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Techno-economic analysis of Bio-diesel 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 summarise in a short and concise document the crucial facts related to the elaboration, distribution and marketing of bio-diesel. 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

SUMMARY

The present paper aims at presenting in a relative condensed format the crucial facts related to the bio-diesel technique. It is meant for 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. The ATLAS database has been used as a basic reference for the techno-economic analysis, but a number of other sources have been used as well. These data have been gathered and harmonised for the sake of comparability, and processed to provide an overview of the techno-economic analysis of bio-diesel in section 3.

Several issues may be highlighted:

- The cost structure of bio-diesel production makes it so that its competitiveness crucially depends on the price of the bio-mass feedstock and of the by-products obtained.
- Technological improvements may contribute to increase the market penetration of bio-diesel, but a mature bio-diesel sector is conditioned by a stable and cheap supply of feedstock.
- The competitiveness of bio-diesel also depends on the evolution of the fossil diesel prices.
- These three parameters are highly volatile and difficult to predict. Policies to ensure price stability should be endeavoured to favour a deeper penetration of bio-diesel crops.
- Bio-diesel is an energy carrier, whose manufacturing and production at industrial scale is totally determined by non-energy EU policies, i.e. agriculture policy (and, in particular, the set-aside schemes adopted), fiscal policy, etc.
- Bio-diesel blends, i.e. mixing bio-diesel and fossil diesel, are viable way to foster a less carbon-intensive automotive sector.
- However, in the long run and considering the agricultural yields, bio-diesel is not likely to supply a two-digit percentual share of the EU road transport fuel needs.
- The set aside policy is a valuable instrument to introduce bio-fuels in transport market, but given the land area needed to cover the EU demand, the competition with food-production crops will principally impeach their massive market penetration.

1. TECHNICAL FUNDAMENTALS

1.1. WHAT IS BIO-DIESEL?

Liquid bio-fuels, primarily bio-diesel and bio-alcohol, are transportation fuels, processed from agricultural crops and other renewable feedstock that can be used instead of fossil fuels in internal combustion engines.

Bio-alcohol:

- Bio-ethanol/ETBE is processed mainly from wheat, sugar beet and sweet sorghum and is employed usually as a gasoline substitute or as a fuel additive to gasoline.
- Bio-methanol/MTBE can be produced from ligno-cellulose material from forestry (either dedicated crops or forest residuals) and agricultural wastes.

Bio-diesel is a mix of methyl esters, obtained from natural renewable sources, such as vegetable oils. The most common raw materials to manufacture bio-diesel are rape-seed, sunflower and soybeans, but also waste oils (industry, kitchen's, etc). Bio-diesel can be used alone or mixed in any ratio with fossil diesel, obtained from crude oil refining. Depending on the bio-fuel share in the blend, bio-diesel mixtures are called B100 (pure, 100 % bio-diesel), B5 (5 % bio-diesel and 95 % fossil diesel), B20 (20 % bio-diesel and 80 % fossil diesel), etc.

Different bio-diesel types can be classified according to their source and manufacturing process as well:

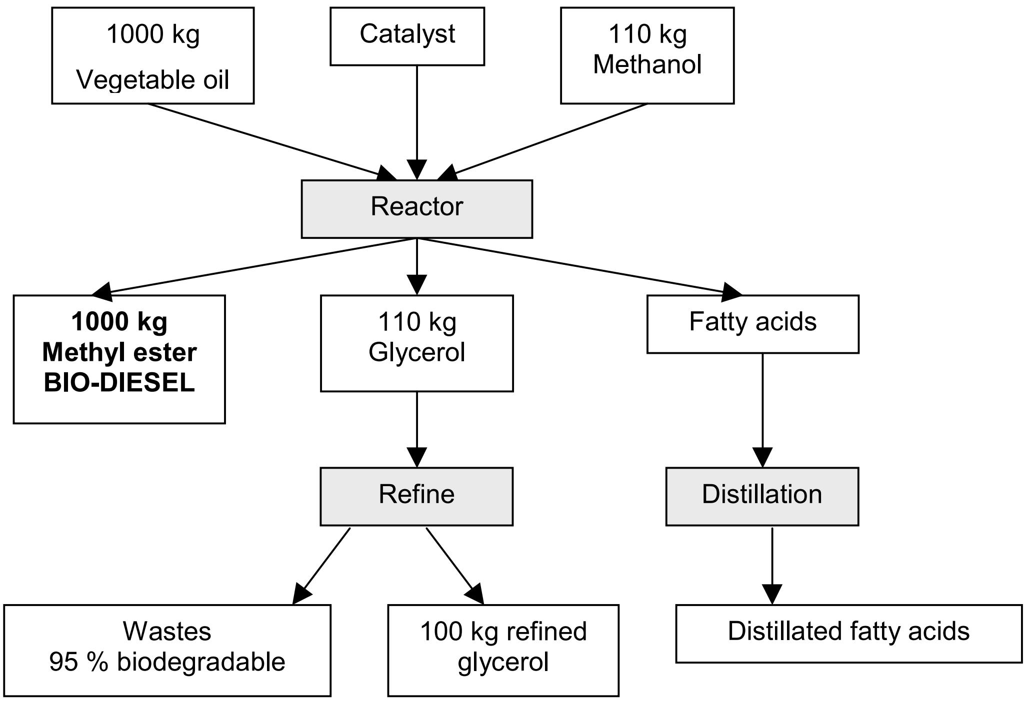
- Esterificated oils: They are produced through reaction with methanol or ethanol in the presence of catalyst, in order to obtain methyl or ethyl ester, depending on the alcohol employed to oils of oleaginous seeds. This is the most wide-spread kind of bio-diesel. It can be injected into Diesel engines either pure or blended with fossil diesel.

- Non-esterificated oils: These oils may be employed only in modified engines with special characteristics. Oils with high acidity degree or other characteristics that could make them unacceptable for human consumption, could be included in this group as well.

- Waste vegetable oils from recycled cooking oils can also be used as bio-diesel. However, before the "trans-esterification" process, they have to be pre-processed, including cleaning and refining. It is required, because of the degradation undergone from the high temperatures reached in their original use.

1.2. BIO-DIESEL PRODUCTION

The most common bio-diesel technology uses the so-called "trans-esterification" technique – a process, which combines oils and fats with mono-alcohol in the presence of base catalyst to form fatty acid esters (bio-diesel), as shown here below. Bio-diesel, glycerol, meals for livestock feeding, fertilisers and other industrial and agricultural by-products are obtained. Yields typically exceed 99 % for most technologies. Bio-diesel has to be filtered and purified to meet fuel grade specifications required for use in diesel engines.



Most alkyl esters produced today are obtained via catalysed reaction, as it is the most efficient for several reasons:

- Low temperature (65º C) and pressure (20 psi) processing;
- High conversion (98 %) with minimal side reactions and reaction time;
- Direct conversion to methyl ester with no intermediate steps;
- No need of special construction materials;

1.3. BIO-DIESEL CHARACTERISTICS AND ENGINE PERFORMANCE

Bio-diesel and fossil diesel have got similar physico-chemical properties – viscosity, boiling temperature, etc. For this reason, bio-diesel may be used in standard diesel engines. The only modifications required are a two-to-three degree retardation of injection timing and replacement of all natural rubber seals with synthetic ones, due to the solvent characteristics of bio-diesel. Bio-diesel is a little bit heavier than fossil diesel (860-900 kg/1000 litres for bio-diesel, towards 820-860 kg/1000 litres for fossil diesel), but this fact does not prevent its mixing with fossil diesel for blended application.

