantages of an export oriented industry, capacities building on standard setting and compliance as well as the negotiation of favourable terms of trade constitute other key aspects.

Policy coherence is another issue. The promotion of a sugarcane bioethanol sector that contributes to sustainable development and poverty reduction should be aligned with existing relevant national and international policies and frameworks such as Sustainable Development Strategies, Poverty Reduction Strategies, Environmental and Social Impact Assessments, the Kyoto Protocol or the Convention on BiologicalBiodiversity. Coordination therefore is required among different government bodies (e.g. Ministry of Agriculture, Energy, Environment, Industry, Trade, etc.), levels and actors.

Finally, at the international level, cooperation is also crucial for the development of a sugarcane bioethanol industry oriented towards poverty reduction and environmental sustainability. South-South cooperation can play an important role in overcoming many of the technical challenges. Countries can benefit from the technical and scientific knowledge of Brazil, which is at the forefront of the industry. One example in that sense is the illustrated by the Brazil-UK-Africa Partnership for bioethanol development. International financial institutions can help, for example, by mitigating political risk for project development in developing countries. Elimination of trade barriers is another issue to be addressed by governments to enhance development opportunities associated with sugarcane bioethanol. This would be also aligned with the last Millennium Development Goal that calls to 'develop a global partnership for development'.

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Chapter 10
Why are current food prices so high?

Martin Banse, Peter Nowicki and Hans van Meijl

1. World agricultural prices in a historical perspective

World agricultural prices are very volatile which is due to traditional characteristics of agricultural markets such as inelastic (short run) supply and demand curves (see, Meijl *et al.* 2003).[13] The volatility is also high because the world market is a relatively small residual market in a world distorted by agricultural policies.[14] The combination of high technological change and inelastic demand cause real world prices to decline in the long run (trend). The prices, however, of many (major) agricultural commodities have risen quickly over recent years (see Figure 1).

Recent increase in agricultural prices are strong, but even with the increase that we have observed in the last three years, real agricultural prices are still low compared to the peaks in prices of the mid-70s. Local prices are linked with these world prices. The transmission effect depends on the transparency of markets, market power and accessibility

[13] 'World food prices are instable and will remain unstable in the future. Forecast errors are large in predictions of world prices. There are always unexpected events in important drivers such as yields which are dependent on weather, plagues and diseases' (See Van Meijl *et al.*, 2003).

[14] Trade share (2006) in global production: rice (7%), cheese (7%), coarse grains (11%) and wheat (20%), FAO Statistics.

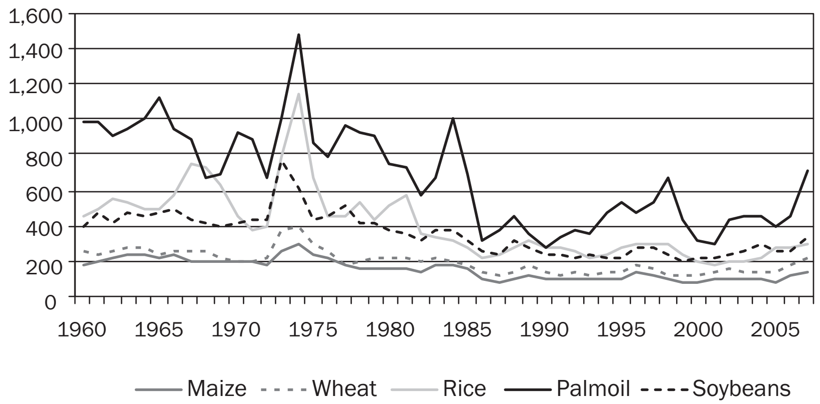

Figure 1. Development of world agricultural prices, 1960–2007, USD/ton, in constant USD (1990). Source: World Bank data base (2008).

Figure 2 depicts the price index for food commodities along with an index for the average of all commodities and an index for crude oil. Although the food commodity index has risen more than 60 percent in the last 2 years, the index for all commodities has also risen 60 percent and the index for crude oil has risen even more (see also Trostle, 2008). Since 1999 food commodity prices have risen 98 percent (as of March 2008); the index for all commodities has risen 286 percent; and the index for crude oil has risen 547 percent. In this perspective, the recent rise in food commodity prices is moderate. Figure 3 shows that spot prices in early 2008 for soybean and wheat are declining again while the spot prices for rice and crude oil continue to rise. The prices of wheat and soybeans declined by almost 30% and almost 20%, respectively, since their peak at the end of February this year.

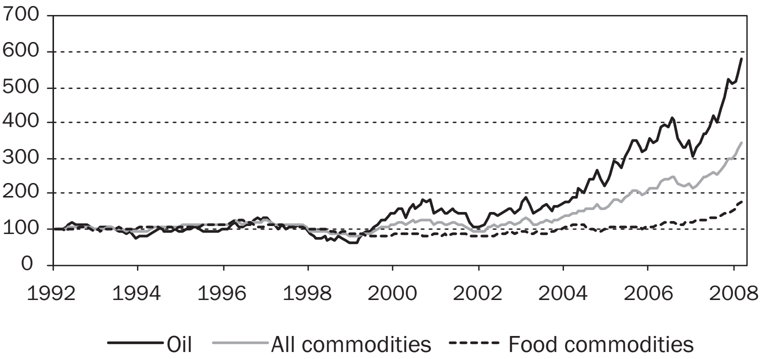

Figure 2. Index of oil, food and all commodities, 1992-2008, January 1992=100. Source: International Monetary Fund: International Financial Statistics.

