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ENVIRONMENTAL EVALUATION OF BIOFUELS

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Abstract

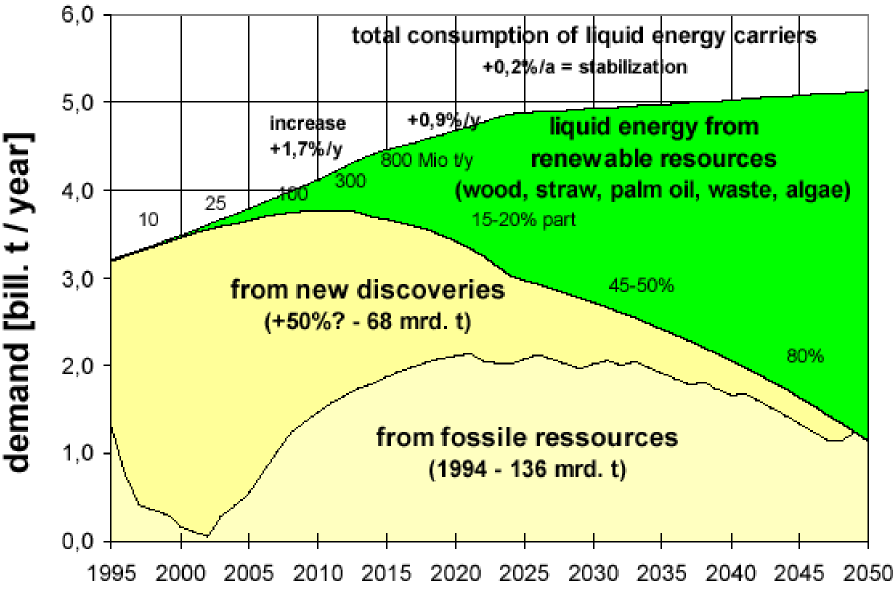
One of today's most important environmental issues is the pollution caused by traffic and transport. There is no doubt that engine emissions, particularly from cars and trucks, have been linked with severe damages to the environment and human health. The substitution of conventional fuels (gasoline, diesel) by biofuels is considered to be a potential way to reduce pollution and support sustainable agriculture. The two most common biofuels are biodiesel and ethanol. The use of biofuels is considered to be environmentally friendly. The production of biofuels, however, might cause pollution. Life-cycle assessment is the scientific evaluation method to investigate the net environmental impacts of biofuels. By means of this method it is possible to determine whether the use of biofuels or the use of conventional fuels trigger more pollution to the environment. Biofuel policy might capitalize on the production of biofuels supporting rural economic development and sustainable agriculture.

Keywords: biofuel, biodiesel, ethanol, life-cycle assessment (LCA), sustainable agriculture.

1. Introduction

The reserves – known and affordable supplies of a nonrenewable resource such as oil – are considered economically depleted when 80% of the supply has been used; the remaining 20% is considered too expensive to extract. Oil's fatal flaw is that its reserves may be 80% depleted within 35–84 years, depending on how rapidly it is used. At the current rate of consumption, global oil reserves will last at least 44 years. Undiscovered oil that is thought to exist might last another 20–40 years. Instead of remaining at the current level, however, global oil consumption is projected to increase by about 25% by 2010. This will hasten depletion of global oil reserves.

The estimated resources of today have a worldwide distribution which implies possible difficulties in future besides the fact that they are limited, while yearly consumption still rises. Since at least 5 years the safe resources are estimated at approx. 140 billion tons of fossil oils, the uncertainties in behind with additional 50% (*Fig. 1*) and thus the resulting gap must be filled with biomass (biodiesel, ethanol etc.)



Source: CONNEMANN, 1999

Fig. 1. Demand and supply of mineral oil in coming decades

2. The Relevance of Biofuels

Besides wind and water power the use of biomass has a tremendous future, especially the so-called biofuels.

Their advantages are the following:

- They represent a CO_2-cycle in combustion, most of them have better emissions, they are biodegradable and contribute to sustainability.
- They have a considerable environmentally friendly potential.

The two most common biofuels are *biodiesel* and *ethanol*. Biodiesel is made by using vegetable oils, animal fats, algae, or even recycled cooking greases. It can be used as a diesel additive or in its pure form to fuel a vehicle. Ethanol is made by fermenting any biomass that is rich in carbohydrates. It is mostly used as a fuel additive. Beyond energy benefits, development of biofuels promotes rural economies that produce crops used for biofuels.