From operational point of view, bio-diesel has got about 92 % of the energy content of fossil diesel, measured on volumetric basis. Due to this fact, on average basis the use of bio-diesel reduces the fuel economy and power with about 8 % in comparison with fossil diesel. In other words, it should take about 1.1 litres of bio-diesel to replace 1 litre of fossil diesel. Some studies indicate that if bio-diesel is used in low blended form, i.e. mixed in relatively low concentrations with fossil diesel (e.g. B5, B20), the fuel economy penalty is reduced. The reason for this improvement stems mainly from the oxygen content of bio-diesel, ensuing better combustion process and improved lubricity, which partly compensate the impact of the lower energy content. However, at present this area still needs further investigations. On the other hand, bio-diesel blends are safer than pure fossil diesel, because bio-diesel has got higher flash point. Most operational disadvantages of pure bio-diesel, e.g. replacement of natural rubber seals, cold start problems, etc., do not arise when using blended kinds of bio-diesel. Low temperatures can cloud and even coagulate any kind of diesel fuel and this applies particularly to bio-diesel. For instance, users of B20 will experience a decrease of the cold flow of approximately 3 to 5°. Precautions beyond those, already employed for fossil diesel, are however not needed for fuelling with B20.

1.4. PRODUCTION OF RAW BIO-MASS AND VEGETABLE OIL FOR BIO-DIESEL

In Europe bio-diesel is predominantly produced from vegetable oils and especially – from rape-seed and sunflower. The production of vegetable oil (either for food or non-food purposes) is carried out with simple, well-tested and efficient agricultural methods.

Rape-seed crop occupies about 85 % of the set-aside area, dedicated to oil crops for non-food purposes. Rape-seed has got higher profitability per hectare with respect to sunflower. Thus, in the present paper rape-seed is considered as a key reference crop for the economic analysis.

Over the past few years, the average rape-seed yield in EU varied between 3.0 and 3.5 t/ha. For the coming years, the average rape-seed yield in EU is expected to be 3.1-3.3 t/ha[1]. However, taking into account that rape-seed for bio-diesel production is cultivated mainly on set-aside areas (which normally have got lower yield), a yield of 2.75 tons per hectare can be considered as a feasible standard. The corresponding mass balance is the following:

[1] "Prospects for agricultural markets 2001-2008", European Commission, Directorate-General for Agriculture, 2001.

- 1 ha rape crop provides 2.75 t seed;
- 1000 kg seed provides in industrial plants:
  - 360 kg oil;
  - 610 kg oil cake ;
  - 12 kg residual fat;
  - 40 kg water;
- 1000 kg oil provides (adding 110 kg methanol):
  - 1000 kg rape oil methyl ester (bio-diesel);
  - 110 kg glycerol;

(Source: IEA-Bioenergy: Biodiesel and Environment in Austria, IPTS data gathering & analysis)

1 ha rape-seed provides about 990 kg oil or about 1090 litres bio-diesel.

Even if rape-seed is the best option for bio-diesel production in most regions of central Europe, the climate of some other areas, e.g. the Mediterranean ones, makes it necessary to assess other options. Amongst all potential oil crops for bio-diesel production in such areas, sunflower should be considered with priority. Sunflower is well adapted to drought conditions (it explores very deep layers, not exploited by other crops), needs little or no fertilisation and little work. For these reasons and despite its lower yield, sunflower is assessed as well.

Over the past few years, the average sunflower yield in EU was above 1.5 t/ha. For the coming years, the average sunflower yield in EU is expected to be 1.7-1.8 t/ha[2]. However, taking into account that sunflower for bio-diesel production will be cultivated mainly on set-aside areas, normally having got lower yield, an average sunflower yield of 1.5 t/ha is assumed for the purposes of calculating its bio-diesel production potential. The mass balance for this crop is the following:

- 1 ha sunflower crop provides 1.5 t seed;
- 1000 kg seed provides 400 kg oil in industrial plants;
- 1000 kg oil provides (adding 110 kg methanol):
  - 1000 kg rape oil methyl ester (bio-diesel);
  - 110 kg glycerol;

(Source: European Energy Crops Inter Network, IPTS data gathering & analysis)

1 ha sunflower provides about 600 kg oil or about 700 litres bio-diesel.

[2] "Prospects for agricultural markets 2001-2008", European Commission, Directorate-General for Agriculture, 2001.

1.5. ENERGY BALANCE

An entire fuel-cycle energy balance assessment should include not only the energy content of bio-diesel and the energy consumed during its manufacturing process, but also the energy absorbed/released by all the necessary processes to obtain the final product. Studies, carried out for bio-diesel, demonstrated that the energy overall balance (including extraction, refining and esterification) is positive.

It has to be pointed out that the overall energy balance depends on the use given to the rape-seed straw. It may be cut and utilised as an energy source or left and ploughed in soil. Several fuel-cycle energy balances for rape-seed, depending on the rape-seed yield per hectare, are shown in Table 1.

Table 1: *Energy balances for bio-diesel from rape-seed in MJ/ha, depending on the rape-seed yield per ha.*

Parameters	ETSU[3]	ARC[4]	Levington[5]	Levington
Seed yield (t/ha)	3.2	3.6	4.08	4.08
Energy inputs				
Agriculture	-4300	-4300	-4687	-4945
Fertilisers	-12800	-12800	-7190	-7190
Agro-chemicals	-600	-600	-337	-337
Seeds	-200	-200	-35	-35
Storage/packaging	-300	-300	-282	-282
Transport	-774	-871	-723	-1122
Processing	-16071	-18080	-17251	-17251
Total input	**-35045**	**-37151**	**-30505**	**-31162**
Final outputs				
Bio-fuel	45800	51525	54346	54346
Cake	3700	4163	1316	1316
Total output without straw	**49500**	**55688**	**55662**	**-**
Energy output / Energy input (straw out)	***1.41***	***1.50***	***1.82***	**-**
Net energy balance without straw	**14455**	**18537**	**25157**	**-**
Straw	38400	43200	0	60000
Total output with straw	**87900**	**98888**	**-**	**115662**
Energy output / Energy input (straw in)	***2.51***	***2.66***	**-**	***3.71***
Net energy balance with straw	**52855**	**61737**	**-**	**84500**

Sources: *Adapted from British Association for Bio Fuels and Oils (BABFO) – (www.biodiesel.co.uk/emissions_from_liquid_biofuels.htm, www.biodiesel.co.uk/levington.htm)*

[3] Energy Technology Support Unit, 1996 study.
[4] Adapted by ECOTEC Research and Consulting the ETSU study with higher yield of rape-seed per ha, according to the more recent standard agricultural pocketbooks (ARC 1999) data.
[5] Levington Agriculture, 2000 study.

In order to optimise the overall process, seed pressing should be carried out close to the crop growing area. This reduces the transportation energy requirements. Bio-oil is then transported to centralised refining plants, where economies of scale are earned.

In addition, the use of dry residuals and crushed seed, still containing 5-10 % oil, may also be burnt to produce electricity. However, this possibility has not been considered in the present techno-economic analysis.

As regard to the sunflower, an energy balance for bio-diesel from this crop gives similar figures. One hectare of sunflower produces less bio-diesel, but on the other hand – more straw is obtained and less fertilisers and agro-chemicals are needed.

1.6. ENVIRONMENTAL PERFORMANCE

Apart from the increased diversity of supply, the use of bio-diesel (in comparison with fossil diesel) provides also environmental benefits in terms of decreased greenhouse and other polluting emissions. The quantification of these environmental benefits usually is performed via the so-called “Well-To-Wheel” (WTW) approach, i.e. measuring the aggregate net emissions over the whole production-consumption chain. On the other hand, the WTW emission results may fluctuate significantly on case-by-case basis, depending on the production pathways and the use of by-products. Therefore, the emission benefits from utilisation of bio-diesel here below are given on tail-pipe measurement basis (except for CO_2, which is always measured on WTW basis), as these parameters can be more precisely defined.

The main advantage of bio-diesel as a renewable fuel is that its use provides significant reductions in CO_2 emissions. There are also reductions in the tail-pipe emissions of Sulphur oxides, particulates and Carbon monoxide (CO). On the other hand, bio-diesel application induces slight increase in emissions of Nitrogen oxides.

It goes without saying that the benefits (and disadvantages) of the bio-diesel use are depending pro-rata on the blend used (B100, B20,…). They depend also on the engine performance, as well as on the engine type.