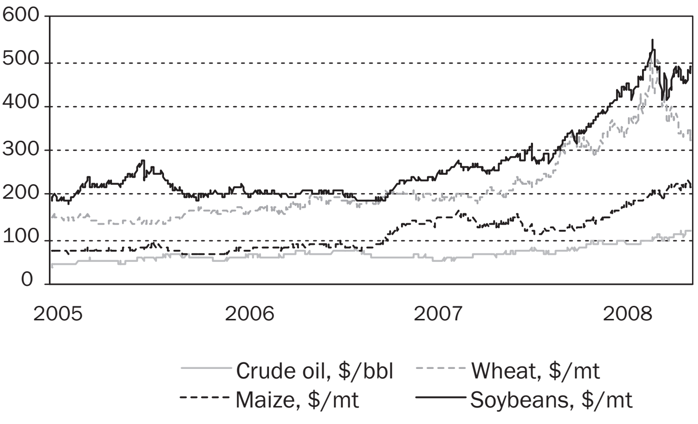

Figure 3. Daily price notations for crude oil, wheat, maize and soybeans; spot prices, 2005-2008, at current USD. Source: World Bank data base (2008) from January, 1 2005 to May, 15 2008.

However, although real food prices are not extremely high in a historical perspective and other commodities have risen more, an increase in the price of food – a basic necessity – causes hardships for many lower income consumers around the world. This makes food-price inflation socially and politically sensitive. This is why much of the world's attention is now focused on the increase in food prices more than on the more rapid increase in prices of other commodities, (see Trostle, 2008: 4).

The question on the minds of many consumers around the world is, 'Will food prices drop again this time?' Or, stated another way, 'Is the current price spike any different from those of the past, and if so, why?'

2. Long run effects

2.1. Long run drivers of demand[15]

Population and macro-economic growth are important drivers of demand for agricultural products. In past years, rapid population growth has accounted for the bulk of the increase in food demand for agricultural products, with a smaller effect from income changes and other factors (Nowicki *et al.*, 2006)[16]. The world's population growth will fall to about 1% in the coming ten years. Continued economic growth is expected over the coming period in almost all regions of the world and this driver of demand will become more important than population growth in the future (see Figure 4).

2.2. Expected population developments in period 2005-2020

- The world's population growth will fall from 1.4% in the 1990-2003 period to about 1% in the coming ten years. This is mainly due to birth or fertility rates, which are declining and are expected to continue to do so.
- Almost all annual population growth will occur in low and middle income countries, whose population growth rates are much higher than those in high income countries.
- Europe's share in world population has declined sharply and is projected to continue declining during the 21st century.
- Population growth in Europe is very low (0.3% yearly for EU-15: old EU member states) or slightly negative (-0.2% for EU-10: new EU member states).
- The uncertainty with regard to birth and death rates at world or regional level is not too large. However, migration flows between countries and regions are much more uncertain.

[15] Based on Scenar 2020 (Nowicki *et al.*, 2006).

[16] Projections for population and GDP for the EU member states are taken from a study of the Economic Policy Committee of the European Commission called 'The 2005 EPC projection of age-related expenditure: agreed underlying assumptions and projections methodologies, 2005'. The projections for the rest of the world are based on assumptions used in the OECD and USDA agricultural Outlooks.

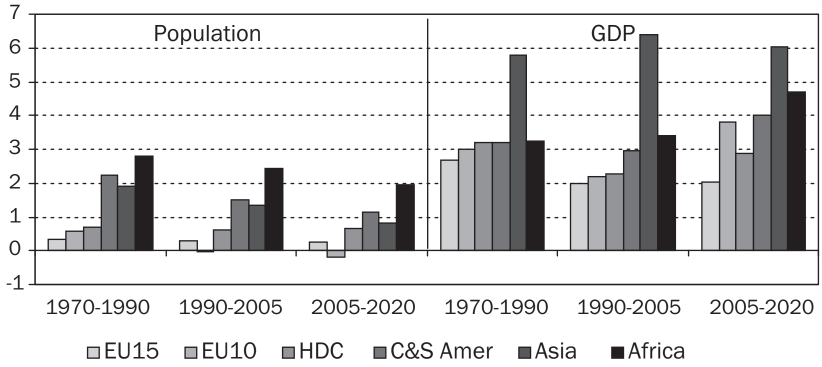

Figure 4. World population and GDP growth (annual growth %). Source: USDA for 1970-1990 and 1990-2005. Projections for 2005-2020 derived from Scenar 2020, Nowicki *et al.* (2006). HDC = High Income Developed Countries, C&S Amer = Central and South America

2.3. Global income growth

- Robust economic growth is expected over the coming period in almost all regions of the world in the baseline scenario (see Figure 4).
- Economic growth will be considerably higher for most of the transitional and developing countries than for the EU-15, the United States and Japan, in particular for Brazil, China, India and the new EU member states. Incomes in Europe are expected to increase slightly over the coming years.
- Annual income growth in Europe is about 2% for EU-15 and 3.8% for EU-10.
- World and EU economic growth in the future stays uncertain and depends on the amount of investments in education and research, on technological opportunities, on the degree of (labour) participation in the political, societal and market arenas, and on the liberalisation of world commodity and factor markets.

The robust growth of income per capita leads to more 'luxury' consumption in developed countries. This implies more convenience food, processed products (ready to eat) and food safety, environmental and health concerns. In developed countries the total amount of food consumed will only grow in a limited manner. However, in developing countries a higher income induces more consumption and a shift to more value-added products. Important is the switch from cereals to meat consumption, as an increased demand for meat induces a relatively higher demand for grain and protein feed. To produce 1 kg of chicken, pork and beef, respectively 2.5 kg, 6.5 kg and 7 kg of feed are required.[17]

[17] The numbers describe upper-bound estimates of conversion rates: 7 kg of maize to produce 1 kg of beef, 6.5 kg of maize to produce 1 kg of pork, and 2.6 kg of maize to produce 1 kg of chicken (Leibtag, 2008). Modern technology, however, require much less feed especially in pork production; here average feed conversion rates are between 3.2-2.6 kg of feed per kg of meat.