2.1. Biodiesel

Biodiesel is the name of a clean burning mono-alkyl ester-based oxygenated fuel made from soybean oil or other vegetable oils or animal fats. A renewable fuel produced from agricultural resources, biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatic compounds.

The concept of using vegetable oil-based fuel dates back to 1895 when Dr. Rudolf Diesel developed the first compression-ignition engine specifically to run on vegetable oil. Because it has similar properties, biodiesel can be blended in any ratio with petroleum diesel and can be used in diesel engines with no major modifications.

Rapeseed oil crushed from rapeseed varieties was the first type of vegetable oil used for transesterification and rather by chance this oil is highly suitable for production of quality biodiesel: With a content of approx. 60% monounsaturated oleic-fatty-acid and only approx. 6% saturated fatty-acids it shows both good stability and winter operability. New varieties (LZ 7632) are reaching even higher levels of up to 87% oleic-fatty-acid. This type of rapeseed (or Canola) is still by far the biggest source of feedstock for biodiesel production, and has become even more interesting as rapeseed breeders have succeeded in improving yield levels of up to 2.9 ton *oil*/ha in Northern Germany when applying ‘precision farming’.

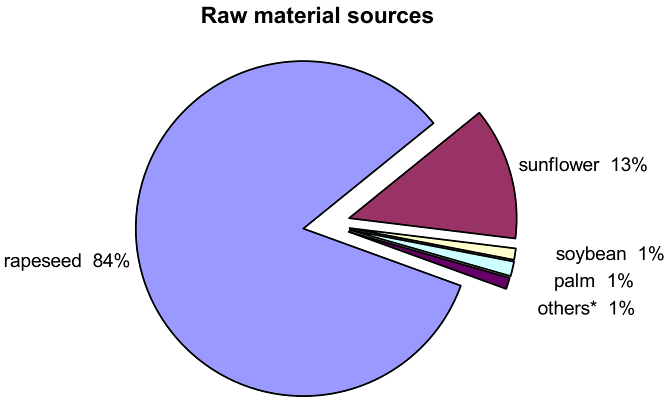
The overall scope of feedstock utilization has become however much broader over time and other vegetable oils in use in bigger volumes today are sunflower oil (e.g. Southern France, Italy) and soybean oil (USA), while palm oil was the feedstock of choice for production of biodiesel in order to fuel the buses of Kuala Lumpur (Malaysia) (*Fig.* 2).

Triggered by the economic squeeze of high oilseed cost on the one hand and at the same time record-low prices for diesel fuel in the period of 1998/1999 on the other hand existing know-how about the utilization of recycled food oils was activated and set into commercial practice. On the basis of a very well controlled logistic system of high security level recycled oils of households and restaurants were ‘discovered’ as a source of suitable feedstock for biodiesel production. The best example is McDonalds with 135 restaurants in Austria collecting approx. 1.100 ton of quality recycled frying oil, which then is transesterified into Fatty-acid-methyl-ester (FAME) of standardized quality.

2.1.1. Process Technology

Soon after having transesterificated rapeseed oil (Rapeseed-oil-Methyl-Ester, RME) established in the market place the search began for additional and alternative feedstocks. A detailed screening process of all available virgin or waste oils and fats of vegetable or animal origin took place and came up with defining some restrictions (e.g. stability of oil, winter operability, Conradson Carbon residue) on the one hand but with the multiple choice offer to select out of a rather broad scope of oils and fats a Multi-Feed-Stock (M-F-S) blend on the other hand. Thus a clever blend the cheapest feedstocks available is the key factor for a low cost biodiesel, of course always with a guaranteed high quality for the fuel at the end of the pipeline.