Specific figures for the potential emission reductions per pollutant from utilisation of bio-diesel are given below.

Carbon Dioxide (CO_2): On WTW basis, every ton of fossil diesel adds about 2.8 tons of CO_2 to the atmosphere. The specific carbon content of 1 ton bio-diesel is slightly lower, about 2.4 tons of CO_2. It may be assumed that this carbon content will be entirely recaptured the next year by crops growing to produce feedstock for vegetable oil, as well as absorbed through the carbon cycle (e.g. like glycerol and solid wastes). Therefore, the net bio-diesel CO_2 emissions might be assumed close to zero, when measured on WTW basis.

Sulphur oxides (SOx): At present, 1 ton of conventional fossil diesel in EU contains 350 ppm Sulphur maximum on average basis. When diesel is burnt, Sulphur is released to the atmosphere in the form of Sulphur oxides, contributing to the formation of acid rain. Bio-diesel is almost free of Sulphur (content between 0 and 0.0024 ppm[6]). On the other hand, in EU there is a steady trend to promote application of low-Sulphur diesel fuels, e.g. with Sulphur content below 50 ppm (The UK) or below 10 ppm (Sweden). The ultra low-Sulphur diesel is expected to enter the EU fuel market in a foreseeable future.

Nitrogen oxides (NOx): NOx emissions from bio-diesel may increase or decrease with respect to those ones from fossil diesel, depending on the engine family and testing procedures. NOx emissions from pure bio-diesel increase with about 6 % compared to fossil diesel on average basis. However, bio-diesel's lack of Sulphur allows use of NOx control technologies, which cannot be used with conventional fossil diesel. So, when used in pure form or blended with ultra low-Sulphur fossil diesel, bio-diesel NOx emissions could be successfully managed and eliminated.

Carbon Monoxide (CO): Bio-diesel contains oxygenates, which improve combustion process and emission profile. This fact significantly decreases (at least with 20 %) Carbon Monoxide emissions.

Particulate matters (PM): Breathing particulate has been proven to be a serious human health hazard. The exhaust emissions of particulate matter from bio-diesel are much lower (40 % and more) than the overall particulate matter emissions from conventional fossil diesel.

Bio-degradability: Fossil diesel degrades only 50 % during the first 21 days after spilling, while bio-diesel is 98 % harmless, broken down over the same period.

In addition to the above data, B100 reduces cancer risk by 94 %. Consecutively, B20 is reducing cancer risk by 27 %.

Table 2 compares bio-diesel emissions with fossil diesel emissions on tail-pipe basis (except for CO_2, which is given on life-cycle basis), considering fossil diesel emissions as to 100 %.

[6] "Biodiesel-Clean, Green Diesel Fuel", US Department of Energy (DOE), September 2001, page 4

Table 2: *Bio-diesel tail-pipe emission changes compared to the tail-pipe emissions of the conventional fossil diesel*

Emission Type	B100	B20
Carbon monoxide	-43.2 %	-12.6 %
Hydrocarbons	-56.3 %	-11.0 %
Particulates	-55.4 %	-18.0 %
Nitrogen oxides	+5.8 %	+1.2 %
Air toxics	-60 % / -90 %	-12 % / -20 %
Mutagenicity	-80 % / -90 %	-20 %
Carbon Dioxide (Life Cycle Emissions)	-78.3 %	-15.7 %

Source: *US Department of Energy (DOE) – National Renewable Energy Laboratory*[7]

It has to be pointed out that the extent of the life-cycle CO_2 emissions is highly depending on the production pathway of bio-diesel. In most cases, it ranges between 80 % and 95 % of CO_2 saving with respect to fossil diesel.

[7] "BIODIESEL Handling and Use Guidelines", US Department of Energy (DOE), September 2001, page 7

2. EU POLICIES CONCERNING BIO-DIESEL

2.1. ENERGY POLICY FOR RENEWABLE ENERGY AND BIO-DIESEL

The increasing emissions of greenhouse gases (due mainly to the increasing demand and use of fossil fuels) and their impact on the world climate, is a reason of growing concern. This issue has led to a number of political commitments and considerations, aiming to reduce the overall emissions of greenhouse gases and especially – of CO_2. In the context of the Rio Conference and the Kyoto Protocol, the EU has committed itself to reduce its overall greenhouse emissions, CO_2 having got the major share in these emissions, with 8 % by 2008-2012 compared to1990.

Back to 1996, the White Paper on "Energy Policy for the European Union" anticipated that, in spite of the increasing energy efficiency gains, final energy demand (and therefore also primary energy consumption) would uninterruptedly increase in the EU. The dependency on imported energy was supposed also to increase in the next decades, unless drastic progress in the renewable energy sector occurs. By that time, characterised with relative low crude oil prices, it was difficult to anticipate significant changes in the supply to the transport sector. These prospects have been modified to some extent by the crude oil shock prices of 1999-2000, but the key conclusions remain basically unchanged.

Putting together these baseline projections with the necessity to curb carbon emissions, it becomes urgent to implement policy measures to reduce carbon intensity of some sectors and particularly – of road transport. In this respect, bio-energy could play larger role in the fuel mix. Bio-mass burning (with or without processing) releases to the atmosphere only as much CO_2 as it has been bound by the plants while growing. Roughly speaking (and depending on the type of fuel and the engine efficiency changes) the utilisation of 1 kg bio-diesel reduces CO_2 emission with about 2.8 kg.

The White Paper for Renewable Energy Resources, adopted in November 1997, introduced indicative targets for a more sustainable energy system in EU. The main objective envisaged was to double (from 6 % to 12 %) the share of renewable energy resources in the total EU energy consumption by 2010. Bio-energy was supposed to play a crucial role in this renewable share expansion. Beyond environmental benefits, a range of other factors argues for greater exploitation of bio-energy carriers, in particular within the transport sector, heavily depending on high-grade fuels. While a number of technologies and energy sources can be used for stationary energy plants, the opportunities for transport are rather limited, being in practice locked within the scope of the internal combustion engine. In this context, liquid bio-fuels are the only renewable source of energy for transport, which can be used at present without any technological changes in the existing vehicle fleet.

The recent Green Paper "Towards an European Strategy for the Security of Energy Supply" delineates a long-term energy strategy for the EU. A rebalance is required to complement the supply policy by clear actions in favour of a demand-side management policy. The paper courageously puts into evidence the narrow margins for manoeuvring, gives the high dependence on imported resources, the cost structure of energy sector and the severe environmental constraints. Supply side measures are therefore expected to be almost useless if not complemented with actions addressing efficiency measures and demand management closer to the final consumer.

This twofold aspect of the policy portfolio, addressed by the Green Paper, is outlined as follows:

- With regard to the demand-side, the Green Paper is calling for a real change in consumer behaviour and highlights the value of taxation measures to steer demand towards better-controlled consumption that is more respectful with environment.
- With regard to the supply-side, development of options, leading to a change towards less carbon-intensive technological solutions, is a crucial priority, given to the constraints imposed by the fight against global warming. The development of new and renewable energies (including bio-fuels) is recognised as a necessary and key step to foster such change.

Amongst final energy demand sectors, transport is a crucial sector, first – due to its increasing share in the final consumption mix (over 30 % of the total final energy consumption), and second – because it is almost fully dependent on liquid fossil fuels. Transport policy is therefore a priority area for energy efficiency. Road traffic is of particular importance as it accounts for about 84 % of the overall CO_2 emissions from transport. Concerning novel road transport schemes, it is expected that new generation fuels will start their market penetration in captive fleets and urban transport, simply to minimise logistic and distribution problems. Such fuels would derive from a larger variety of primary energy vectors, including bio-fuels. In this context, the market for transportation bio-fuels in EU is still poor. In 1998 it amounted to about 0.2 % of the total consumption of fossil fuels in transport. The key barriers for a deeper market penetration of bio-fuels are mainly due to their high cost. Their price differential with fossil fuels currently varies from 1.5 to 3 times for products before tax, depending on the type of bio-fuel and the prevailing crude oil price. Therefore, it is generally considered that a steady enhancement of bio-fuel application (and in particular – of bio-diesel) is feasible only if a number of economic and regulatory incentives takes place.