2.4 Long-term drivers of supply

With regard to grain and oilseed production, yield and area developments are important drivers of supply. Figure 5 shows that production growth was almost totally determined by yield increase while the total area harvested was more or less constant. The growth in yields declined from 2% per year in the 1970-1990 period to 1.1% in the 1990-2007 period. USDA expects the growth to decline to 0.8% per year for the period 2009-2017 (USDA, 2008). At the global scale, crop production area increased in the 1970-2007 period by 0.15% per year, and USDA expects the area to grow by 0.4% per year in the period 2007-2017.

Figure 6 shows that growth rates of yields for major cereals in developing countries are slowing. It should be mentioned that the decline in annual growth rates is not necessarily related to a decline in absolute yield growth per annum. An important explanation for the decreasing yield growth rates might be the declining public agricultural research and development spending over time in both developing and developed countries (Figure 7). Although private sector research has grown, private sector R&D is mostly cost reducing\short run oriented instead of public R&D, which is often more yield enhancing\long term oriented.

- The direct link between R&D spending and yield growth had been intensively discussed amongst agricultural scientists and is not fully clear.
- The general outcome of this discussion is that an additional growth in yield rates requires more than additional spending in capital stock but also investment in human capital stock and improvements in market institutions

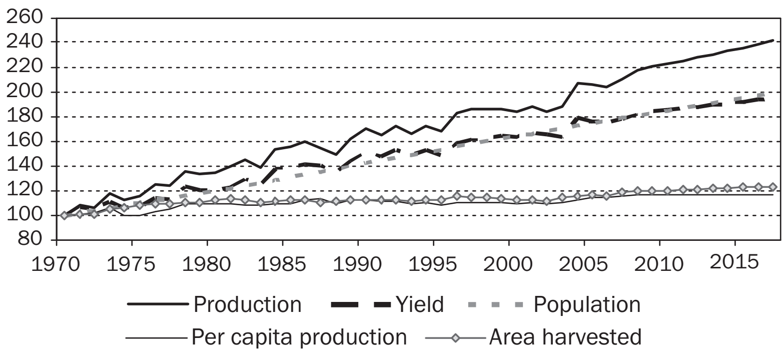

Figure 5. Development of world grain and oilseed production. Source: USDA Agricultural Projections to 2017.

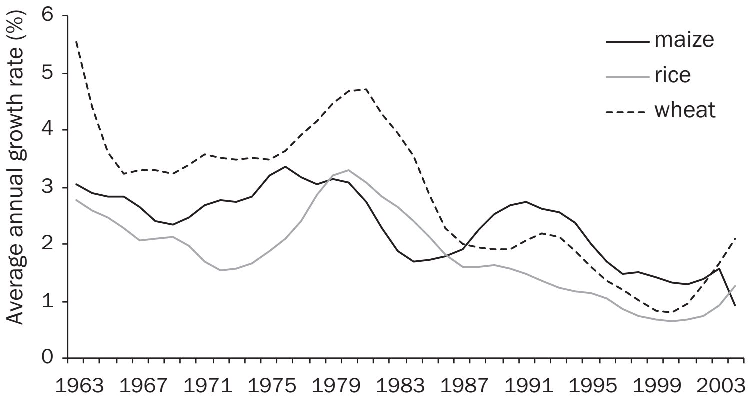

Figure 6. Development annual yields for selected cereals in developing countries. Source: World Development Report 2008.

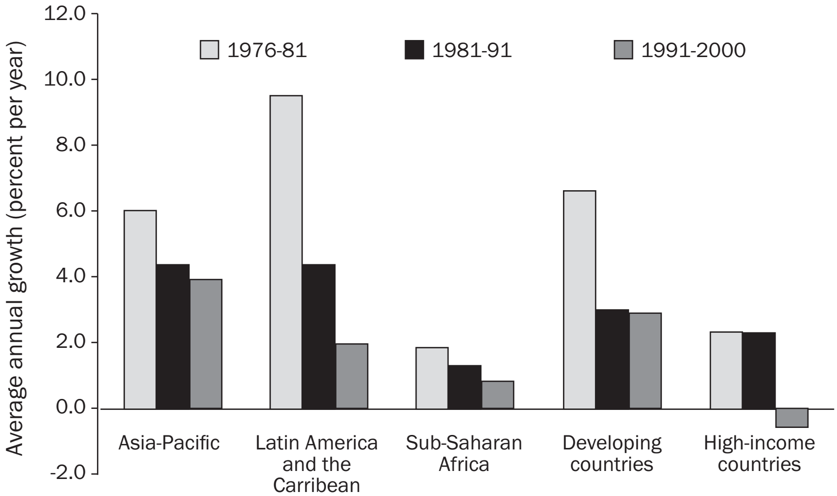

Figure 7. Public Agricultural R&D Spending Trends, 1976-2000. Source: Pardey *et al.* (2006).

3. What explains the recent increase in agricultural prices?

A combination of record low global inventory levels, weather induced supply side shocks, surging outside investor influence, record oil prices and structural changes in demand for grains and oilseeds due to biofuels have created the high prices. The question is whether it is a coincidence that the past and current high price levels coincide with high oil prices or whether other reasons for the current price peak are more important.

