Techno-economic analysis of Bio-alcohol production in the EU: a short summary for decision-makers

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FOREWORD

This paper has been prepared by IPTS in order to summarize in a short and concise document the crucial facts related to the elaboration, distribution and marketing of bio-alcohol as transportation fuel. It includes analyses related to the barriers hindering a deeper market penetration of this energy carrier, with particular emphasis on fiscal instruments.

The paper intends to be used to inform and foster the debate among the actors involved, in particular in view of the forthcoming Directive on Bio-Fuels promoted by DG TREN.

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SUMMARY

ABSTRACT

This report aims at presenting in a relative condensed format the crucial facts relative to the bioethanol technique. It is meant for the reference of non-technical decision makers that require an overview of the techno-economic characteristics of this emerging approach towards a more sustainable transportation system.

Data have been extracted from a number of different sources. A basic reference for the techno-economic analysis has been the Institut National de la Recherche Agronomique-France and Teagasc Crops Research Centre-Ireland, but several other sources have been used also. These data have been gathered and harmonized for sake of comparability, and processed to provide an overview of the techno-economic of bioethanol in section 2.

Several issues may be highlighted:

- Due to the cost structure of bioalcohol production, its competitiveness mainly depends on the price of the biomass feedstock and processing costs.
- Technological improvements may contribute to increase the market penetration possibilities of bioethanol, but a mature bioethanol economic sector is conditioned by a stable and low cost feedstock supply.
- The competitiveness of bioethanol also depends on the evolution of the prices of mineral fossil fuels.
- Two of these parameters are highly volatile and difficult to predict: feedstock and fuel prices. Policies to ensure price stability should be endeavored to favor a deeper penetration of bioethanol crops.
- Technology developments on lignocellulosic feedstock processing may be key in order to achieve bioalcohol cost competitiveness against fossil fuels.
- Bioethanol blends, mixing bio-fuel and mineral fossil fuel are a viable way to foster a less carbon-intensive automotive sector.
- In the long-run, however, and considering the agricultural yields, bioethanol is likely to be able to supply a two-digit percentual share of the European automotive transportation needs.

1. TECHNICAL FUNDAMENTALS

1.1. WHAT IS BIOALCOHOL?

Bioalcohol is today probably the most used alternative transport fuel in the world. Brazil's decision to produce fuel alcohol from sugar cane, and the use of bioalcohol in USA as an octane enhancer of gasoline, among other reasons have made of transportation bio-alcohol a relatively well-developed industry.

Fermenting and distilling sugar crops, starch crops that have been converted into simple sugars or processing cellulosic biomass can produce Bioalcohols. These bioalcohols are mainly bioethanol and biomethanol.

Bioethanol can be produced from any biological feedstocks that contain appreciable amounts of sugar or materials that can be converted into sugar such as starch or cellulose. To date, the most widely used raw materials for bioethanol are sugar-cane (Brazil), maize (USA), sugar-beet and wheat (European Union). Cellulosic materials such as straw, maize stalks and wood are expected to be used as processing technology is developed. Bioethanol is mainly converted into bioETBE or used mixed with gasoline and diesel.

BioETBE (ethyl tertio butyl ether) is an additive to enhance the octane rating of petrol as a replacement to fossil MTBE (replacing lead and benzene in unleaded petrol) and reduce emissions. It is produced by combining bioethanol and isobutylene. European countries have opted for ETBE to petrol blends, whereas it is not used in Brazil and the USA.

Biomethanol can be produced from biomass and biodegradable fraction of waste and it is equivalent to methanol from non renewable resources. It offers, compared to bioethanol, a lower reduction of regulated and unregulated pollutants. It is highly corrosive and toxic, being hazardous to both people and environment. Due to these facts it is considered a less promising technology option as a biofuel and will not be included in this analysis as an alternative fuel.

Bioethanol is used mixed in different proportions with gasoline or diesel fuel. The most well known blends by volume are[1]:

1) Low fossil fuel-bioethanol blends: mixture of 5–22 per cent bioethanol with gasoline (E5–E22G) and 15 per cent bioethanol in diesel fuel (E15D). All these blends may be used in conventional unmodified engines. Brazil has employed E22G fuel blends of bioethanol successfully since the mid seventies, and in the USA bioethanol is mainly used in an average blend of 10%.

2) High fossil fuel-bioethanol blends: 85 per cent bioethanol in gasoline (E85G) and 95 per cent bioethanol in diesel fuel (E95D), both requiring engine modifications[2].

3) BioETBE may be used in blends of 10-15% in unmodified engines.

1.2. BIOETHANOL/ETBE PRODUCTION

Bioethanol is produced from the fermentation of sugar by enzymes produced from specific varieties of yeast. The most abundant sugars in agricultural crops are sucrose and glucose (the latter usually obtained from starch). Lignocellulosic materials such as straw, maize stalks and wood are potential sources of sugars.

The **technology** for the production of industrial ethanol has improved considerably, but the underlying principles remain the same: extraction of fermentable carbohydrate from feedstock, followed by fermentation and recovery of ethanol in a three-stage distillation. The organisms and enzymes for carbohydrate conversion and glucose fermentation on a commercial scale are readily available.

The most energy intensive part of the process, fermentation and recovery of ethanol, is the same for all raw materials; where the individual processes differ is in the extraction and preparation of fermentable carbohydrates. In the case of starch, the conversion to sugar is derived from enzymatic hydrolysis, which is a cheap, simple and effective process. Lignocellulosic materials are made up from cellulose components (essentially long chains of sugars, and protected by lignin). An extensive process is requires for the extraction and fermentation of carbohydrates. Enzymes required for these processes are currently too expensive for commercial use.

A further stage concerns transformation of bioethanol to **bioETBE** by addition of isobutylene (fossil fuel). This activity is carried out by the large petroleum companies, which intervene directly in the transformation process. Its use could be limited by the availability of isobutylene needed in bioETBE production.

The drawback to producing bioethanol from sugar or starch is that the feedstock tends to be expensive and demanded by other applications as well.

On the other hand, part of these costs is offset, depending on the feedstock used, by the sale of by-products. Bioethanol production process generates useful **by-products** such as vegetable animal feed (Dried Distillers Grains Soluble, DDGS) more than ever necessary now that Bovine Spongiphorm Encephalopathy has made the use of animal protein feed impossible. CO_2 released during fermentation can be captured and used as a refrigerant, in carbonated beverages or to help vegetable crops grow more rapidly in greenhouses.

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[1] Technical Study on Fuels Technology related to Auto-Oil II Programme. Final Report. December 2000.
[2] E85G has been extensively tested in light-duty flexible fuel vehicles (FFV). The vehicle has only one fuel tank and its engine can adapt automatically to the type of fuel.
E95D is used in buses in Sweden, Brazil and Mexico.

Lignin is generated as a by-product of bioethanol production process using lignocellulosic feedstocks. The lignin is a renewable solid fuel, suitable for domestic heating and district heating plants.

A list of feedstocks, including the corresponding bioethanol and bioETBE yield, is given in Table1.

Carbohydrate contents and bioethanol yields are based on data from INRA and Teagasc Crops Research Centre.

Table 1. *Bioethanol and bioETBE yields from various feedstocks and by-products.*

	Carbohydrate		Bioethanol yield	BioETBE yield	By-product	
Crop	**Material**	**Content (%)**	**(litre/ton)**	**(litre/ton)**	**Material**	**Content (%)**
Sugar beet	Saccharose	16.5	100	227	Pulp	7
Wheat	Starch	60	350	794	DDGS	40
Straw	Cellulose	37	183	415	Lignin	10

DDGS: Dried Distillers Grains Soluble
Source: INRA, Teagasc.