2.2. AGRICULTURAL POLICY AND BIO-DIESEL

The Common Agricultural Policy Reform of 1992 established crop specific payments per hectare to compensate the reduction or abolition of institutional prices. These payments are based on historic regional yields and are awarded to producers, who set aside a defined percentage of land, which it was requested for.

The reference set-aside share is currently 10 %, but the applied set-aside rates have been adapted year-by-year, taking into account the market forecasts. Furthermore, farmers are flexible in the management of their set-aside obligations. They may use the set-aside land to grow crops, whose final dedication is non-food or feed – the so called “non-food crops”, still receiving compensatory payments. Oil-seeds are the main crops concerned by this scheme (for chemical application and bio-fuels) – almost 90 % of the EU non-food production area on set-aside are planted with oil-seeds.

Within Agenda 2000, there are no specific proposals for non-food agricultural policy. On the other hand, by closing the gap between internal and world prices, it aims to put at the disposal of food and non-food agro-industries more competitive feedstock.

Under Agenda 2000, the level of direct payments is the same for cereals, oil-seeds and set-aside. Given that the cultivation of non-food crops under set-aside scheme still remains possible, food and non-food crops are put on equal footing. The slight reduction of set-aside payments under Agenda 2000 will not have any effect. The key factor is the **relative profit margin**.

In principal, producers, subject to set-aside obligations, will have two alternatives: either setting land aside or growing crops for non-food application. The key factor, governing their choice, will be the income, which they expect.

In the case of set-aside, the income is incurred by the difference between the regional set-aside payment per hectare and the cost for maintaining the land in set-aside condition.

In the case of non-food production, they will receive (in addition to the set-aside payment) market revenue for the cultivated and sold crop. On the other hand, they will face costs of producing the crop. Since land and also in most cases – machinery are available, these costs will be normally variable costs of production.

The market revenue will depend on the yield per hectare and on the price, which can be obtained for the crop, when it is sold for non-food purposes. In the case of bio-fuels, prices, which processors are willing to pay to farmers, are lower than the prices for the same crop but for food or feed use. In fact, these prices are based on the prices of the competing fossil fuels. On the other hand, these prices generally are not attractive for farmers, unless supporting measures are taking place. Partial or total exemption from hydrocarbon taxes, applicable to bio-fuels, is a feasible measure, which might be applied in this context.

With no compulsory set-aside rate, farmers will have no more reason to grow and sell rape-seed for diester production at lower prices. When selling rape-seed to the crusher, farmers will not accept price lower than that one they expect from the food or feed market. Thus, the key question is to assess to what extent processors will be able to pay such a price. This will depend on the price, which they can get for their product on the fuel market, as well as on the production costs of diester. Under these conditions, the main risk barrier for the bio-diesel market in Europe is the uncertainty surrounding the feedstock availability. Farmers will hesitate to tie-up their most important resource – the land, for a number of years, with a crop, whose market is uncertain.

The possibility of **growing non-food crops under compulsory set-aside scheme is an opportunity for the bio-diesel market, but it is not an appropriate instrument to promote non-food production**. The sustainability of non-food crops and consequently – of the bio-diesel industry, cannot be based on a set-aside rate, which can vary from year to year, according to the prevailing market situation for food commodities

In this context and in addition to the opportunity provided by the compulsory set-aside scheme, the **tax exemption is a key condition for the market feasibility of liquid bio-fuels**. In absence of compulsory set-aside, this condition becomes even more important.

2.3. CURRENT RTD IN EUROPE

Most current RTD activities in EU are pilot demonstration projects, implemented in several cities. Some examples are given here below (main source: ATLAS database).

France

The AGRICE research group was established in 1994, co-ordinating research projects on Agriculture, Industry and Environment. Activities are co-ordinated with the INRA (National Institute for Research in Agronomy), IFP (French Institute of Petroleum), many private companies (TOTAL, Rhône-Poulenc) and professional associations. The French agency for Energy Management (ADEME) has been appointed to ensure the co-ordination and management of this group. AGRICE's mission is to develop research partnerships for new market outlets for agricultural products such as liquid and solid bio-fuels, biodegradable products. The objectives are protecting the environment, increasing energy independence and farmer’s income, reducing the amount of fallow land, etc. A top priority is to reduce the production cost of liquid bio-fuels with 0.152 Euro/l before 2005.

Belgium

The Flemish technology agency VITO has financed and co-ordinated demonstration projects for use of B100 in light duty vehicles. TEC Hainaut has performed experiments, using bio-diesel in public buses. Successful tests were made with B20 and B100.

Spain

There is an on-going experimental program to demonstrate the technical viability of using rape-seed bio-diesel in public transport in Vitoria, with involvement of the central, regional and local governments, and financial support from the EU Altener Program. There is also an experimental program in Zaragoza to demonstrate the technical viability of using sunflower bio-diesel, with involvement of the local university and electric utilities. Similar programs for using sunflower bio-diesel are ongoing in Madrid and Valladolid, with involvement of the central government and other stakeholders. The project will operate four buses, running at B30 for the period of 1 year. All these projects are also supported by the EU Altener Program.

The Netherlands

Demonstration project for rape-seed bio-diesel is under way in the city of Rotterdam. There is also a demonstration project to assess the viability of bio-diesel as a fuel in marine engines.

United Kingdom

There is a number of projects demonstrating the use of bio-diesel in the UK. Research has been carried out also on the life-cycle energy use and environmental impacts, associated with the production and use of a variety of alternative fuels for transport.

3. TECHNO-ECONOMIC ANALYSIS

3.1. BIO-DIESEL PRODUCTION ECONOMIC BALANCE

It should be pointed out that several (non-technological) limiting factors have been stopping until now the development of the bio-diesel industry. These limiting factors are feedstock prices, bio-diesel production costs, crude oil prices and taxation of energy products.

3.1.1. Feedstock prices

No matter the technological process adopted for bio-diesel manufacturing, the largest share of production cost of bio-diesel is the feedstock cost. In this context, the feedstock cost is the major obstacle to the market feasibility of bio-diesel. Rape-seed, used in bio-diesel sector, covers around half of the non-food area under set-aside scheme. Therefore, special emphasis is given to the analysis of costs and the performance of this crop as a key raw material for bio-diesel production.

In the recent years, the total production costs of bio-diesel have fallen, despite the progressive increase of the prices paid for rape-seed. The downward trend in bio-diesel production costs is expected to continue.

According to the outlook projections of DG AGRI[8], whereas the short-term perspectives will remain characterised by very low prices, induced by excess supply, the medium-term prospects for world oil-seed prices indicate that a gradual and moderate price recovery can be assumed. According to this forecast, rape-seed prices are expected to increase from 214 Euro/t in 2000/01 to 242 Euro/t in 2007/08.

In order to consider bio-diesel as a real choice for farmers, the final price paid for non-food rape-seed should be equal to the food rape-seed price. Therefore, it seems reasonable to establish 214 Euro/t as a reference price for the next few years

[8] "Prospects for Agricultural Markets 2000-2007", European Commission, Directorate-General for Agriculture, November 2000.

3.1.2. Bio-diesel production costs

The estimated costs for bio-diesel can be split up into fixed and variable costs. Fixed costs are estimated for extracting the vegetable oil from seed and for processing this vegetable oil into bio-diesel. These costs include manufacturing, capital (considering depreciation) and labour costs.

Referring to different sources, the typical cost of a bio-diesel manufacturing plant is ranging about 100 Keuro/1000 t/y. This parameter is not likely to undergo significant reductions in the near future. Assuming 10 % discount factor and 15 years average lifetime of the plant, this would yield an annualised capital cost of around 0.012 Euro/l.

Glycerol and protein-meal for livestock feeding are by-products that might help to offset the cost of bio-diesel production. The sale of these by-products is considered as a fixed income.