3.1. Effects on the supply side

As mentioned above the variation of yields due to climatic conditions, the development of input prices – fertilizer, diesel and pesticides – as well as the level of political support are the main drivers of supply. The following items provide some information on these points (Figure 8):

- Poor harvests in Australia, Ukraine and Europe for wheat and barley. According to FAO statistics, these three regions contributed on average 51% of total world barley production and 27% of total world wheat production for the period 2005-2006.
- Lower harvests in wheat and barley are more than compensated by a bumper harvest for maize worldwide.
  - Therefore, world cereal production increased in total even in 2007.
  - The bumper harvest in maize kept maize prices low and the wheat-maize spread increased significantly (Figure 3).
  - Only recently have maize prices also strongly increased.
- Higher energy prices lead to higher food prices as costs (e.g. fertilizer, processing, and transport) increase. Higher transport costs induce higher price effects as distances increase.
- CAP policies such as mandatory set-aside regulation or production quota restrained supply. Furthermore, there was a change from price to income support and compensatory payments became decoupled, set aside was introduced and export subsidies were diminished. Some of these measures limited supply within the EU. However, the general aim of the last CAP reforms was an enforcement of farmers' ability to react to market signals instead of following policy signals given by market price support. Measures

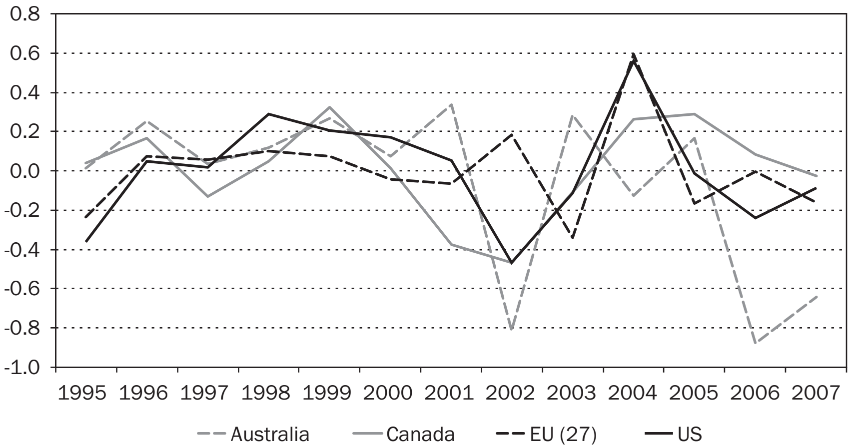

Figure 8. Deviation from trend in yields (wheat and coarse grains) in tons/ha. Source: OECD-FAO Agricultural Outlook 2008-2017 (2008).

aimed to restrict supply, e.g. production quota or set-aside requirements, are instruments designed for a world with declining prices, but which may act to reinforce prices in case of food shortages.
- Low prices in the last decades did not provide an incentive to invest in productivity enhancing technologies.

3.2. Effects on the demand side

Compared to the variability of agricultural supply, the demand of agri-food products is rather inelastic. For most agricultural commodities price and income elasticities are small, i.e. long-term demand for primary agricultural products is more determined by population growth and less by income growth. Within the last years the demand for agri-food products have been determined by the following driver:

- Constant demand in Europe and Northern America with an increase in demand in Asian countries
- Change in diet in emerging economies.
- Additional demand for biofuels:
  - 5% of global oilseed production is processed to biodiesel or is used directly for transportation.
  - 4.5% of global cereal production is used for ethanol production.
  - Therefore, this marginal extra demand triggered the markets.
  - However, biofuels are not new. Ethanol based on sugarcane exists in an economically profitable way in Brazil for a long time.
  - Increasing food and feedstock prices make biofuels less profitable and food more profitable. This shifts production back to food (in US is this already visible; Trostle, 2008, p.17). With current high prices for soybeans in the US margins for biodiesel became already negative and the biodiesel production slowed down [see presentation of Gerald A. Bange (USDA) on the Agricultural Markets Roundtable held April 22, 2008 Washington, DC at the Commodity Futures Trading Commission].

The development of both – supply and demand side – contribute to the development of stocks which is illustrated in the following Figure 9. The trend of a declining stock to use ratio as has increased and stocks for wheat are currently running on empty. This implies that all the shocks mentioned above could not be mitigated by using stocks but lead immediately to price increases. Furthermore, it enabled speculation (with stocks available there would have been less room for speculation)

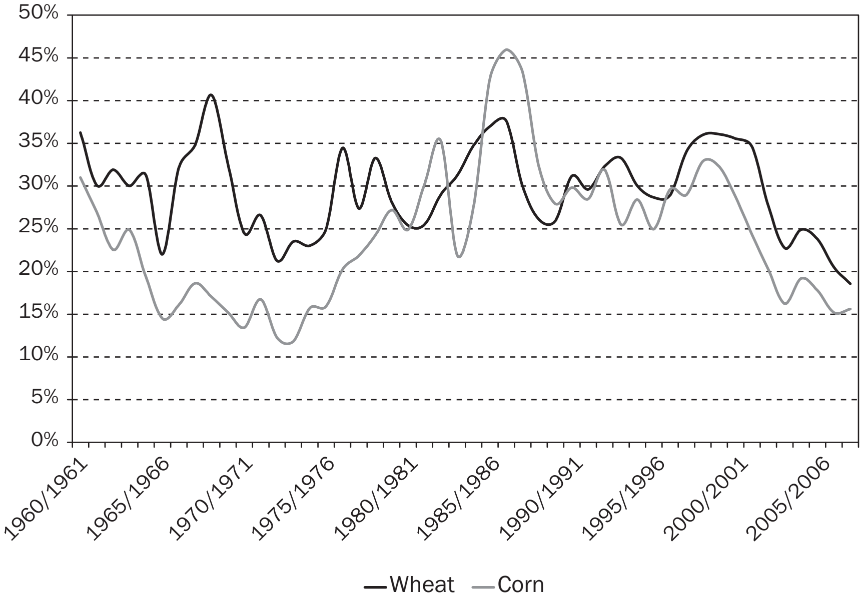

Figure 9. Development of stock to use ratio, 1960-2007. Source: US Department of Agriculture PSD View database, June 2008.