A list of other alternative feedstocks with corresponding bioethanol and bioETBE yield and by-products is given in annex 1.

1.3. PRODUCTION OF RAW BIOMASS FOR BIOETHANOL

In the European Union the most widely used feedstocks are wheat and sugar beet. Given that its bioethanol process is already available, in this paper wheat and sugar beet will be considered as the reference crops for the economic analysis, comparing its results to straw based bioethanol production.

Attainable crop yields are estimated on the basis of national and European statistics. For wheat three alternative crop yield levels are examined: average yield for the EU (7t/ha), high yield (9 t/ha), and average yield for Mediterranean climates and CEECs countries (3.5 t/ha).

In the case of sugar beet, two crop yield levels, for a further economic analysis, are considered: average yield level for the EU (66 t/ha) and high yield level (78 t/ha).

Substantial reductions in bioethanol production costs may be made possible by replacing cereals or sugar beet with less expensive lignocellulosic based feedstocks[3]. These feedstocks can be categorized as agricultural waste, forest residue, and energy crops. Agricultural wastes

[3] The Swedish government has set up a support program for research and development of bioethanol from wood biomass, aiming at making bioethanol from wood competitive in 2004

available for bioethanol conversion includes crop residues such as wheat straw, corns stove and rice straw. Forestry waste includes under utilized wood and logging residues; rough, rotten and salvable dead wood and excess sapling and small trees. Energy crops, developed and grown specifically for fuel, include fast-growing trees, shrubs and grasses such as hybrid poplars, willows, and switchgrass.

Although the choice of cellulosic feedstock for bioethanol conversion is largely a cost issue, feedstock selection should also focus on environmental issues: the collection of forest residues represents an opportunity to decrease the risk of forest fires[4];the use of straw can decrease the extent of burning the residuals of cereals after harvest.

In Table 2 bioethanol yield per hectare is presented for the selected raw materials.

Table 2. *Bioethanol and bioETBE yields per hectare.*

Crop	Crop yield (t/ha)	Bioethanol yield (l/t)	Bioethanol (l/ha)	BioETBE (l/ha)	Bioethanol (toe/ha)
Sugar beet	66	100	6600	14982	3.17
	78	100	7800	17706	3.74
Wheat	3.5	350	1225	2780	0.59
	7	350	2450	5561	1.16
	9	350	3150	7150	1.48
Straw		183			

These figures show that sugar beets are more productive per hectare compared with wheat in bioethanol production, but the suitability of each crop depends on climatic, agricultural or economic conditions as well.

1.4. BIOEHANOL/ETBE CHARACTERISTICS AND ENGINE PERFORMANCE

Bioethanol is a high quality, high-octane fuel capable of reducing air pollution and improving engine performance; it reduces particulate emissions; contains no sulfur, is less toxic than biomethanol and biodegradable.

Bioethanol is the most environmentally friendly, renewable, readily available fuel for **fuel cells**. In fuel reformers, which convert ethanol and other hydrocarbons to hydrogen, ethanol has demonstrated lower emissions, higher efficiencies and better performance.

[4] Mediterranean forests suffer the ravages of dramatic forest fires: in southern Europe 500,000 to 600,000 ha burn each year, destroying biomass equivalent to 14-15 Mtoe.

The main disadvantages of bioethanol are: lower cetane number than diesel; low vapor pressure and high latent heat of vaporization which makes cold starting in cooler climates more difficult; increased formation of acetaldehyde; corrosion of metals and rubber engine elements. However, all of these obstacles have rather easy technical solutions.

BioETBE is an alternative to MTBE in its role as oxygenated compound into gasoline. It offers similar performance as octane enhancer with slights improvements in thermal efficiency.

The introduction of bioethanol into the transportation sector can be achieved through different paths:

a) The use of various blends of bioETBE with gasoline.
b) The use of pure bioethanol in modified engines.
c) The use of bioethanol blended with gasoline or diesel.

a) ETBE in a low concentration (15%) blend with gasoline performs as an ignition enhancer due to its high octane rate. ETBE allows to reduce benzene levels and replaces lead, which was traditionally used to increase the octane rate. The slight decrease on thermal efficiency is balanced with a better combustion due to the presence of oxygen in bioethanol.

b) Pure bioethanol is widely used in Brazil. The large capacity and potential of the country's distilleries help the extensive use of bioethanol. Moreover, engines designed to run with gasoline can easily be modified to a bioethanol engine. If no specific modifications to improve the efficiency are made, bioethanol consumption in this engine rises up to 60-100%. On average, and with appropriate engine modifications, pure bio-ethanol (E100) is reducing the fuel economy and power by 50 %. In other words, it is needed 1.5 liters of E100 in order to replace 1 liter of conventional fossil diesel. Another disadvantage from the use of pure bio-ethanol is that any components, made from zinc, brass, lead, aluminum or other softer metals ought to be avoided, as the ethanol could cause leaching from such soft metals. At the end, cold start problems could be observed when running the car on E100 as well.

In theory, gasoline engines may be able to run without any material problems and engine modifications with up to 22% bioethanol blends, which seems to be the upper limit for cold climates. However, in practice car manufacturers do not recommend to use gasoline blends with more than 10 % content of bio-ethanol The use of blended type E10 ought to reflect into 5 % average increase of the overall fuel consumption. As a result, the fuel consumption ratio between conventional fossil gasoline and blended gasoline with bio-ethanol content not more than 10 % might be considered as 1:1. While E10 gasoline contains about 97 % of the energy of pure fossil gasoline, this is compensated by the fact that combustion efficiency of the E10 gasoline is increased. In this case, engines are designed to take advantage of the higher-octane benefits of ethanol while increasing fuel efficiency. On average basis, the E10 increases octane number of gasoline by 2.5 to 3 points. Moreover, the bio-ethanol is better octane booster in comparison with other octane enhancers like aromatic compounds and methyl tertiary butyl ether (MTBE), being amongst the most toxic components of gasoline. The use of gasoline / bio-ethanol blends in spark-ignition engines improves its thermal efficiency and reduces regulated pollutants through more stable combustion at high compression ratios as well. The use of bio-ethanol is also advantageous because it is absorbing small volumes of water, contained in fuel tanks.

Last but not at the least, the great majority of operational disadvantages of pure bio-ethanol, like obligatory replacement of all rubber seals, gaskets and softer metals, cold start problems and etc., in most cases are not observed when using blended types of gasoline. So, it seems that bio-alcohol blends could successively combine advantages of pure bio-ethanol and in the same time could potentially eliminate its disadvantages.

1.5. ENERGY BALANCE

Even when analyzing the entire fuel-cycle energy balance, bioethanol generates more energy than used during its production. A number of studies that reviewed the entire fuel-cycle conclude that ethanol contains more energy than is used in its production process, including the energy used to grow, harvest and process grain into bioethanol.

According to the analysis and prospects from the CCPCS (Commission Consultative pour les Carburants de Substitution), the energy balance of bioethanol is positive as shown in the following table:

***Table 3**. Bioalcohol energy yield*

	Energy produced by bioethanol / fossil energy employed	total energy produced / total energy employed
Bioethanol from wheat		
average value	3.7	1.14
highest value	3.4	1.15
prospective for 20001	3.8	1.37
Bioethanol from sugar beet		
average value	1.7	1.14
highest value	2.4	1.65
prospective for 20001	3.0	2.07
ETBE	1.3	
gasoline	0.8	-
diesel	0.9	-

Source: ADEME,1991.

- For every unit of fossil energy provided, the energy production of bioethanol is the equivalent of 1.15 units if wheat is used, rising to 1.65 in regions with better crop efficiency (1.14 national average for France),

- Considering all by-products obtained during the production process (straw, DDGS, etc.), 1 unit of fossil energy provides 3.4 to 3.7 energy units from wheat and 1.7 to 2.4 energy units from sugar-beet. In the case of ETBE, this rate is 1.3 for ETBE vs. 0.8 for petrol products.