Rape-seed price (Pr) is considered as a variable one. It is also considered that manufacturing 1 litre of bio-diesel needs 2.23 kg. rape-seed on average basis.

The cost breakdown of bio-diesel production, as a function of rape-seed price, is given in Table 3.

Table 3: *Bio-diesel cost production depending on rape-seed price in Euro/l*

Fixed costs	
Manufacturing costs	0.147
Capital costs (annualised)	0.012
Staff and overhead costs	0.005
Fixed income	
By-products income	0.084
TOTAL fixed factors	**0.080**
Variable costs	
1 l of bio-diesel requires 2.23 kg of rape-seed	**Pr*2.23**
TOTAL PRODUCTION COSTS	**0.08 + Pr*2.23**

Remark: (Pr) - rape-seed price

Sources: ATLAS Database, US National Renewable Energy Laboratory (NREL), IPTS data gathering & elaboration

By assuming the reference rape-seed price of 0.214 Euro/kg, a net cost of 0.557 Euro/l bio-diesel is obtained.

Three salient facts have to be underlined with respect to this cost structure.

First of all, the largest share in the final costs belongs to the procurement costs of bio-mass. In the above case, the share of the rape-seed cost in the final product is about 70 %. Other reports, quoted by the US NREL, state a raw material cost share up to 90 % of the total cost. This share mainly depends on the assumptions made about the prices of raw bio-mass.

The second salient fact is that the sale of by-products is an important source of income, which rises significantly the competitiveness of the overall process. In the above scenario, the income from by-products consists of about 15 % of the total production costs. Other reports state for this figure even 35 % share of the total production cost.

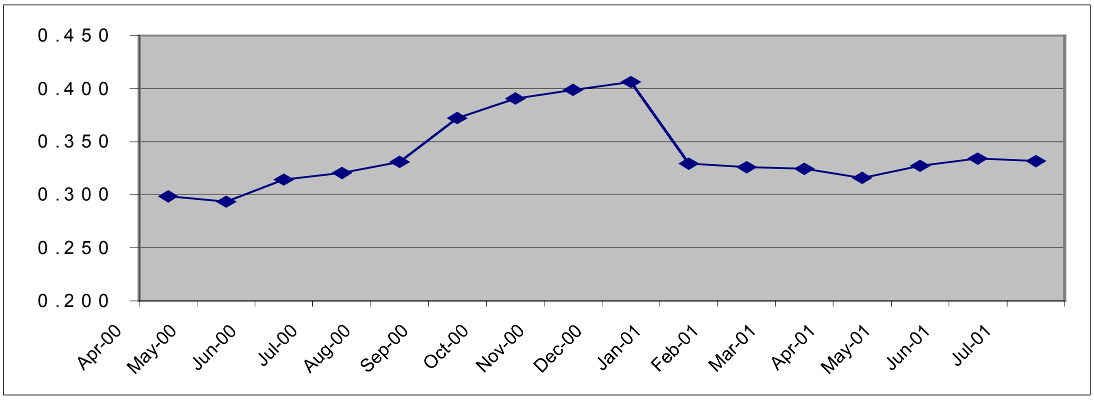
At the last, but not at the least, when making cost and price comparisons between bio-diesel and fossil diesel, a parameter, reflecting the fuel consumption substitution ratio between bio-diesel and fossil diesel, ensuing from their different energy content, should be applied. For the purposes of the calculations in the present paper, the average energy content of bio-diesel is taken as 32.8 MJ/litre and the average energy content of fossil diesel is taken as 35.7 MJ/litre[9]. Referring to these figures, the fuel consumption substitution ratio “bio-diesel / fossil diesel” is equal to 1.088.

3.1.3. Crude oil prices

Low production costs of crude oil derivatives are another crucial handicap for the bio-diesel marketing. In this sense, the continuous increase of crude oil prices approaches bio-diesel production cost to those ones of fossil diesel, converting this difference from handicap to a potential opportunity for enhancing the bio-diesel application.

The evolution of fossil diesel prices in EU is shown in Figures 1 and 2 respectively.

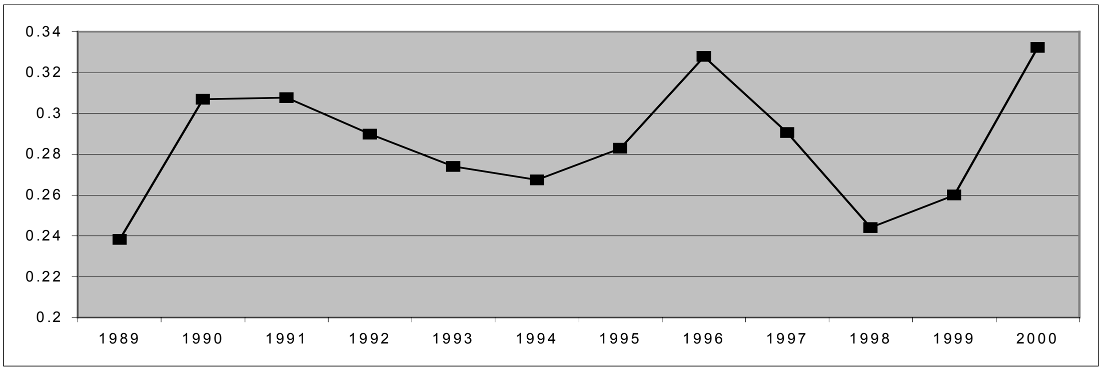
Figure 1: *Automotive average fossil diesel consumer prices, net of duties and taxes, in Euro/l.*



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

[9] Source: “Automotive Fuels for the Future – The Search for Alternatives”, International Energy Agency, page 20.

Figure 2: *Price of fossil diesel (commercial use) Euro/l (excluding taxes)*



Source: *Enerdata Data Base*

3.1.4. Taxation of energy products

There is no harmonised European policy, either for fossil fuels or for bio-fuels. Each Member State implements own domestic regulations, inside the EU framework for taxation of energy products.

However, there are **minimum levels of taxation**, applicable to automotive gas oil (including fossil diesel): ECU 343 per 1000 litres as from 1 January 2000 and EUR 393 per 1000 litres as from 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.

On the other hand, Member States may apply **total or partial tax exemptions** or reductions for energy products used under fiscal control in pilot projects for technological development. Also, such preferences might be applied for more environmentally-friendly products or in relation to fuels from renewable sources, e.g. bio-diesel.

3.2. BIO-DIESEL TAXATION SCENARIOS

In the following paragraphs different tax level scenarios are presented. First of all, the current bio-diesel production costs (see 3.1.2.) are assessed. Then, a scenario, assuming 0.152 Euro/l reduction in production costs, according to the RTD priorities of the EC-ATLAS report, is described. Finally, a possible tax, linked to the CO_2 emissions, applied to fossil diesel, is calculated, as well as the cost of the avoided emissions, due to the fossil diesel replacement by bio-diesel.

3.2.1. Bio-diesel taxation scenarios at current production costs

The EC intends to develop a market for bio-fuels and recommends time-limited considerable exemptions or reductions of taxes on bio-fuels during the first 10 years and then to increase them stepwise. Table 4 compares the final bio-diesel price with this one of fossil diesel, depending on the tax level applied. The scenarios considered are total exemption, 10 % partial exemption from diesel taxation and full diesel taxation.

The following pre-conditions have been taken into account:

- Current production costs: 0.08 + 2.23*rape-seed price.
- Fossil diesel prices as an average over the period July 2000 / July 2001.
- Taxes: minimum level of taxation applicable to fossil diesel – 0.393 Euro/l.
- Rape-seed price is considered fixed to 0.214 Euro/kg.
- 1.088 fuel consumption substitution ratio "bio-diesel / fossil diesel".