3.3 Policy responses to rising food prices

- The rapidly increasing world prices for food grains, feed grains, oilseeds, and vegetable oils are causing domestic food prices at the consumer level to rise in many countries. In response to rising food prices, some countries are beginning to take protective policy measures designed to reduce the impact of rising world food commodity prices on their own consumers. However, such measures typically force greater adjustments and higher prices onto global markets.
- In the fall of 2007, some exporting countries made policy changes designed to discourage exports so as to keep domestic production within the country. The objective was to increase domestic food supplies and restrain increases in food prices. Table 1 depicts a partial list of these policy changes.

Table 1. Policy responses to rising food prices.

Eliminated export subsidies:

China eliminated rebates on value-added taxes on exported grains and grain products. The rebate was effectively an export subsidy that was eliminated.

Export taxes:

China, with food prices still rising after eliminating the value-added tax rebate, imposed an export tax on a similar list of grains and products.

Argentina raised export taxes on wheat, maize, soybeans, soybean meal, and soybean oil.

Russia and Kazakhstan raised export taxes on wheat.

Malaysia imposed export taxes on palm oil.

Export quantitative restrictions:

Argentina restricted the volume of wheat that could be exported even before raising export taxes on grains.

Ukraine established quantitative restrictions on wheat exports.

India and Vietnam put quantitative restrictions on rice exports.

Export bans:

Ukraine, Serbia, and India banned wheat exports.

Egypt, Cambodia, Vietnam, and Indonesia banned rice exports. India, the world's third largest rice exporter, banned exports of rice other than basmati, significantly reducing global exportable supplies.

Kazakhstan banned exports of oilseeds and vegetable oils. Early in 2008, importing countries also began to take protective policy measures to combat rising food prices. Their objective was to make high-cost imports available to consumers at lower prices. A partial list of policy changes follows.

The following countries reduced import tariffs:

India (wheat flour).

Indonesia (soybeans and wheat; streamlined the process for importing wheat flour).

Serbia (wheat).

Thailand (pork).

EU (grains).

Korea and Mongolia (various food commodities)

Subsidizing consumers:

Some countries, including Morocco and Venezuela, buy food commodities at high world prices and subsidize their distribution to consumers.

Other decisions by importers:

Iran imported maize from the United States, something that has occurred rarely – only when they could not procure maize elsewhere at reasonable prices.

The policies adopted by importing countries also changed price relationships in world markets. Their policy changes increased the global demand for food commodities even when world prices were already rapidly escalating.

Source: Trostle (2008).

3.4. Other effects

- USD exchange rate developments. World prices are denominated in dollars and the dollar depreciated against most currencies. The increase in prices in other currencies is therefore much less.

Speculation:

- In recent months spot and future prices do not fully converge.
- Future prices remain higher than prices on spot markets.
  - Reason for this development:
    - Most hedging (90%) is Index-hedging, i.e. 'traditional' short- and long hedging does not dominate the price development in the future markets.
    - Thus, if everybody expects high prices, then future prices tend to be higher than the spot prices.
  - So, part of current high prices can be attributed to this 'bubble'.
- Difficult to estimate the impact of speculation in this story.
  - The crises on the financial markets are diverting funds away from traditional financial institutions leading to a large pool of funds available for investments in other markets.
  - There is definitely a impact of speculation in current high prices
  - Hard to say it makes X %.
  - Growing volatility in food markets due to the fact that most of hedging is based on index funds and not anymore on the 'traditional' short and long hedging. This share is less than 10% in total market volume.
  - An example for the current volatility: In the 1st week of March the fluctuation of maize prices was more than 150 USD/t, which is more than last year's average maize price!
- Impact of speculation on current spike in agricultural prices is difficult to quantify. Figure 10 shows the composition of the maize futures markets broken down between commercial merchants, managed money funds and commodity index traders together with the price development in USD per bushel of maize (right-hand scale).
  - It clearly shows that not only the 'speculative' index and fund hedging but also the increase in short futures by commercial merchants contributed to the dramatic increase in maize future prices.
  - However, the managed money funds which are mostly pension funds – which diversify their portfolio now also to agricultural commodities – cut down their purchase of additional contracts on long position when prices increased dramatically (Figure 10).
  - A formal assessment is hampered by data and methodological problems, including the difficulty of identifying speculative and hedging-related trades.

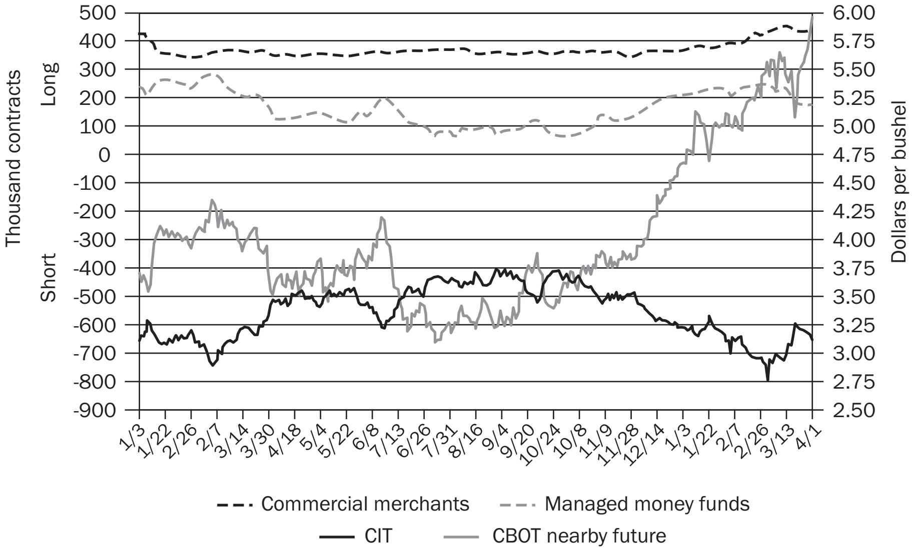

Figure 10. CBOT Corn Market Composition January 2007 – April 2008. Source: Derived from a presentation of Dave Kass at the Agricultural Markets Roundtable held April 22, 2008 Washington, DC at the Commodity Futures Trading Commission.