This energy balance may be improved mainly through the reduction on nitrogen fertilizers. Studies carried out for bioethanol demonstrate the significant energy efficiency improvements that have been made in bioethanol production: higher yielding varieties, use of improved farming practices (precision and no-till farming) and technological advances in ethanol production such as new biotechnology tools to improve enzymes and fermenting organisms.

A detailed energy balance for bioethanol obtained from wheat is shown in annex 3. It includes the energy employed to grow, harvest and process grain into bioethanol. The overall energy balance depends on the use given to the wheat straw. However, regardless of how the straw is used, final energy balance is positive.

1.6. BIOETHANOL AND ENVIRONMENT

Bioethanol is an efficient tool to prevent from air pollution originated by vehicles. As it contains 35% oxygen, adding it to gasoline results in a more complete fuel combustion, thus reducing harmful tailpipe emissions. Bioethanol also displaces toxic gasoline components such as benzene and butadiene unregulated emissions. It is non-toxic, water soluble and quickly biodegradable.

The use of grain based bioethanol resources (cereals, maize,..) reduces greenhouse gas emissions 35-45% compared with conventional gasoline. Bioethanol made from lignocellulosic biomass provides an even greater reduction.

Specific comments for the potential emission reductions per pollutant are given in the following:

<u>Carbon dioxide (CO_2).</u> Bioethanol production process represents a short carbon cycle, where CO_2 released to the atmosphere during the production process and fuel combustion is entirely recaptured by crops, as well as absorbed through the carbon cycle (e.g. vegetable animal feed).

Carbon Monoxide (CO). Oxygenated gasoline, such as bioethanol blends, emit lower levels of CO, since they allow a more complete combustion of the fuel. Blends with 5 to 7% bioethanol inhibit the production of monoxides, resulting in a 15 to 40% reduction in CO emissions[5].

The two most common methods to increase the oxygen level of gasoline and reduce CO emission are blending with MTBE and with ETBE. Because MTBE has a lower oxygen content than ETBE and due to its proven contamination of ground water supplies, ETBE competes favorably with MTBE, although it is more expensive.

Particulate matter (PM) Bioethanol reduces particulate emissions, especially fine-particulates that pose a health threat to children, senior citizens, and those with respiratory ailments.

Acetaldehydes: the use of bioethanol does result in slightly increased levels of acetaldehyde and peroxyacetyl nitrate, these compounds are more than offset by reductions in formaldehyde, a toxic air more harmful than acetaldehyde.

Bio-degradability. bioethanol is the safest component in gasoline today. Bioethanol is rapidly biodegraded in surface water, groundwater and soil.

Overview of the emissions reductions from low-level and high-level ethanol blends

Emission	**Low-level Blends (i.e., E10)**	**High-level Blends (i.e., E85)**
Carbon Monoxide (CO)	25-30% decrease	25-30% decrease
Carbon Dioxide (CO_2)	6-10% decrease	Up to 100% decrease (E100)
Nitrogen Oxides (NO_x)	5% increase or decrease	Up to 20% decrease
Volatile Organic Carbons (VOC's) – Exhaust	7% decrease	30% or more decrease
Sulfur Dioxide (SO_2) and Particulate Matter	Decrease	Significant decrease
Aldehydes	30-50% increase (but negligible due to catalytic converter)	Insufficient data
Aromatics (Benzene and Butadiene)	Decrease	More than 50% decrease

[5] The Clean Air Act Amendments of 1990 in USA made the sale of oxygenated fuels compulsory in areas with unhealthy levels of carbon monoxide. Since then, there has been strong demand for ethanol as an oxygenate blended with gasoline. In the United States, more than 1.5 billion gallons are added to gasoline each year to increase octane and improve the emissions quality of gasoline.

2. TECHNO-ECONOMIC ANALYSIS

2.1. BIOETHANOL PRODUCTION ECONOMIC BALANCE

Several (non-technological) limiting factors have stopped until now the development of the bioethanol industry[6]. These limiting factors are feedstock prices, bioethanol production costs, oil prices and taxation of energy products.

In this section cost structure for bioethanol and its elements will be analyzed, as well as the different alternatives that will be the basis for the discussion of possible taxation scenarios on section 3.2., bioethanol blends and potential in the EU.

While technologies for energy production from crops are improving rapidly, the costs remain non-competitive with mineral fuels

As far as bioethanol is the main output of the upstream process, all comparisons are also directly in terms of this fuel assuming they do not significantly differ for those of bioETBE.

2.1.1 Feedstock prices

The main advantage of bioethanol as an outlet for arable crops is that it can be produced from several types of feedstock, many of which are already being grown. The technology for the production, harvesting, drying and storage is in most cases already available.

This economic balance is done on the basis of the two main feedstock for bioethanol production already developed in the EU. Because of its importance as an alternative to decrease bioethanol production costs, data from lignocellulosic feedstock such as straw, grass or wood will be given, when available.

The estimates for bioethanol production costs depend greatly on the assumptions made for crucial factors such as those on the productivity of farming and the prices used for feedstock. Two different costs are given for the feedstock considered:

<u>Wheat costs:</u>

a) EU domestic prices are expected to benefit from improved medium-term perspectives in world markets which should keep domestic prices above 1999 levels. After a five-year period of low market prices for cereals, in 1999 wheat producer prices recovered slightly, and reached

[6] All techno-economic analyses in the present chapter are based on the assumption of parity between fuel efficiency of conventional fossil gasoline and bio-ethanol. This pre-condition means that the techno-economic analysis actually treats blended types of gasoline with bio-ethanol content not more than 10 %, but not the pure (E100) bio-ethanol.

an average at the EU of 120 Euro/t[7]. Calculations based on this price and a bioethanol yield of 350 l bioeth/t wheat, give a cost of wheat as raw material of 343 Euro/000 l bioethanol.

b) According to DG Agriculture calculations, considering the current situation of CAP subsidies with a compulsory set-aside rate of 10%, the final feedstock cost in the case of wheat can decrease to 220Euro/000 l. This means that processors will receive feedstock at lower prices and farmers will receive a crop specific payment per hectare to compensate the reduction in institutional prices.

Sugar beet costs:

a) A producer price for sugar beet as B-quota 32.42 Euro/t $_{\text{sugar beet}}$, and a bioethanol yield of 100 lbioeth/t $_{\text{sugar beet}}$, would give a final feedstock cost of 324.2 Euro/t.

b) However, the price of sugar beet grown for bioethanol production purpose is freely negotiated between farmers and processors. Processors benefit from raw feedstock bought at non regulated prices and much lower than the institutional prices of sugar beet devoted to sugar production. However, although sugar beet for bioethanol can be grown on set-aside area, it is not eligible to the set-aside premium. Under these conditions there are farmers that could accept grow sugar beet at lower prices than institutional ones.

For these reasons a feedstock cost of 200 Euro/000l bioethanol, closer to world sugar beet prices, seems to be more accurate.

Feedstock costs are summarised on section 2.1.2. and show that **bioethanol production costs depend for 60% on the raw biomass costs in the case of price, and for 50% in the case of sugar beet[8].**

It should be noted that upstream production process for fossil fuel is not likely to change. Thus, a **reduction on bioethanol production costs relies primarily, in the case of sugar beet and wheat, on feedstock cost reductions**. This goal may be achieved improving productivity in current crops or using low cost feedstock (such as lignocellulosic biomass).