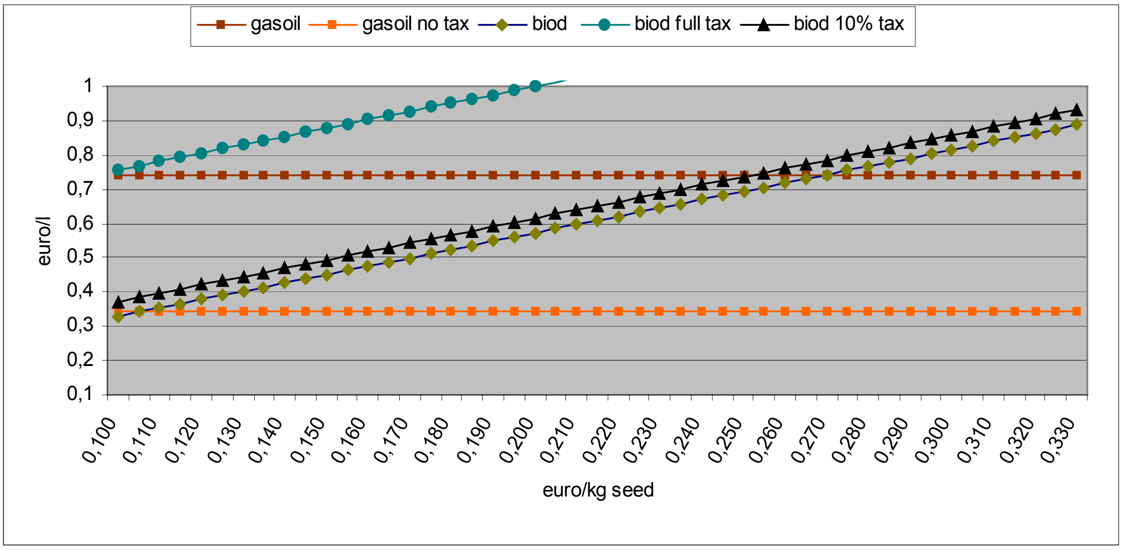
Table 4: *Bio-diesel taxation level scenarios at current costs*

Euro/l	BIO-DIESEL Total tax exemption	BIO-DIESEL 10 % level of the full fossil diesel taxation	BIO-DIESEL Full fossil diesel taxation	FOSSIL DIESEL Average price full taxation
Production cost	0.557	0.557	0.557	0.346
Taxes	0	0.039	0.393	0.393
Total, per litre	0.557	0.596	0.950	0.739
TOTAL, including the fuel substitution ratio	**0.606**	**0.650**	**1.034**	**0.739**

The figures from the last row of Table 4 indicates that a final cost of bio-diesel lower than the final cost of fossil diesel can occur only within scenarios of total or partial tax exemption.

Figure 3 presents the same scenarios, but depending now on the rape-seed prices.

Figure 3: *Bio-diesel taxation level scenarios at current costs, depending on rape-seed price*



Some results may be outlined from Figure 3:

- Producing bio-diesel at the same price as gas-oil (fossil diesel), considering current costs, is only possible at very low rape-seed prices - about 0.092 Euro/kg, which is less than half of the price expected for the year 2007. This is not a feasible scenario if we consider that farmer's income should be maintained.
- Considering total tax exemption, prices paid for rape-seed could reach 0.269 Euro/kg.

3.2.2. Bio-diesel taxation scenarios at lower production costs

A top priority of RTD, identified by ATLAS (according to the ADEME paper), is to reduce the production cost of liquid bio-fuels by at least 0.152 Euro/l before 2005. Assuming this target as a feasible cost reduction (and assuming also that the cost curve is still linear in the price range of raw material), it is obvious that such a cost reduction will require both lower production costs and higher prices of by-products. Under these circumstances, the bio-diesel cost, depending on the rape-seed price, is compared with the fossil diesel price in Figure 4.

The following pre-conditions have been taken into account:

- Bio-diesel “low cost”, obtained by reducing with 0.152 Euro/l the current production costs: 0.08 - 0.152+ Pr*2.23
- Fossil diesel price as an average over the period July 2000 / July 2001.
- Taxes: minimum level of taxation applicable to fossil diesel: 0.393 Euro/l.
- 1.088 fuel consumption substitution ratio “bio-diesel / fossil diesel”.

Figure 4: *Bio-diesel taxation level scenarios at lower production costs, depending on rape-seed price*

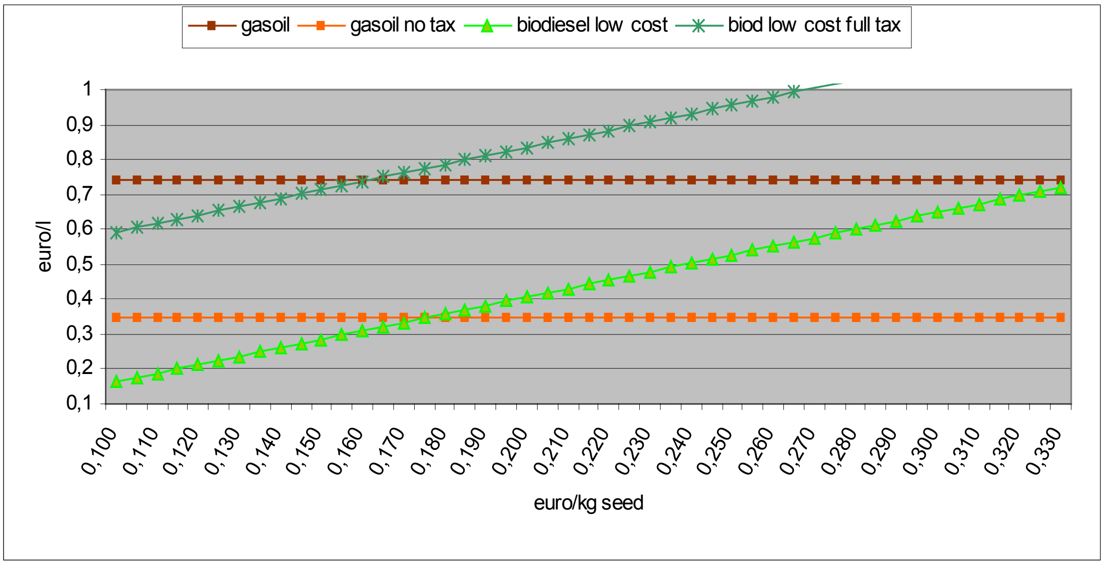


Figure 4 shows that the production of low-cost bio-diesel at competitive prices (without fiscal incentives) is feasible if stable supply of rape-seed at prices not higher than 0.161 Euro/kg is guaranteed. However, if we combine the assumption about lower total production costs (due to cheaper technology, lower running costs and higher prices for by-products) and total tax exemption, the rape-seed price paid to farmers could reach 0.337 Euro/kg preserving the competitiveness of bio-diesel with respect to the full-taxed fossil diesel.

It can be concluded that partial or total exemption of bio-diesel might be followed by an increased supply of feedstock, based on long-term supply commitment of farmers. Nevertheless, as the continuous technological progress decreases more and more the total production costs of bio-diesel, total tax exemption potentially might become unnecessary in a long run, being modified accordingly, depending on the technological achievements obtained.

Bio-fuels are not likely to become competitive without fiscal incentives, guaranteed supplies of raw materials and stable prices. No investment should be expected without certainty in gaining long-term fiscal advantage.

3.2.3. Tax linked to the CO_2 emissions

The still increasing fossil fuel consumption of transport is responsible for the large growth rate in greenhouse gas emissions, mainly of CO_2, in the most advanced economies. According to Eurostat estimations, about 28 % of the CO_2 emissions in the EU presently come from transport, only road transport being responsible for 84 % of them. 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 sector structure of carbon emissions in many advanced economies is that, while other sectors (industry, residential, tertiary, power generation, etc.) reduce their greenhouse gas emissions, transport increases its emissions with a relatively large and stable growing rate. CO_2 emissions from transport have increased by 18 % between 1990 (the Kyoto Protocol reference year) and 1998 in the EU. Over the whole period 1990-2010 the baseline projections foresee the share of transport-generated CO_2 emissions to reach 40 % of the total carbon emissions. Thus, transport sector continues to face the well-known conflict between consumption and environmental protection. On the one hand, society is warmly welcoming the new opportunities for personal mobility, offered by the technology progress. On the other hand, society is less and less willing to accept the negative impacts on safety, health and environment, induced by such a consumer's behaviour. Therefore, meeting the Kyoto Protocol commitments of EU and controlling CO_2 emissions are a key point in the EU energy and transport policy. Without measures in both these sectors, any climate changes policy is most likely to fail. Climate protection measures can only be effective if the EU makes a firm commitment to undertake concrete measures (including fiscal and regulatory ones), aiming at promotion of energy saving and utilisation of renewable energy sources. Despite significant disparities amongst Member States, taxation can be an effective tool in the EU energy policy. The internalisation of external costs, linked to degradation of the environment and the application of the polluter-pays principle can be effectively attained by tax incentives.