- A number of recent studies seem to suggest that speculation has not systematically contributed to higher commodity prices or increased price volatility.
  - › For example, a recent IMF staff analysis (September 2006 World Economic Outlook) shows that speculative activity tends to respond to price movements (rather than the other way around), suggesting that the causality runs from prices to changes in speculative positions.
  - › The Commodity Futures Trading Commission has argued that speculation may have reduced price volatility by increasing market liquidity, which allowed market participants to adjust their portfolios, thereby encouraging entry by new participants.

4. First quantitative results of the analysis of key driving factors

- OECD Outlook 2007-2017: The OECD performed some scenarios to see the impact of various drivers on their Outlook projection (OECD-FAO, 2008). This analysis highlights the outcome of a situation where biofuel policies are in place under the reference scenario and different assumptions are moderate, e.g. income growth, development of crude oil prices, etc.:
  - – If biofuel production stays at its 2007 level, then world wheat prices would be 5% lower, maize 13% lower and vegetable oil 15% lower compared to the reference scenario where biofuel production in 2017 more than doubles relative to the 2007 level.

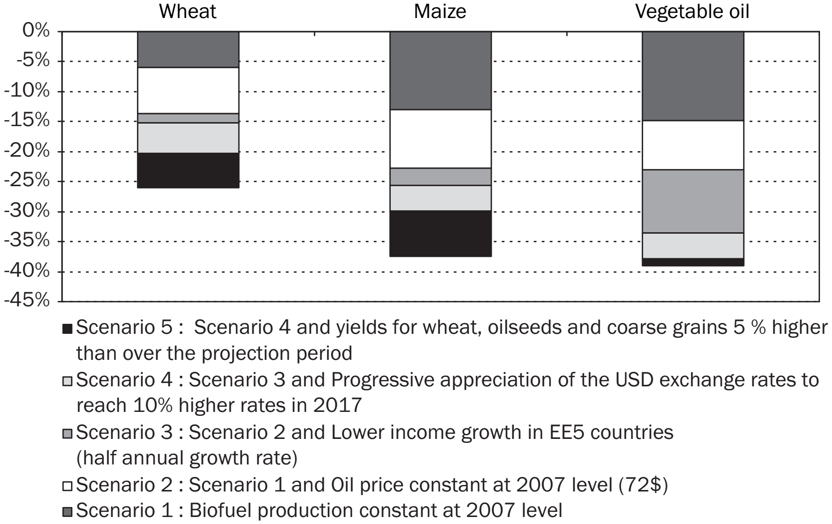

Figure 11. Sensitivity on analysis of world price changes. Source: OECD-FAO Agricultural Outlook 2008-2017. Highlights. (2008).

- A constant crude oil price implies 10% lower prices for all three commodities, due to the fact that the assumed high crude oil price under the reference scenario will make biofuel crops more profitable.
- Lower income growth is especially relevant for vegetable oils (more than 10%).
- A stronger US dollar of 10% leads to about 5% lower prices for wheat, maize and vegetable oil relative to the baseline.
- Higher growth rates in yields for important biofuel crops will lower the world market prices for their production by more than 5% for wheat and maize.

These results are inline with our own results on the impact of biofuel policies, which are presented in Figure 12.

- International Food Policy Research Institute (IFPRI) study (e.g. Von Braun *et al.*, 2008).
  - The percentage contribution of biofuels demand to price increases from 2000-07 is the difference between 2007 prices in the two scenarios, divided by the increase in prices in the baseline from 2000-2007.
  - The increased biofuel demand between 2000 and 2007, compared with previous historical rates of growth, is estimated to have accounted for 30 percent of the increase in weighted average cereal prices during 2000-07.
    - Maize – 39%.
    - Rice – 21%.
    - Wheat – 22%.

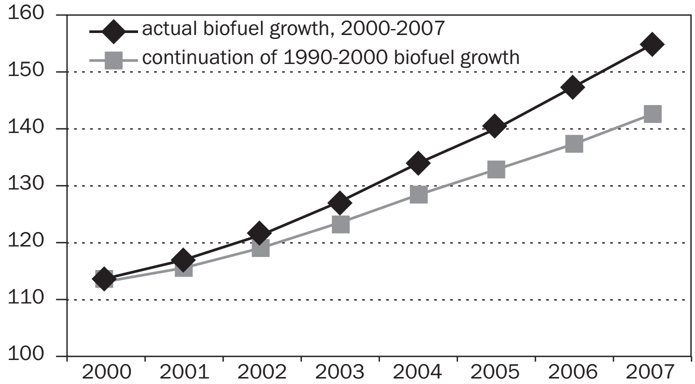

Figure 12. Biofuels: Impact on world cereal prices since 2000. Source: Impact Simulations 2008. IFPRI.

- Rapid growth in biofuel demand has contributed to the rapid rise in cereal prices, but it has not been a dominant driving force in the 2000-07 period, except perhaps in the case of maize.
- The fundamentals of supply and demand seem to be playing more of a role in the rapid increase in prices during this period, especially for commodities like rice and wheat.
- After 2007 prices increases – for rice in particular – seem to be driven by the relatively 'thin' nature of the rice market with a limited amount of international trade compared to total production.
- Unilateral trade policy actions of individual Asian countries, which have sought to put into place export bans and import subsidies for rice.
- Speculative trading and storage behaviour; private operators taking advantage of opportunities.

- Agri-Canada quantified the impact of all the policy responses (Figure 13). The impact of policies added a few percent for almost all commodities, except for rice where the impact is substantial (16%).