In this sense, research developed by AGRICE conclude that using specific sugar beet seeds for bioethanol production could reduce feedstock cost by 0.152 Euro/l (1 FF/L) within the next ten years.

The reductions in agricultural subsidies and protection agreed in the Uruguay Round of GATT may lead to an increase on feedstock imports with lower tariff rates. This feedstock importation (with lower costs) could be delivered to the bioethanol generating a demand for these products. Moreover, the Common Agricultural Policy reform contained in Agenda 2000 foresees

[7] Statistics and Prospects. Directorate General for Agriculture. European Commission.
[8] Production costs of biodiesel depend for 80% on feedstock prices.

an approach between internal and world prices and aims to put at the disposal of biofuel industries more competitive feedstock.

Lignocellulosic material costs

The ability to produce bioethanol from low cost biomass will be key to making bioethanol competitive with gasoline. A large variety of feedstocks is currently available for producing bioethanol from lignocellulosic biomass, but for this analysis straw, as an important agricultural waste, has been selected.

According to Voest Alpine, the estimated price for straw is about 240 Euro/000 l[9].

An issue of environmental concern in the agricultural regions of the EU is the straw burn after the cereal harvest (wheat, barley, rice, etc). The exploitation of straw as bioethanol feedstock could be an ideal opportunity to phase out this practice.

2.1.2. Bioethanol production costs

The estimated costs for bioethanol, assuming tax exemption, include feedstock and processing costs with a credit allowance for the value of by-products.

Feedstock costs have already been discussed on the preceding paragraph. With regard to processing costs, they depend on plant scale and design, labor and energy costs, hence values reported in the different studies consulted vary considerably. Processing costs and by-product values given by INRA constitute an updated and balanced indication for the previously considered feedstocks (wheat and sugar beet).

Table 4. *Production costs of bioethanol (Euro/000 l)*

	Feedstock cost	Processing cost	By-product	Total production costs
Wheat	343	284	145	482
	220			359
Sugar beet	324	218	3	539
	200			415
Straw	240	355	38	557

Source: Sourie et al.(2000) and Teagasc.

Cost production from sugar beet takes advantage from the existing sugar and alcohol industry, so that its processing costs are the lowest.[10]. Bioethanol processing from straw is not yet carried out on an industrial scale, and costs here presented correspond to pilot plant scale experiments[11].

[9] Teagasc, Crops research Centre, Oakpark Carlow (Ireland)
[10] Sourie et al. (2000) Analyse Economique des filières biocarburants françaises à l'aide d'un modèle d'equilibre partiel. INRA (travaux soutenus par AGRICE)
[11] Voest Alpine (1992)

Two salient facts have to be underlined with respect to this cost structure. The important share in the final cost attributable to the procurement costs of biomass. In the presented cost structure, the share of feedstock cost in the final product ranges between 50 and 70%. The second salient fact is that processing cost here presented for straw is rather high. Although cellulosic materials have lower costs than other feedstocks, they are at present more costly to convert to bioethanol because of the extensive processing required.

However, some remarks should be made in relation to the possibility of a reduction on bioethanol processing costs:

- One of the top priorities of RTD identified by ATLAS (according to the ADEME paper) is to reduce the production cost of liquid bio-fuel by at least 0.2 $/l (0.152 Euro/l) before 2005.
- The positive externalities (including effects on employment, climate change and trade balance) of bioethanol have been estimated in France to be near 0.17Euro per liter, whereas potential progress through R&D and scale economies could reach 0.17 Euro per liter. French officials assume that bioethanol could close the gap between fossil fuels at the macro-economic level within the next ten years.
- According to US National Renewable Energy Laboratory the cost of producing bioethanol from lignocellulosic materials could be reduced by 60 cents per gallon (0.12 Euro/l) by 2015[12].

Considering the mentioned possibilities to reduce bioethanol production costs, an attainable decrease by 0.150 Euro/liter is estimated.

As cereals used in bioethanol sector cover an important area of the industry, special emphasis will be placed on wheat as a key crop for bioethanol production.

In the following table estimated costs for bioethanol from wheat are broken down into: operating costs, capital cost and feedstock cost. Both operating and capital costs have been considered as fixed costs, while feedstock is considered as variable.

The cost of a bioethanol manufacturing plant may range around 100 Keuro/'000 t/y. Assuming a discount factor of 10% and an economic plant lifetime of 15 years, this would yield a capital cost annualized of around 12 Euro/t.

By-products generated during the process (Dried Distillers Grains Soluble) are sold and considered as fixed income.

Wheat price (Pr) is considered as a variable. The manufacture of 1 litre bioethanol needs 2.86 kg wheat.

[12] Outlook for Biomass Ethanol Production and Demand. Department of Energy (USA)

Table 5. Bioethanol cost production depending on wheat price in Euro/'000 l.

Fixed costs	
Capital costs (annualized)	12
Operating costs	
Energy	60
Labour	50
Chemicals	30
Overhead	20
Maintenance	50
Fixed income	
By-products income	114
TOTAL fixed factors	108
Variable costs	
1 l of bioethanol requires 2.86 kg of wheat	Pr*2.86
TOTAL PRODUCTION COSTS	108 + Pr*2.86

Pr: wheat price
SOURCE: EC ATLAS Database, US National Renewable Energy Laboratory (NREL)
IPTS data gathering & elaboration

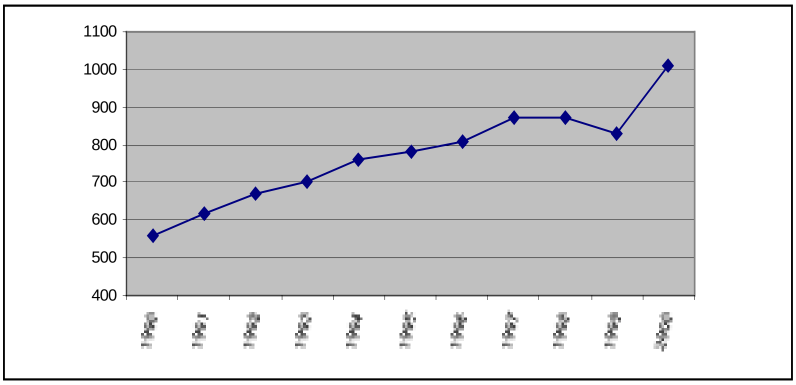
2.1.3. Oil prices

The use of bioethanol as an automobile fuel dates as far back as 1908, to the Henry Ford's Model T designed to run on home-grown renewable fuels. However, after World War, there was little interest in the use of agricultural crops to produce liquid fuels. Fuels from petroleum became available in large quantities at low cost, eliminating the economic incentives for production of liquid fuels from crops. Interest in bioethanol was renewed in the 1970s, when supply disruptions in the Middle East made the automotive industry rediscovered bioethanol's potential.

Nowadays, low production prices of oil compared to bioethanol ones are another crucial handicap for the development of bioethanol. In this sense, the increase in oil prices, observed over the past ten years, approaches bioethanol cost production to gasoline ones, converting this difference from a handicap to an opportunity for bioethanol.

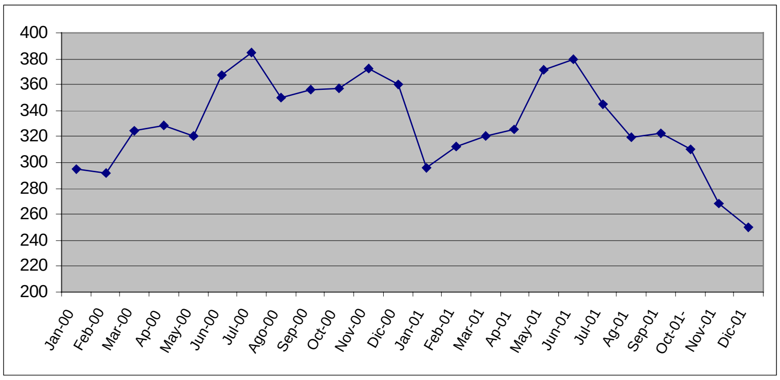
The evolution of gasoline prices in the European Union is shown in the figure 1 and 2.