The following section faces eventual taxation of fossil diesel (gas oil), linked to the CO_2 emissions, as well as the cost of the avoided emissions, due to the replacement of fossil diesel by bio-diesel.

Tax linked to the CO_2 emissions, applied to fossil diesel

Assuming that on WTW basis CO_2 emissions of bio-diesel could be entirely recaptured and absorbed through the carbon cycle, then the net bio-diesel CO_2 emissions are close to zero (see 1.6). Given the carbon content of fossil diesel, the replacement of 1 litre fossil diesel by 1.1 litres bio-diesel will avoid emission of about 2.8 kg CO_2, measured on WTW basis**.**

According to some analysis, the equivalent carbon tax, linked to CO_2 emissions, would range from 30 to 80 Euro per CO_2 ton emitted[10]. The corresponding equivalent tax for fossil diesel then would be between 0.084 and 0.224 Euro/l. If these amounts are added to the average price of fossil diesel (0.739 Euro/l), its final price will be between 0.823 and 0.963 Euro/gas-oil. These prices are much closer to the bio-diesel price calculated on a full tax scenario (1.034 Euro/l, including the fuel consumption substitution ratio), and definitely above the bio-diesel price in the case of full tax exemption (0.606 Euro/l, including the fuel consumption substitution ratio). Therefore, an eventual taxation of carbon emissions, either by (further) taxing fossil carbon or by establishing an emission allowance market, would increase the competitiveness of bio-diesel.

Cost of the avoided emissions due to the fossil diesel replacement by bio-diesel

Taking into account the prices for fossil diesel and bio-diesel under the scenario of full fuel taxation and the rape-seed price of 0.214 Euro/kg (0.739 Euro/l for fossil diesel and 1.034 Euro/l for bio-diesel, including the fuel consumption substitution ratio), the difference between bio-diesel and fossil diesel price is 0.295 Euro/l. **Consequently, this price difference would imply 105 Euro per ton fossil diesel equivalent as an implicit cost of the avoided CO_2 emissions**.

3.3. BIO-DIESEL BLENDS

As it has been already shown, at current production costs bio-diesel is not competitive to fossil diesel. Up to present the high production cost of bio-diesel has notably hindered its wider application in road transport. However, the economic balance of blended application of bio-diesel shows that bio-diesel mixtures are much more feasible alternative to promote application of bio-diesel on the fuel market, than application of pure bio-diesel.

Currently, 50 % of French diesel cars run on up to 5 % diester, incorporated into fossil diesel and 4000 vehicles (mainly city buses) use 30 % diester blend of diesel fuel. The mix of diester into fossil diesel was favoured by the 1997 EU regulation, requiring reductions in the Sulphur content in fossil fuels. As diester is almost free of Sulphur it has been largely used as a Sulphur-free lubricant since the implementation of the 1997 regulation.

Figure 5 presents the possible costs of 5, 20 and 30 % bio-diesel blends, depending on the rape-seed prices. Bio-diesel additive is free of taxes, but the fuel consumption substitution ration between bio-diesel and fossil diesel (1.088) is taken into account.

[10] Green Paper on the Establishing of an EU Market for CO_2 Emissions Rights, EC 2000 and references therein

Figure 5: *Prices for B5, B20 and B30 blends depending on the rape-seed prices*

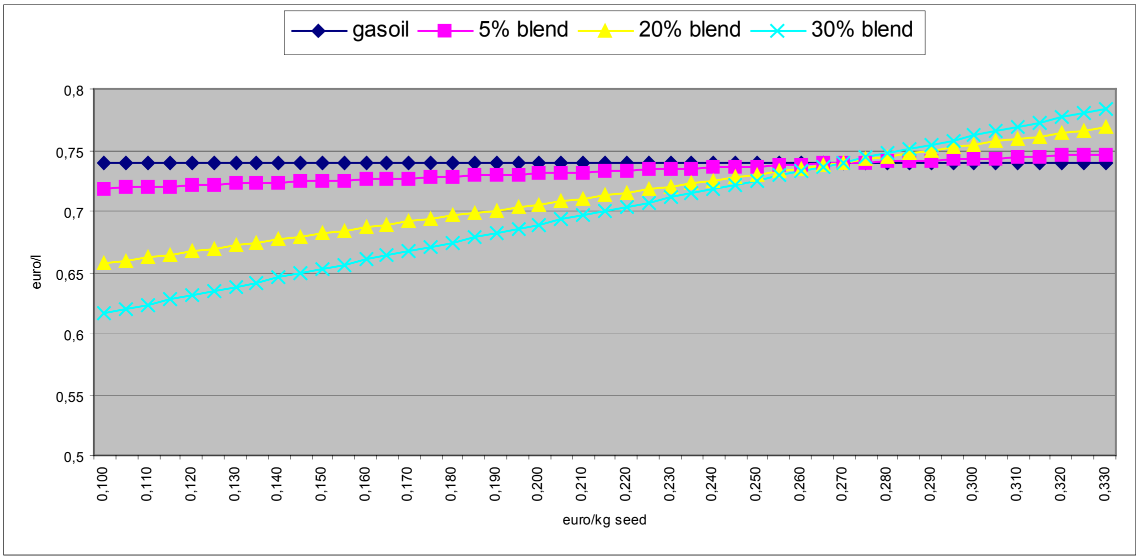


Figure 5 shows that with prices for rape-seed below 0.270 Euro/kg, all bio-diesel blends have got lower cost than the full-taxed fossil diesel. This threshold price is much higher than those ones, expected for the next few years. However, it should be pointed out one more time that the bio-diesel share in the blended fuel is free of any fuel taxes.

Assuming full tax exemption for bio-diesel, fossil diesel price of 0.739 Euro/l and three hypotheses about trends in rape-seed prices (low, average and high price), the corresponding reductions in the final price of blended diesel are shown in Table 5. Calculations include the 1.088 fuel consumption substitution ratio for the bio-diesel additive.

Table 5: *Costs reductions of blended diesel as compared to the full taxed fossil diesel*

Euro per litre	**Rape-seed price 0.200 Euro/kg**	**Rape-seed price 0.214 Euro/kg**	**Rape-seed price 0.242 Euro/kg**
5 % blend	0.008	0.007	0.003
20 % blend	0.033	0.027	0.013
30 % blend	0.050	0.040	0.019

Blends are a real opportunity to promote bio-diesel application, giving an appropriate income to farmers and competitive prices to final fuel consumers. In parallel, they contribute (pro-rata of the share of the bio-additive) to a better environmental performance of transport.

3.4. BIO-DIESEL POTENTIAL IN EU

In EU vegetable oils are considered as the most appropriate raw material for bio-diesel production. Oil-seeds account to a considerable land area in France, Spain, the U.K. and Germany, as well as in many Eastern European countries.

The large scale production of bio-diesel started upon the implementation of the reformed EU Common Agricultural Policy. The set-aside, which previously had been non-existent, has been made compulsory with the option to grow non-food crops. For this reason, almost all the oil-seed production for non-food purposes is now grown on set-aside land.

According to the information available[11], the set-aside land in EU, used for production of non-food crops, totalled 474 000 hectares in 1998/99, compared with 451 000 hectares in 1997/98.