Experts are pointing out that it is hard to quantify the separate impacts. The contribution of biofuel demand to the increase in average cereal prices of 30% presented by IFPRI was criticized by some colleagues. Some find it too high, other too low. However, all studies point out that a combination of factors was responsible for the rise. The analyses of OECD, FAPRI and also of Banse *et al.* (2008a,b) indicated that the impact on world price levels is commodity specific. For maize the impact is relatively high due to the fact that most US ethanol production is maize-based. For other cereals – e.g. wheat and rice, where the use for biofuels is almost zero – only indirect effects over the land use affects the world price level. For those commodities an estimated increase of 30% – as indicated in the IFPRI estimates – seems to be rather high.

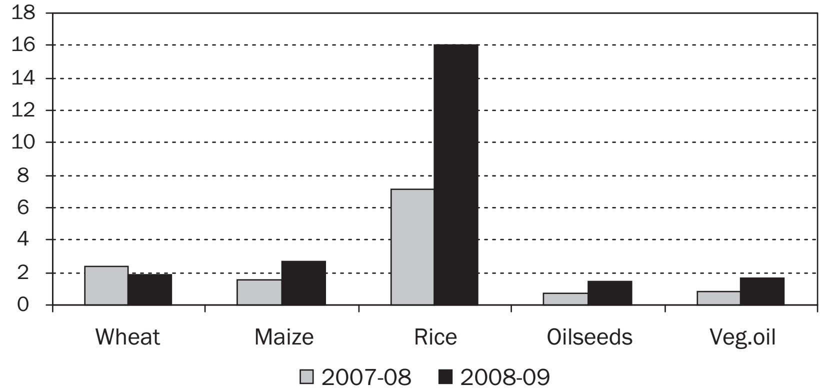

Figure 13. Impact of export restriction policies on world prices. Source: Agriculture and Agri-Food Canada, unpublished.

5. The future

After the discussion of those driving elements which contributed to the current spike in food prices this section depicts some elements which might contribute to the long-term development of agri-food prices. This sections also allows to identify possible solutions for the current crisis on world food markets.

- High prices are their own worst enemy. Increased profit margins entice entrepreneurial investment, which results in increased production. Lower market prices inevitably follow. The 'invisible hand' of Adam Smith ensures that winners' gains and losers' losses will be temporary, as entrepreneurs correct market imbalances. In the USA, in the 2008 spring planting farmers are shifting from maize to wheat and soybeans, setting the prices of the latter on a downward trajectory and stabilising the price of the former.
- Higher prices induce more production as planted areas increase and available arable land will be used more intensively. Therefore, the current situation is not structural and as a result prices will go down again. However, first stocks have to be built up again. Both effects take some time. In Brazil and Russia there are ample opportunities as additional land can be taken into production, whereas in many other countries production can only be higher due to intensification. According to USDA analyses, Russia, Ukraine and Argentina can become one of the world's top grain exporters.
- R&D investments in agriculture (e.g. yields, etc.) become more profitable with higher food prices.
- Strategic stocks are essential to limit price volatility in world agricultural markets, but they are costly.
- The expected impact on world prices of the 10% EU-biofuel directive and the various global biofuel initiatives is depicted in the graph below (Banse *et al.*, 2008a,b). If all initiatives are implemented together and technological change stays on the historic trend,

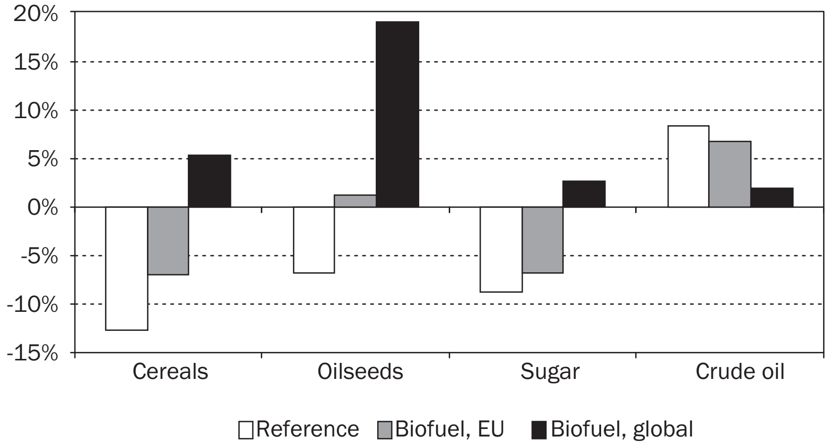

Figure 14. Change in real world prices, in percent, 2020 relative to 2001. Source: Banse *et al.* (2008a,b).

then the impact on world prices is substantial and the long term trend of declining world prices in the reference scenario might be dampened or reversed. The arrival and impact of second generation biofuels is uncertain. According to Banse *et al.* (2008a,b), biofuels lead to higher agricultural income, land use and land prices, and a loss of biodiversity.

Development of oil prices is crucial for the development of biofuels. Some experts point that prices stay high due to increased demand in Asia and depleting supply resources. Others indicate that this is a temporary situation as capacity is lacking at the moment due to too few investments in the past. If oil prices stay high, food and energy markets will be more interlinked. The oil prices will then put both a floor and a ceiling[18] for prices in the food markets (Schmidhuber, 2007). As energy markets are more elastic, the long-term trend of food prices might be changed (less negative to positive dependent on development oil price).

- High feedstock prices make biofuels less profitable (ceiling effect), as does a low oil price (floor effect). Even at current level of crude oil prices of 120 USD per barrel almost no biofuels are economically viable without policies. A low oil price implies that only biofuels will be produced under mandates or that they are heavily subsidized. Without an increase in oil prices the impact of biofuels is therefore limited to the impact of filling the mandates.

[18] Ceiling price effect: as feedstock costs are the most important cost element of all (large scale) forms of bioenergy use, feed stock prices (food and agricultural prices) cannot rise faster than energy prices in order for agriculture to remain competitive in energy markets. Floor price effect: if demand is particular pronounced as in the case of cane-based ethanol, bioenergy demand has created a quasi intervention system and an effective floor price for sugar in this case.