Figure 1 *Price of euro-super 95 (commercial use) Euro/000l (taxes included)*



Source: Eurostat

Figure 2 *Euro-super 95 consumer prices net of duties and taxes in Euro/000 l. Weighted average for EU.*



Source: European Commission Directorate General for Energy and Transport. Oil Bulletin

The average price for euro-super 95 gasoline over the past two years amounts to 330 Euro/000 l.

2.1.4. Taxation of energy products

Fuel tax systems are very fragmented throughout the EU, and large differences exist among EU Member States with regard to specific tax exemptions given for different fuel specifications. Greater EU harmonization in this field (given in the legislative proposal for a Council Directive amending Council Directive 92/81/EC) would bring stability to the market and improve conditions for growth of the biofuels sector in general.

There are, though, **minimum levels of taxation** applicable to automotive gasoline. These minimal taxes are ECU 450 per 1000 liters on 1 January 2000 and ECU 500 per 1000 liters on 1 January 2002.

The minimum levels of taxation are modified depending on whether these motor fuels are used for certain industrial or commercial purposes. The proposal refers to: agriculture and forestry; stationary motors; plant and machinery used in construction, civil engineering and public works; vehicles intended for use off the public roadway; passenger transport and captive fleets which provide services to public bodies.

Member States may apply **total or partial exemptions** or reductions in the level of taxation to energy products used under fiscal control in the field of pilot projects for the technological development of more environmentally-friendly products or in relation to fuels from renewable sources, bio-fuels, among other possibilities.

For instance, in **France**, industrial plants producing ETBE must obtain an official authorization from the Minister of Agriculture and Fisheries to produce these chemicals, and then are exempted from the tax on petroleum-derived products. Consequently, bioethanol benefits from a partial exemption of the excise tax on petroleum products for an amount of 3.29 F per liter (0.503 Euro/l).

The government of **Sweden** has given relief from excise duties to pure bioethanol used as motor fuels in pilot projects and has set the energy tax at 0.90SEK (0.10 Euro) per liter and the carbon dioxide rate at 0 SEK for bioethanol used in mixtures with other fuel components, such as gasoline or diesel.

2.2. BIOETHANOL TAXATION LEVEL SCENARIOS

Agenda 2000 has represented a significant move to a major de-coupling of the support to crops, therefore the possibility to subsidize raw material production under the Common

Agricultural Policy is will not be considered. In this context, tax reduction or exemption is a key condition for the relative profitability of bioethanol.

In the following paragraphs different tax level scenarios will be discussed. Current bioethanol production costs (see 2.1.2.) will be considered first. Then, a scenario assuming production costs reduced by 150 Euro/000 l, according to the potential progress through R&D both in feedstock or processing costs. Finally a possible tax linked to CO_2 emissions applied to fossil diesel fuel will be calculated as well as the cost of the avoided emissions due to fossil diesel replacement by bioethanol.

2.2.1. Bioethanol taxation level scenarios at current costs

The following table compares the final bioethanol price with gasoline, depending on the tax level applied. The scenarios considered are total exemption, a partial exemption of 10% and 50% of gasoline taxation and full gasoline taxation.

The following assumptions have been considered:

- Current production costs for wheat, sugar beet and straw (see 2.1.2.)
- Gasoline prices as an average of the past two years of euro-super 95 consumer prices net of duties and taxes: 330 Euro/000 l.
- Minimum full taxation level applicable to gasoline 500 Euro/000 l.

***Table 6** Bioethanol taxation level scenarios at current costs in Euro/000 l*

Euro/000 l	Total Exemption	Full gasoline taxation	10% level of full gasoline taxation	50% level of full gasoline taxation
Taxes	0	500	50	250
Gasoline	330	830	380	580
Wheat	482	982	532	732
Sugar beet	539	1039	589	789
Straw	557	1057	607	807

This table indicates that a final cost of bioethanol lower than gasoline can occur only within scenarios of total or partial hydrocarbon exemption for bio-fuels. For instance, a 50% reduction of the full tax level of taxation applied to bio-fuels would make competitive bioethanol at consumer prices (whatever the feedstock is used) with gasoline ones. The final costs would be, in this case 830 Euro/000l vs 732 Euro/000l, 789 Euro/000l and 807 Euro/000l, for wheat, sugar beet and straw, respectively.

In Figure 3 bioethanol final cost (depending on the level of taxation applied to the bio-fuel) is compared to gasoline prices.

Figure 3. *Bioethanol price at current costs, depending on tax level, in Euro/000 l*

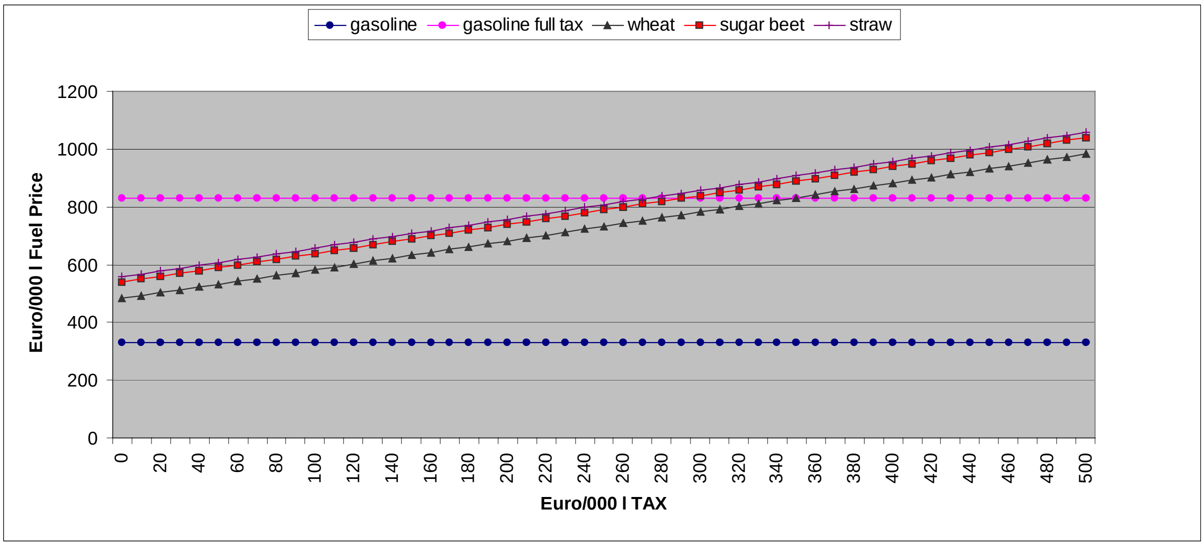


Figure 3 shows that the price of bioethanol can be lower than that of gasoline, considering current costs, even in scenarios where the level of taxation is higher than 50% of the minimum full taxation level.

For the particular case of wheat as bioethanol feedstock, the same taxation level scenarios (tax exemption, 10%, 50%) depending on feedstock prices are represented on figure 4. Final fuel costs are expressed in figure 4 as a function of raw biomass price. Assumptions on gasoline prices and taxes are the same as described before. Production costs (see 2.1.2) are given by the expression 108 + 2.86*wheat price.