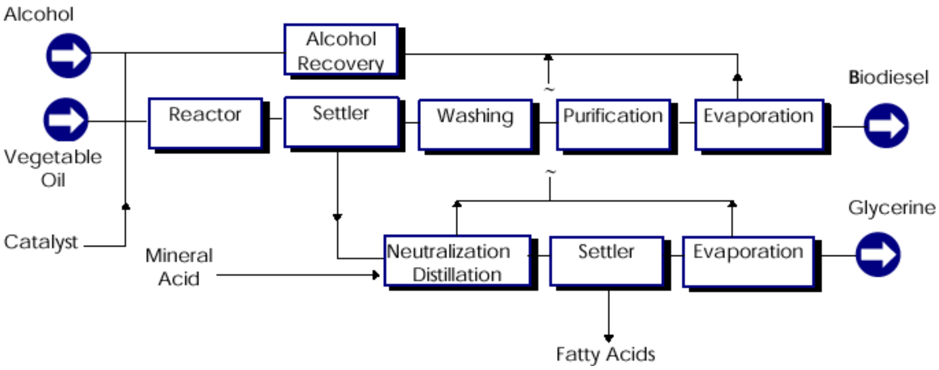
The production of biodiesel, or alkyl esters, is a well understood process. Most biodiesel is produced through the process of base catalyzed transesterification,



Source: KÖRBITZ, 2000

Fig. 2. Raw material sources

because the reaction is low temperature (66°C), low pressure (20 psi) and has a high conversion factor (98%) with minimal side reactions and reaction time. The general process is depicted in *Fig. 3*. A fat or oil is reacted with alcohol (like methanol) in the presence of a catalyst to produce glycerine and methyl esters or biodiesel. The methanol is charged in excess to assist in quick conversion and recovered for reuse. The catalyst is usually sodium or potassium hydroxide, which has already been mixed with the methanol.

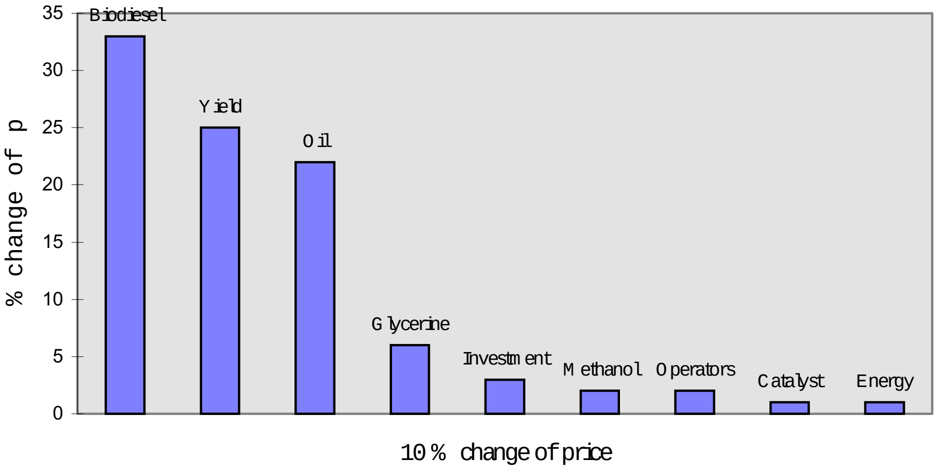


Source: National Biodiesel Board, 2001

Fig. 3. Biodiesel process technology

As the availability and supply pattern of the various raw materials may vary in volume and price and as recipes of blends have to be varied as well for climatic conditions, it is a tremendous commercial advantage, if production recipes can be changed quickly, even on a daily basis. In a modern plant the cheapest blend of the day can be selected by a quick switch of recipes, which are stored and installed automatically, thus improving the profitability of a biodiesel plant significantly.

In early days biodiesel producers were satisfied when achieving a transesterification rate or yield of approx. 85–95% leaving thus quite a volume of potential feedstock as waste in the glycerin phase. However, as it is shown in *Fig.4* below yield is the second biggest factor affecting profitability, i.e. a 10% decline of yield is reducing profitability by approx. 25%. It is therefore crucial to transfer any potential molecule into a fatty-acid-methyl-ester, and this includes all the tricglycerides but additionally also all Free-Fatty-Acids (FFA). A modern and profitable process technology today is able to achieve a 100% yield without any expensive losses.



Source: KÖRBITZ, 2000

Fig. 4. Biodiesel profitability factors

2.1.2. Fuel Standards and Quality Assurance

In the early days of developing biodiesel it became quickly obvious that it will be of key importance to win the confidence of diesel engine producers as stakeholders in this project. A working group was set up within the Austrian Standardization Institute and the first biodiesel fuel standard was issued already in 1991 as ON C 1190 for RME or Rapeseed-oil-Methyl-Ester. This was the basis for numerous diesel engine warranties issued by all key tractor companies.