- The interrelation with the energy markets may slowdown or reverse Cochrane's treadmill or Owens development squeeze which imply declining real agricultural prices, less farmers, larger scale farming and possible depopulated areas.
- Volatility of world prices might be an important problem in the future that causes hunger in terms of very high prices for poor consumers and problems for poor farmers when prices are low. The ceiling and especially the floor may act as an intervention price in case of very volatile prices. A floor may also stimulate agriculture in the (poor) world. Hunger is not a problem directly related with biofuels but often of bad policies, and improperly functioning factor and commodity markets.[19] In principle, there is enough food in the world but there is a distribution problem.
- Rising food commodity prices tend to negatively affect lower income consumers more than higher income consumers. First, lower income consumers spend a larger share of their income on food. Second, staple food commodities such as maize, wheat, rice, and soybeans account for a larger share of food expenditures in low-income families. Third, consumers in low-income, food-deficit countries are vulnerable because they must rely on imported supplies, usually purchased at higher world prices. Fourth, countries receiving food aid donations based on fixed budgets receive smaller quantities of food aid. A simplified comparison of the impact of higher food commodity prices on consumers in high-income countries and on consumers in low-income, food-deficit countries illustrates these differences (see Table 2).

[19] AG assessment (2008), 'Policy options for improving livelihoods include access to microcredit and other financial services; legal frameworks that ensure access and tenure to resources and land; recourse to fair conflict resolution; and progressive evolution and proactive engagement in Intellectual Property Rights (IPR) regimes and related instruments.'

Table 2. Impact of higher food commodity prices on consumers' food budgets.

	High income countries	**Low income, food deficit countries**
Initial situation		
Income	€ 40,000	€ 1,000
Food expenditure	€ 4,000	€ 500
Food costs as % of income	10%	50%
30% increase in food prices		
New costs for total food expenditure	€ 5,200	€ 650
Food costs as % of income	13%	65%

This illustrative comparison shows that for a consumer in a high-income country a 30-percent increase in food prices causes food expenditures to rise 3 percent (€1,200), while for a consumer in a low-income country food expenditures increase by 15 percentage points.

6. Concluding remarks

The motivation at the origin of this chapter can be summarised in four questions:

- Is the current price increase driven by real or monetary issues (notably a speculation phenomenon)?
- Are natural resource and basic food commodity prices linked together?
- Is the shortfall in production also linked to governance issues that limit investment and production?
- To what extent is the underused capacity in land and man-power a result of lack of investment capacity, both at the micro level (tools and seed) and at the macro level (storage and transportation infrastructure)?

The work on these questions allows the formulation of responses, and also some broader observations. From our work it is clear that the price increases have several roots and that a normally functioning market will in time provide a certain degree of corrective action. But policy/political decisions can prevent the market from doing so. In any case, the time lapse for the market to act does not remove the acuity of the price distortion that affects the poorest people, and urgent intervention is necessary to alleviate the effects of short-term price peaks.

Natural resource prices *lead* basic food commodity prices; the rate of growth of the former has historically been (and is again at present) higher than the latter. Biofuels create a more direct link between food and fuel prices, if fuel prices are high: the long-term trend of declining real food prices might be dampened or reversed.

The influence of policy/political decisions mentioned above is certainly present when considering why production in many countries is below the potential capacity to produce food. Not only has land been voluntarily removed from production in some cases, but the access to technology and markets is sometimes also limited by factors that are strictly in the realm of governance. But then there are also potential producers, who simply can not make it into the market, and they can be assisted through micro-credit or through the donation of tools, seeds and the development of irrigation, storage capacity and transportation facilities to integrate into market structures.

Our further observations are of several orders, and theses are with regard to policy implications, market failure, social equity, and required policy action.

6.1. Policy implications

With regard to the EU, CAP reform was designed to enforce farmers' reaction to market signals. There should be no surprise, therefore, when farmers do, and therefore production falls close to the level of world demand. The problem, however, is the time lag between the demand in the market and a farmer's decision on what – and how much – to plant. There is always some degree of 'inadequate' response on the supply side. Around the world, farmers are now responding to price signals and are increasing their production of cereals. Building up and managing stocks is not the primary responsibility of farmers, and in a free market this is left to traders; some government intervention might be considered, but a return to automatic intervention based solely on commodity prices should be absolutely avoided!

6.2. Will current price level persist?

High prices can only 'cured' by high prices. This may initially seem to be a provocative statement, but the simple fact is that – as stated above – farmers do react to price signals. So do all the other agents in the economy, including speculators! The food price 'crisis' will certainly be prolonged through protective measures by national governments, although the issue of civil stability may encourage some governments to take such actions, to reassure their populations that 'something is being done'. Biofuels, however, create a more direct link between food and fuel prices and if fuel prices increase further, the long-term trend of declining real food prices might be dampened or reversed.

6.3. Who is mostly affected?

The consumers of food in low-income countries with food and energy deficits are those who will suffer most in any sudden or rapid price shift for basic commodities, of which foremost is food. In principle, current high prices provide additional income opportunities for farmers. Whether farmers in developing countries will benefit from current high prices on world food markets remains questionable and depends on the degree of integration of regional in global food markets. But if there is no structural market failure involved *per se*, as stated above, then this means that the conditions of productivity and market access are the priorities that have not been addressed successfully for a long period of time *before* a price crisis occurs.

6.4. Required policy action

Short-term action is to urgently increase spending on food aid (which has gone down during the last years). Long-term production capacity improvement (including publically financed agricultural research) is essential to avoid repeated price crises. The current crisis is not a crisis in terms of shortage of food, but a crisis in terms of income shortage (in terms of purchasing power and of investment potential to increase productive capacity). Policy measures should enable especially the poor to be able to participate in the economy, and therefore for the poor countries to generate income within a world market.

Acknowledgements

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