***Figure 4**. Bioethanol taxation level scenarios at current production costs, depending on wheat price*.

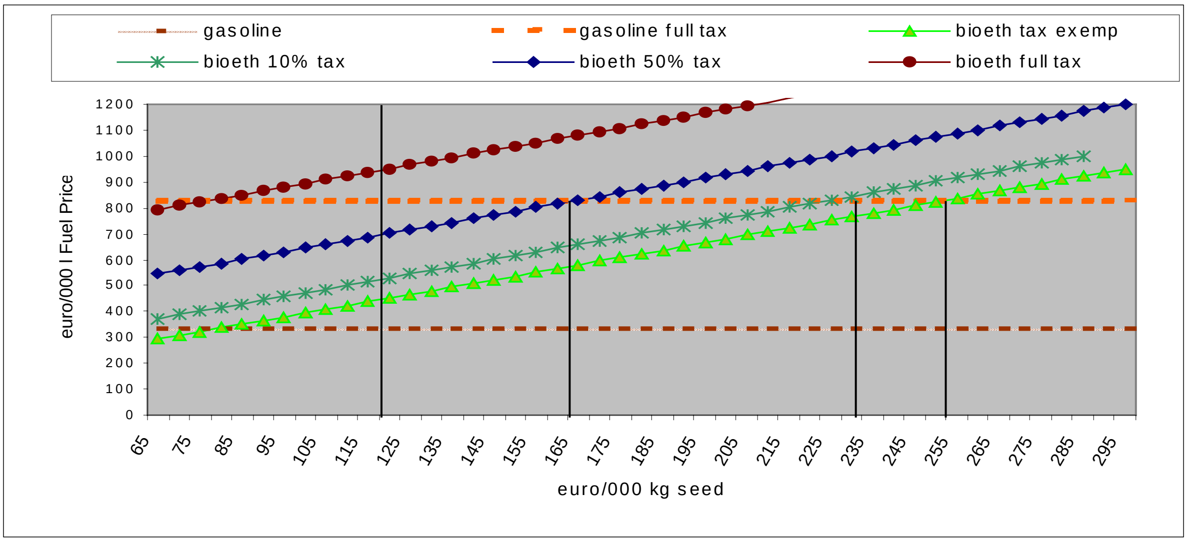


Figure 4 shows that at current costs, produce bioethanol at the same price as gasoline would be possible at wheat prices below 75 Euro/'000 kg.

At current wheat prices (120 Euro/'000 kg) bioethanol production would only be profitable at 10% or 50% taxation level scenario.

Price paid for wheat could reach considering 50%, 10% or total exemption scenario, 165, 235 or 255 Euro/'000 kg respectively.

2.2.2. Bioethanol taxation level scenarios lowering raw biomass costs

Assuming different targets of cost reduction identified by ATLAS and US NREL (see 2.1.2.), a decrease by 150 Euro/000l before 2005 is feasible. This cost reduction comes from both feedstock and processing costs reduction. Under these circumstances, bioethanol cost is compared with gasoline price in Table 7.

The underlying assumptions are the following:

- Current production costs for wheat, sugar beet and straw (see 3.1.2.) reduced by 150 Euro/000 l.
- Gasoline prices as an average of the past two years of euro-super 95 consumer prices net of duties and taxes: 330 Euro/000 l.
- Minimum full taxation level applicable to gasoline 500 Euro/000 l.

Table 7. *Bioethanol taxation level scenarios at lower production costs, in Euro/000 l*

Euro/000 l	Total Exemption	Full gasoline taxation	10% level of full gasoline taxation	50% level of full gasoline taxation
Taxes	0	500	50	250
Gasoline	330	830	380	580
Wheat	332	832	382	582
Sugar beet	389	889	439	639
Straw	407	907	457	657

With this cost structure, non-taxed prices become quite similar and there is more room for fiscal incentives. Table 7 shows that the production of bioethanol with competitive prices in a scenario of reduced costs by 150 Euro/000 l, is possible if wheat is employed as feedstock almost without changing the fiscal structure. Using sugar beet as feedstock, bioethanol would have clearly competitive prices compared to full-taxed gasoline in the case of 50% hydrocarbon taxation, (830 Euro/000l vs 582 Euro/000l , 639 Euro/000l and 657 Euro/000l for wheat, sugar beet and straw, respectively).

Bioethanol price depending on the level of taxation is compared with gasoline price in Figure 5.

Figure 5. *Bioethanol price, lowering costs, depending on tax level, in Euro/000*

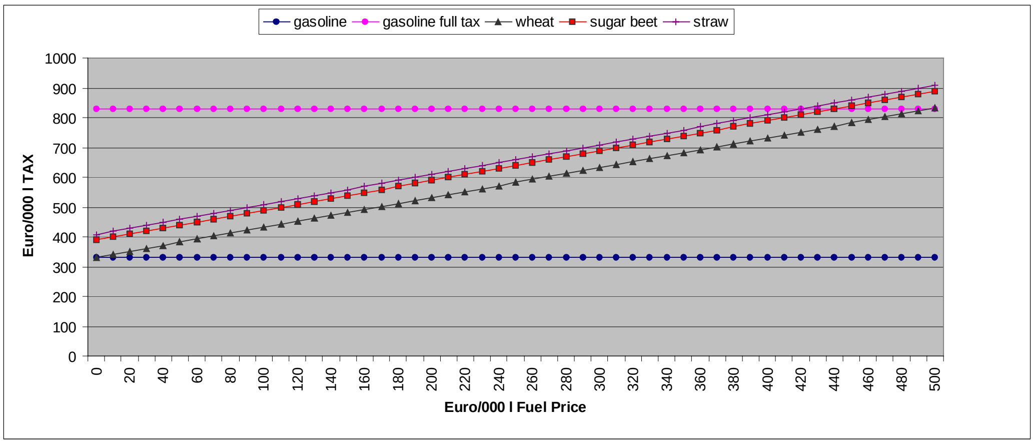
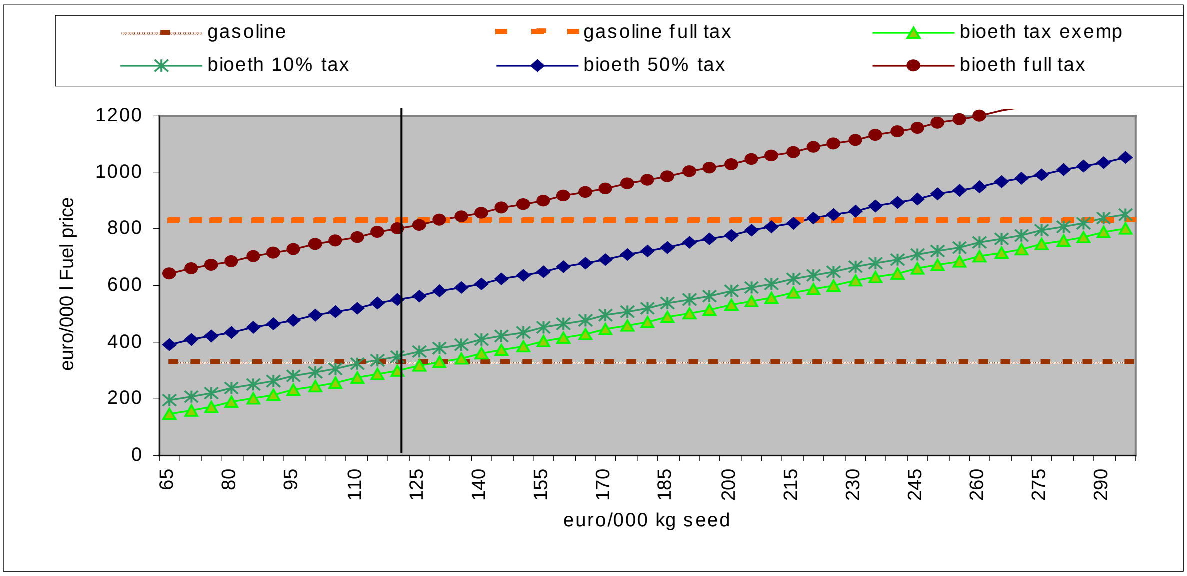


Figure 5 shows that, as the development of technologies lowering current raw biomass costs increases (yielding a raw biomass price decrease of 159 Euro/000l), total exemption could be even unnecessary and should be modulated, depending on the economic results obtained.