From these 474 000 hectares for non-food purposes in 1998/99, 408 000 hectares were under oil-seed crops, i.e. rape-seed (354 000 hectares) and sunflower (61 000 hectares). About 60 % of this production were used for production of bio-diesel and 40 % for production of lubricants and chemicals.

Table 6: *Non-food production area on set-aside in EU (1000 ha)*

	EU-12		**EU-15**			
1000 ha	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**
Rape-seed	172	479	825	571	311	354
Sunflower seed	32	138	144	89	82	61
Linseed	22	59	28	0	0	0
Cereals	9	16	18	18(e)	18(e)	18(e)
Sugar beet	1	6	6	12(e)	12(e)	12(e)
Short rotation	0	0	14	18	18	19
Medicine plants	4	6	6	6(e)	6(e)	6(e)
Others	2	3	4	4(e)	4(e)	4(e)
TOTAL	**242**	**707**	**1045**	**718**	**451**	**474**
Set-aside area	15%	12%	10%	5%	5%	10%
% oilseeds	**94%**	**96%**	**95%**	**92%**	**87%**	**88%**

Remark: (e) estimation

Source: *Directorate-General Agriculture*

According to the "Prospects for Agricultural Markets 2000-2007", the non-food oilseed area is estimated to adapt to the level of the set-aside rate and to stabilise at around 0.8 million hectares over the period 2000/01-2007/08. Oil-seed yields are expected to increase in medium-term aspect and to reach 2.7 t/ha on average basis for all oil-seeds in 2007/08. Thus, the non-food production is expected to increase up to about 2.3 million tons in medium-term.

[11] COM (2000) 485 final, The Agricultural situation in the European Union, 1999 Report.

Finally, different potential replacement rates of fossil diesel by bio-diesel are presented in Table 7, considering:

- Diesel consumption of road transport in EU: 120 million tons.
- Rape-seed and sunflower as bio-diesel raw materials, with average yield of bio-diesel per hectare – 990 and 600 kg respectively.
- Three hypotheses on crop distribution:
  - 100 % of the surface for bio-diesel production occupied by rape-seed;
  - 70 % of the surface for bio-diesel production occupied by rape-seed and 30 % - by sunflower;
  - 50 % of the surface for bio-diesel production occupied by rape-seed and 50 % - by sunflower;
- 1.14 fuel consumption substitution ratio "bio-diesel / fossil diesel" on weight basis[12].

Table 7: *Oil-seed surface and potential bio-diesel production*

Fossil diesel Replacement Rate (%)	Fossil diesel Replaced 1000 tons	Bio-diesel Needed 1000 tons	Land area needed (1000 ha)		
			100 % Rape-seed	70 % rape-seed 30 % sunflower	50 % rape-seed 50 % sunflower
1	1 200	1 368	1 382	1 651	1 831
2	2 400	2 736	2 764	3 303	3 662
3	3 600	4 104	4 145	4 954	5 493
4	4 800	5 472	5 527	6 605	7 324
5	6 000	6 840	6 909	8 256	9 155
6	7 200	8 208	8 291	9 908	10 985
10	12 000	13 680	13 818	16 513	18 309
15	18 000	20 520	20 727	24 769	27 464
20	24 000	27 360	27 636	33 025	36 618

Apart from the figures in Table 7, following conclusions might be highlighted as well:

- With the prevailing surface, dedicated for growing non-food oil-seeds, the replacement rate reaches only 0.3 % of the total diesel consumption.
- If the whole EU set-aside area (about 5.5 mio hectares) is used for production of bio-diesel, the replacement rate would be:
  - 4.0 % for 100 % rape-seed,
  - 3.5 % for 70 % rape-seed & 30 % sunflower and
  - 3.2 % for 50 % rape-seed & 50 % sunflower crop composition scenarios.

[12] As calculations in Tables 7 are given in tons, the 1.088 fuel consumption substitution ratio between bio-diesel and fossil diesel on volumetric basis is re-calculated on weight basis, being 1.14. The re-calculation has been done basis average density of fossil diesel and bio-diesel 840 kg / 1000 l and 880 kg / 1000 l respectively (see 1.3.) and average energy content per liter of fossil diesel and bio-diesel 35.7 MJ and 32.8 MJ respectively (see 3.1.2.).

4. CONCLUSIONS

It is well known that transport is almost totally dependent on fossil fuels. This critical situation requires searching alternatives to fossil fuels. Bio-fuels and in particular – bio-diesel, is one of these feasible alternatives.

Production of crops for non-food purposes has got a long tradition in the EU-15 Member States. In the recent years, the importance of noon-food crops increased significantly. This was due to the development of renewable energy sources, in order to secure the EU energy supply and to improve the overall EU environmental performance. In this context, agriculture might become a large provider of energy in the future.

Considering the EU policies related to bio-fuels and especially – to bio-diesel (energy, agriculture, RTD, etc.), following conclusions can be drawn based on the analyses in the present paper:

- Bio-diesel is a technologically feasible alternative to fossil diesel, but nowadays bio-diesel cost is 1.5 to 3 times higher than the fossil diesel cost.

- Bio-diesel has got better lubricant properties than fossil diesel. Its oxygen content improves the combustion process, leading to a decreased level of tail-pipe polluting emissions. Bio-diesel is non-toxic and quickly biodegradable. The risks of handling, transporting and storing bio-diesel are much lower than those ones, associated with fossil diesel.

- Key weak point of bio-diesel as a fuel for road transport is the need of engine modifications, when pure bio-diesel is applied. However, this disadvantage is overcome when bio-diesel is blended with fossil diesel in relatively low concentrations. Therefore, from technical and technological point of view, blended application of bio-diesel is more promising and feasible alternative, than utilisation of pure bio-diesel.

- Important operating disadvantages of bio-diesel in comparison with fossil diesel are cold start problems and the lower energy content. This increases fuel consumption when bio-diesel is used (either in pure or in blended form) in comparison with application of pure fossil diesel, in proportion to the share of the bio-diesel content. Taking into account the higher production value of bio-diesel as compared to the fossil diesel, this increase in fuel consumption rises in addition the overall cost of application of bio-diesel as an alternative to fossil diesel.

- In comparison with fossil diesel, bio-diesel shows better emission parameters. It improves the environmental performance of road transport, including decreased greenhouse emissions (mainly of CO_2).

- The overall energy balance of bio-diesel is highly depending on the feedstock used and the utilisation of by-products. However, in all cases the overall energy balance of bio-diesel is positive.

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

- The competitiveness of bio-diesel to fossil diesel depends on the fuel taxation approaches and levels. Generally, the production costs of bio-diesel remain much higher compared to the fossil diesel ones. Therefore, bio-diesel is not competitive to fossil diesel under current economic conditions, where the positive externalities, such as impacts on environment, employment, climate changes and trade balance are not reflected in the price mechanism.

- The opportunity to grow non-food crops under the compulsory set-aside scheme is an option to increase the bio-diesel production. However, it has to be recalled that the compulsory set-aside is a supply-management instrument, conceived to deal with the cereal surplus cases. The uncertain future of this policy precludes long-term investment. Therefore, this instrument generally is not a sufficient tool to promote non-food production and in particular – production of bio-diesel.

- Until significant reductions both in feedstock and processing costs are reached, fiscal incentives will be the key instrument to enhance the bio-diesel application as an alternative fuel for transport. In this context, tax exemptions are the most important element from such fiscal incentives.

- The advantages offered by bio-fuels (and by bio-diesel in particular) have to be considered at levels, beyond the agricultural, transport and energy sectors only. It is a matter of public interest, where complex policy instruments have to be applied.

- Blends are the most feasible way for enhancing the bio-diesel share on the fuel market, giving an appropriate income to farmers, competitive prices to end-users and requiring less taxation incentives and exemptions.

- Dedicating the whole set-aside area of the EU-15 (5,5 mio hectares) to cultivate non-food crops for production of bio-diesel, the replacement rate “bio-diesel instead of fossil diesel” would range between 4.0 % and 3.2 %, depending on the raw material breakdown.