This first standard was followed by the already sophisticated ON C 1191 for FAME or Fatty-acid-methyl-ester in July 1997, as a successful attempt to define the quality of a fuel not by its feedstock source but by what is filled into the tank. Later in 1997 the DIN E 51606 (as well for FAME) was published in Germany, while other national standards were established in the CSSR, in France, Italy, Sweden and the USA. This was the necessary basis to build customer confidence, obtain warranties from many diesel engine manufacturers and injection pump producers, to provide transport reliability and to create a positive image in the market place.

The most recent development is the process to develop a CEN-standard for Biodiesel with validity all over Europe. This work is still in progress and an even more elaborated CEN-standard may be published by the end of 2001.

2.1.3. Biodiesel Production

Having started with a rather small farmers' cooperative biodiesel plant in 1988 with a capacity of approx. 500 ton/year in Austria other plants followed soon and the first industrial scale biodiesel production plant with a capacity of 10.000 ton/year went into operation in 1991 as well in Austria.

In the coming years larger plants were established all over Europe e.g.: in Livorno, Italy (capacity up to 80.000 ton), in Rouen, France (capacity 120.000 ton – so far the largest biodiesel production plant of the world), in Germany and in Sweden. The Czech Republic completed a program to establish 16 biodiesel plants, making this country the leading one in number of production sites.

The study 'Review on Commercial Biodiesel Production Worldwide' as commissioned by the International Energy Agency, completed by the Austrian Biofuels Institute and published in April 1998 had identified 21 countries around the world, in which Biodiesel projects with a commercial objective had been implemented. With all these many worldwide initiatives Europe kept the lead by far and only in recent times the production has increased also in the USA, location of the most modern MFS-Biodiesel plant of Griffin Industries in Kentucky.

The biodiesel production community experienced recently a very difficult period in 1998/1999, when non-food oilseeds were grown at only minimal acreages, food vegetable oil prices soared to extreme heights and at the same time the crude mineral oil price reached a record low level of approx. 9 US$/barrel leading many producers into a loss position. *Table 1* shows the major European biodiesel producers.[1]

With the European Commission resetting the set-aside percentage back to 10% non-food crops larger volumes of non-food oil at reasonable prices became available again, triggering a renaissance for biodiesel producers. This is especially true for Germany, where an increase in production capacity from today approx. 90.000 ton/year up to impressive 250.000 ton/year by the year 2001 is forecasted, most of it located in Eastern Germany.

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[1] Source: UFOP, 2000

Table 1. Biodiesel producers in Europe 2000

Country	Capacity (t/year)	Production since
Germany	340 000	1991
France	230 000	1993
Italy	140 000	1993
Belgium	80 000	1995
Austria	15 000	1991
Sweden	6 000	1992

2.2. Ethanol

Ethanol (ethyl alcohol, grain alcohol, EtOH) is a clear, colorless liquid with a characteristic, agreeable odor. In dilute aqueous solution, it has a somewhat sweet flavor, but in more concentrated solutions it has a burning taste. Ethanol (CH_3CH_2OH) is a group of chemical compounds whose molecules contain a hydroxyl group, $-OH$, bonded to a carbon atom. Ethanol is produced from a variety of renewable agricultural feedstocks, including grains such as corn, wheat and milo, citrus and potato wastes and forestry residues. Ethanol is an important value-added market for farmers. As the third largest use of corn, behind only feed and exports, ethanol production utilizes approximately seven percent of the U.S. corn crop, adding $4.5 billion in farm revenue annually. Ethanol production from grain utilizes only the starch, an abundant and low-value component. A variety of highly valuable feed co-products are produced from the remaining protein, minerals, vitamins and fiber and are sold as high-value feed for livestock.

The primary co-products from the wet milling process include sweeteners, corn oil, gluten feed and gluten meal. Co-products from the dry milling process include dried distillers grains and corn meal. The market for co-products adds tremendous economic viability to the domestic ethanol industry. Ethanol made from cellulosic biomass materials instead of traditional feedstocks (starch crops) is called bioethanol.

The eight steps in the ethanol production process follow (*Fig.*5):

1. *Milling:* The feedstock passes through hammer mills, which grind it into a fine meal.
2. *Liquefaction:* The meal is mixed with water and alpha-amylase, and passes through cookers with a high temperature stage (120–150 °C) and a lower temperature holding period (95 °C), where the starch is liquefied. Heat is applied to enable liquefaction. The high temperatures reduce bacteria levels in the mash.
3. *Saccharification:* The mash from the cookers is cooled and the secondary enzyme (gluco-amylase) is added to convert the liquefied starch to fermentable sugars (dextrose).