In the case of bioethanol produced from wheat, Figure 6 shows the different scenarios lowering costs and depending on wheat price.

***Figure 6**. Bioethanol taxation scenarios at lower costs, depending on wheat price*



Considering the cost reduction of 150 Euro/'000 l, the production of bioethanol from wheat with competitive prices is possible at a full tax scenario. Price paid to farmers could even go above current price until 130 Euro/'000 kg wheat, preserving the competitiveness of its farms.

Bioalcohols are likely to become competitive if cost-effective process are developed or positive externalities taken into account in the final price.

2.2.3. Tax linked to CO_2 emissions

Increasing fossil fuel consumption by transport is responsible for the large growth rate in greenhouse gas emissions, mostly CO_2 emissions in most advanced economies. According to Eurostat estimates, about 28% of the CO_2 emissions in the EU presently come from transport, with 84% of it from road transport alone. The former share is expected to increase in most baseline projections, whereas the latter is certainly not expected to decline.

A common pattern in the sectoral structure of carbon emissions in many advanced countries is that, while other sectors (industry, residential, tertiary and power generation) have reduced their emissions, greenhouse gas emissions from transport have been increasing with a relatively large, stable growth rate. CO_2 emissions from transport have increased by 18% from 1990 (Kyoto reference year) to 1998 in the EU. Over the whole period 1990-2010 a baseline projection indicates a possible growth of transport-generated CO_2 emissions to reach 40% of total carbon emissions. The transport sector therefore continues to face the well-known conflict between consumption and environmental protection. On the one hand society is extremely fond of the personal mobility possibilities offered by technology, on the other hand society is less and less willing to accept the negative impacts on safety, health and environment induced by such consumer behaviour.

Therefore, the fulfillment of the Kyoto commitments and control of CO_2 emissions are essentially a matter of energy and transport policy. Without measures in both these sectors, any climate change policy is very likely to fail. Climate protection measures can only be effectively met if the European Union makes a firm commitment to undertake concrete measures (notably fiscal and regulatory) geared to energy-saving and the promotion of renewable energy sources. Despite major disparities between Member States, taxation can be an effective tool in energy policy. The internalisation of costs linked to degradation of the environment and/or the application of the polluter pays principle, can be effective attained by tax incentives.

In this section will be discussed the possible tax linked to CO_2 emissions applied to gasoline as well as the cost of the avoided emissions due to fossil gasoline replacement by bioethanol.

Tax linked to CO_2 emissions applied to gasoline

Assuming that carbon dioxide released from burning bioethanol will be entirely recaptured and absorbed through the carbon cycle, net bioethanol carbon dioxide emissions are zero. Given the carbon content of gasoline, the replacement of one liter of gasoline by one liter bioethanol will reduce the emission by 2.64 kg of CO_2**.**

The equivalent carbon tax linked to CO_2 emissions, according to different analysts (Green Paper on the Establishing of an EU Market for CO_2 Emissions Rights, EU 2000 and references therein) would range from 30 to 80 Euro per CO_2 ton emitted. The corresponding **equivalent tax calculated for gasoline would have a value between 79 and 211 Euro/000 l gasoline**. These figures are obtained, depending on a number of assumptions and hypothesis, either by assuming an equivalent carbon tax or as the equilibrium price that the carbon emission permit would reach in a perfect market for emissions rights. If this amount is added to the average price of gasoline (830 Euro/000 l), the final price will be between 909 and 1041 Euro/000 l gasoline. These prices are considerably much closer to the bioethanol price calculated on a full tax scenario (982, 1039 and 1057 Euro/000 l, respectively for wheat, sugar beet and straw), and definitely above the bioethanol price in the case of full exemption from hydrocarbon tax (amounting 482, 539 and 557 Euro/000 l). Under this respect, putting a price to carbon emissions either by (further) taxing fossil carbon or by establishing a emission allowance market would lead to a better competitiveness of the bioethanol *filière*.

Cost of the avoided emissions due to fossil diesel replacement by bioethanol

Considering the prices for gasoline and bioethanol calculated on the precedent section, under the scenario of full gasoline taxation, the difference between bioethanol and gasoline price, depending on the feedstock used, is presented on Table 8.

Table 8. *Cost of avoided emissions*

	Difference between gasoline and bioethanol price Euro/000 l	Cost of CO_2 emissions Euro/t CO_2 emitted
Wheat	151	57
Sugar beet	209	79
Straw	227	85

In terms of CO_2 emissions, this difference in emissions avoided would imply an implicit cost of about 55 to 85 Euro/ton CO_2 emitted.

2.3. BIOETHANOL AND GASOLINE BLENDS

Blends of gasoline or diesel with bioethanol in percentages below 15 percent can be used without any operating problems and require no ignition improver. However, as explained previously, it has been proved that at current production costs bioethanol is not competitive against gasoline. Up to present the high cost of production has prevented bioethanol from becoming a more widely used alternative fuel.

A comparison of the prices of different blend levels show that they could represent a more likely scenario. In the following Table, prices of 5, 10 and 15% bioethanol blends are presented. Current costs for bioethanol are considered as well as two tax level hypothesis: tax exemption and 50% of minimum level of taxation for gasoline.

Table 9. *Price for E5, E10 and E15 blends depending on level of taxation*

	5% BLEND		**10%BLEND**		**15%BLEND**	
Euro/000 l	**tax exemption**	**50% level gsn taxation**	**tax exemption**	**50% level gsn taxation**	**tax exemption**	**50% level gsn taxation**
Wheat	813	825	795	820	778	815
Sugar beet	815	828	801	826	786	824
Straw	816	829	803	828	789	827

Figures in Table 9 show that, assuming tax exemption for bioethanol, an important reduction of blend prices in relation to gasoline (830 Euro/ 000) is observed. In the scenario of 50% of minimum taxation level for gasoline, final price for bioethanol is competitive with gasoline whatever the feedstock employed on the bioethanol production.

Blends are a real opportunity for bioethanol development, and its use would make feasible the production of cost-effective bioethanol giving competitive prices for final consumers and a well-functioning supply chain.

Bioethanol blends market introduction strategy

From the point of view of the introduction of the bioethanol, in a first stage it is more appropriate to do it in form of bioETBE (blending up to 15% bioETBE with gasoline) since it represents advantages in what concerns to its distribution, not requiring any modification neither in the existent supply chain nor in the engines.

In a second stage, the introduction would always be carried out on the base of a certain economic interest for the consumer and following the sequence: mixing in small proportion in captive fleets (5-15% bioethanol and gasoline or diesel blend), mixing in high proportion in captive fleets and, finally mixing in small proportion in any vehicle type (E5G).

2.4. BIOETHANOL POTENTIAL IN EUROPEAN UNION

Among the factors that will influence the development of bioethanol sector (cost competitiveness, energy efficiency of the process, value of by-products, etc) the production of the raw material could represent a bottleneck. In this sense, the reform of the Common Agricultural Policy encouraged the use of agricultural areas for the production of non-food crops. In particular, the compulsory set-aside scheme has provided an opportunity for the development of non-food crops in the Community. The potential for bioethanol in the European Union will be discussed in this section depending on the availability of land to grow raw materials.