4. *Fermentation:* Yeast is added to the mash to ferment the sugars to ethanol and carbon dioxide (CO_2). Using a continuous process, the fermenting mash is allowed to flow, or cascade, through several fermenters until the mash is fully fermented and then leaves the final tank. In a batch fermentation process, the mash stays in one fermenter for about 48 hours before the distillation process is started.
5. *Distillation:* The fermented mash, now called 'beer,' contains about 10% alcohol, as well as all the nonfermentable solids from the corn and the yeast cells. The mash is pumped to the continuous flow, multicolumn distillation system where the alcohol is removed from the solids and the water. The alcohol leaves the top of the final column at about 96% strength, and the residue mash, called stillage, is transferred from the base of the column to the coproduct processing area.
6. *Dehydration:* The alcohol from the top of the column passes through a dehydration system where the remaining water is removed. Most ethanol plants use a molecular sieve to capture the last bit of water in the ethanol. The alcohol product at this stage is called anhydrous (pure, without water) ethanol and is approximately 200 proof.
7. *Denaturing:* Fuel ethanol is denatured with a small amount (2%–5%) of some product such as gasoline, to make it unfit for human consumption.
8. *Coproducts:* Two main coproducts – CO_2 and distillers grain – are created during ethanol production. CO_2 is given off in great quantities during fermentation. Many ethanol plants collect the CO_2, clean it of any residual alcohol, compress it, and sell it for use in carbonate beverages or to flash freeze meat. Wet and dried distillers grains are high in protein and other nutrients and are highly valued livestock feed ingredients. Some ethanol plants also create a 'syrup' that can be sold in addition to, or combined with, the distillers grain. Ethanol production is a no-waste process that adds value to the feedstock by converting it into more valuable products.

2.2.1. Ethanol as Biofuel

Alcohol fuels[2] and, in particular, fuels of ethanol blended with gasoline are well-suited for replacing gasoline in light-duty vehicles and diesel fuel in trucks and buses. The other fuel alcohol commercially available today is methanol. Although it sounds similar to ethanol, it is derived from different sources, its properties are

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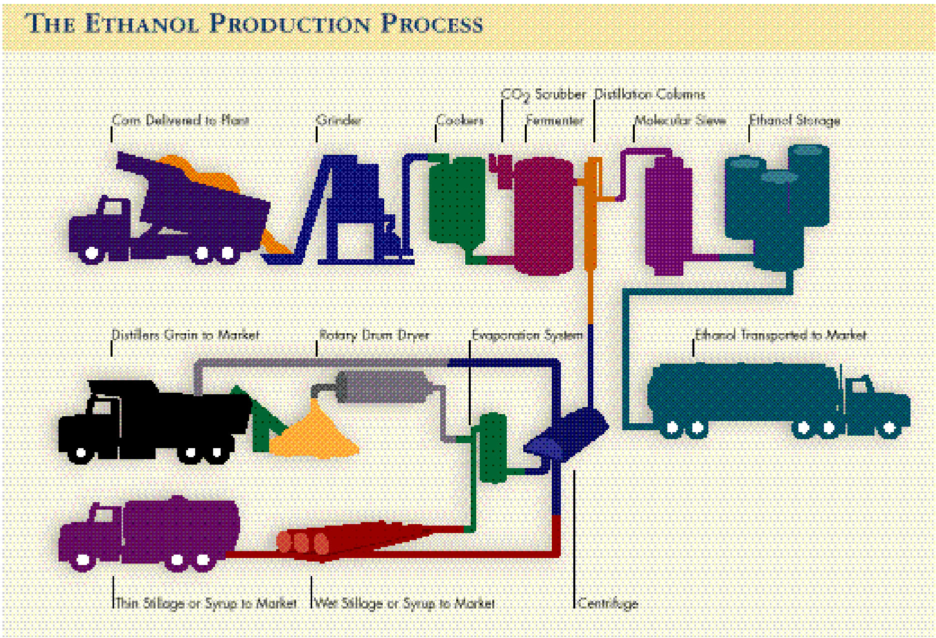
[2] Alcohol fuel blends are designated by E for ethanol or M for methanol, followed by a number representing the percentage of alcohol (by volume) in the blend. The ethanol used in fuel blends is denatured and can contain up to 5% hydrocarbons (gasoline or gasoline-like additives) before blending. Additional gasoline is added to the ethanol to make up the desired percentage in the blend. The fuel E10, or '*gasohol*,' is 10% denatured ethanol blended with 90% gasoline; E85, commonly called fuel ethanol, is 70–85% denatured ethanol blended with 30–15% hydrocarbons; and E100 is 100% denatured ethanol.