Regarding to the crops presented in this analysis, wheat for bioethanol grown on set-aside land is eligible to the set-aside premium increasing its competitiveness. Conversely, although sugar beet can be grown on set-aside is not eligible to this support.

The replacement rate by bioethanol depending on the surface distribution is presented in Table 10 considering that:

- Gasoline consumption of road transport in EU: 147 119 million liters.
- Wheat and sugar beet as bioethanol main raw materials source with an average yield of bioethanol per hectare of 7200 and 2 275 liter of bioethanol per hectare respectively for sugar beet and wheat.
- Four hypothesis on relative surface distribution:
  1. 100% of the surface needed to bioethanol production occupied by sugar beet;
  2. 100% occupied by wheat;
  3. 70% occupied by sugar beet and 30% by wheat (current French bioethanol crops distribution;
  4. 30% occupied by sugar beet and 70% wheat.

Table 10. *Raw material surface depending on gasoline EU road transport consume replacement by bioethanol*

Replacement rate %	Bioethanol production 1000 l	SURFACE DEDICATED TO GROW RAW MATERIALS (1000 ha) 100% sugar beet	100% wheat	70% sugar beet 30% wheat	30% sugar beet 70% wheat
1	1.471.190	204	647	337	514
2	2.942.380	409	1.293	674	1.028
3	4.413.570	613	1.940	1.011	1.542
4	5.884.760	817	2.587	1.348	2.056
5	7.355.950	1.022	3.233	1.685	2.570
6	8.827.140	1.226	3.880	2.022	3.084
10	14.711.900	2.043	6.467	3.370	5.140
15	22.067.850	3.065	9.700	5.056	7.710
20	29.423.800	4.087	12.934	6.741	10.279

The figures in the preceding table show that:

- Dedicating the whole set-aside surface of the EU (5.5 mio hectares), the replacement rate would range between 27% and 8.5% depending on the raw material grown.
- In order to reach a 15% rate of replacement, the set-aside area would be enough in 1st, 3rd and 4th scenarios.

Given that one unit of bioethanol, by adding isobutylene, provides 2.27 units of bioETBE, agricultural surfaces would reduce proportionally to this rate. Table 10 presents the surfaces needed to provide raw material in order to achieve the different replacement rates.

Table 10. *Raw material surface depending on gasoline EU road transport consume replacement by bioETBE*

Replacement rate %	BioETBE production 1000 l	SURFACE DEDICATED TO GROW RAW MATERIALS (1000 ha) 100% sugar beet	100% wheat	70% sugar beet 30% wheat	30% sugar beet 70% wheat
1	1.471.190	90	285	148	261
2	2.942.380	180	570	297	521
3	4.413.570	270	855	445	782
4	5.884.760	360	1.140	594	1.043
5	7.355.950	450	1.424	742	1.304
6	8.827.140	540	1.709	891	1.564
10	14.711.900	900	2.849	1.485	2.607
15	22.067.850	1.350	4.273	2.227	3.911
20	29.423.800	1.800	5.698	2.970	5.215

A 20% replacement rate of gasoline by bioETBE could be feasible, within the set-aside surface, whatever the distribution hypothesis is considered.

3. CONCLUSIONS

Development and use of alcohol fuels in transport have for the most part been driven by the desire to find renewable substitutes for imported petroleum-based fuels. The production of crops for non-food purposes has a long tradition in the 15 EC Member States and thus bioalcohol has been the focus of attention as a possible means of reducing greenhouse gas emissions and noxious emissions from transport. In this context, agriculture and forests might become in the future a very large provider of energy.

Considering the different policies related with the bioethanol development (energy, agriculture and RTD), from the analysis made in this paper, some conclusions can be pointed out:

- Bio-fuels provide an alternative to fossil fuels, but nowadays bioethanol price is 2 to 3 times higher than gasoline price.

- Bioethanol is one of the best tools to fight air pollution from vehicles. Added to fuel reduces harmful tailpipe emissions. Bioethanol is non-toxic, water soluble and quickly biodegradable. It also displaces the use of toxic gasoline components such as benzene.

- On the energy level it is clearly proved that bioethanol presents better yields than fossil fuels.

- A wide range of feedstock may be employed for the bioethanol production, many of which (cereals, sugar beet, sugar cane, etc) have efficient processing technology available but high costs. Conversely, the development of technology to produce bioethanol from ligno-cellulosic materials should bring about a big reduction in raw material.

- The competitiveness of bioethanol relies on the price of bio-mass feedstock and the costs linked to the conversion technology. Depending on the feedstock used, by-products have more or less relative importance.

- The competitiveness of bioethanol on a first stage, is heavily dependent on the level of duty levied on them by Governments. Production costs of bioethanol remain very high compared to fossil fuels and are not competitive under current economic conditions where positive externalities such as effects on employment, climate change and trade balance are not reflected in price.

- The possibility of growing non-food crops under the compulsory set-aside scheme was an opportunity for the non-food sector, but it seems not to be an appropriate instrument to promote non-food production It has to be recalled that compulsory set-aside is a supply-management instrument conceived to deal with cereal surplus situations. The uncertain future of this policy precludes long-term investment. The possibility of growing non-food crops under compulsory set-aside scheme is an opportunity for bioethanol development, but is not an appropriate instrument to promote non-food production.

- Until the reduction in both feedstock and processing costs is reached, fiscal incentives are an instrument to develop bioethanol industry where tax exemption has proven to be an effective approach.
- Blends are a real opportunity for bioethanol development, giving an appropriate income for farmers, competitive prices for final consumers and even in scenarios of 50% of full minimum level of taxation.
- The use of bioETBE blends is recommended at a first stage, given that it requires no engine modifications. The distribution and marketing system is already in place, so the only additional requirement is the process plant.
- Dedicating the whole set-aside surface of the EU 15 (5,5 mio hectares) to cultivate non-food crops, the replacement rate would range between 27% and 8.5% depending on the raw material grown.
- Taxation and legal obligations linked to international commitments of the Member States and the European Union are key issues.

4. ANNEXES

Annex 1. *Bioethanol and bioETBE yields from various feedstocks and by-products.*

Crop	Carbohydrate Material	Carbohydrate Content (%)	Bioethanol yield (litre/ton)	BioETBE yield (litre/ton)	By-product Material	By-product Content (%)
Potatoes	Starch	14	91	206	Pulp	7
Barley	Starch	48	298	676	DDGS	34
Grass	WSC, cellulose	45	38	87	Grass protein	29
Wood chips	Cellulose	48	237	538	-	-
Wood chips	Cellulose, xylose	71	340	771	-	-

Source: TEAGASC

Two alternative processes are examined for wood-chips: one assuming that only cellulose is utilized, the other assuming that both cellulose and xylose are converted.

Annex 2*. Bioethanol and bioETBE yields per hectare.*

Crop	Crop yield (t/ha)	Bioethanol yield (l/t)	Bioethanol (l/ha)	BioETBE (l/ha)
Potatoes	50	91	4550	10328
Barley	5.5	298	1639	3720
Grass	60	38	2280	5175

Source: TEAGASC

***Annex 3**. Energy balance for bioethanol from wheat in MJ/ha*

	WHEAT	
Energy yield	**Straw ploughed in**	**Straw utilised**
(+)or cost(-)	MJ/ha	MJ/ha
Bioethanol	**74189**	**74189**
Straw	0	97500
Total	**74189**	**171689**
Agricultural fuel	-4300	-4773
Fertilizers	-7815	-8070
Agrochemicals	-1045	-1045
Seed	-925	-925
Packaging	-447	-485
Transport	-1495	-2149
Processing	-50810	-50810
Total	**-66837**	**-68257**
BALANCE	**7352**	**103432**