Source: ULRICH, 1999

Fig. 5. Ethanol production process

quite different, and it cannot be used in place of ethanol. Currently, a small amount of ethanol (10% by volume) is added to gasoline to increase the octane rating and to provide oxygen to decrease tail-pipe emissions of carbon monoxide (CO); the resulting fuel blend, called *gasohol* by the public and E10 by the industry in the United States, is a widely accepted vehicle fuel. New vehicle technologies have been developed that can use blends having higher concentrations of ethanol in gasoline as fuels while achieving reliable, low-emission operation. The new flexible-fuel vehicles operate on blends of up to 85% ethanol (known as E85). The gasoline in E85 makes the vehicle easier to start in cold weather and increases the vehicle's range.

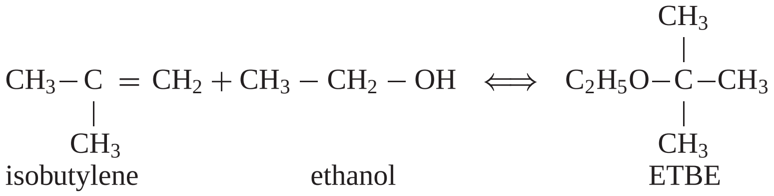
In addition to the traditional use of ethanol as a low level blend component in conventional and reformulated gasoline, other potential transportation fuel uses of ethanol have varying degrees of potential. E-85 is in the early stages of commercialization. Oxydiesel is in the experimental/demonstration phase. The use of ETBE is currently clouded due to concerns about ethers and ground water quality. Other uses such as aviation applications and fuel cells are much less clear. This section discusses these other transportation fuel uses for ethanol, their current status, and considerations for development of their respective markets.

2.2.1.1. *E-85*

The term E-85 is commonly used to denote fuels containing 75 v% to 85 v% of denatured ethanol. The remainder of the blend is comprised of either conventional or reformulated gasoline. The guiding industry specification for this fuel is ASTM D 5798 Standard Specification for Fuel. The hydrocarbon content of E-85 is altered seasonally. Neat ethanol does not vaporize as easily as gasoline. The specification therefore requires more gasoline during the colder months to increase fuel volatility to minimize cold start and warm up performance problems. E-85 is viewed by many experts to be an ideal alternative to gasoline. Since it is a liquid fuel it can be handled much like gasoline both in the distribution system and the automobile fuel system. E-85 also has a higher octane than gasoline. It does, however, contain less energy per gallon necessitating more frequent fuelling events or alternatively, a larger fuel tank. In the past few years some automakers have started offering Flexible-Fuel Vehicles (FFV). These autos are capable of operating on 100% gasoline or up to 85% denatured ethanol or any mixture of the two. Such vehicles meet the definition of an alternative fuel vehicle to comply with the 1992 U.S. Energy Policy Act (EPACT92). The American automakers receive credits for their Corporate Average Fuel Economy (CAFE) for each FFV produced. This provides their incentive to produce such vehicles that require relatively inexpensive modifications to achieve their fuel flexibility. These credits were established in the U.S. in the Alternative Motor Fuels Act of 1988. The credit for alcohol FFVs is 1.2 miles per gallon through model year 2004 and 0.9 miles per gallon for model years 2005 to 2008 (if the Act is extended to 2008).

2.2.1.2. *ETBE*

Ethyl Tertiary Butyl Ether (ETBE) was once thought to be the most likely avenue to overcome some of ethanol's negative handling characteristics (water sensitivity and vapor pressure increase). ETBE is produced similarly to MTBE[3], i.e. by reacting ethanol will isobutylene (MTBE is produced by reacting methanol with isobutylene)



$$\underset{\text{isobutylene}}{CH_3-\underset{\displaystyle CH_3}{\underset{|}{C}} = CH_2} + \underset{\text{ethanol}}{CH_3 - CH_2 - OH} \Longleftrightarrow \underset{\text{ETBE}}{C_2H_5O-\overset{\displaystyle CH_3}{\overset{|}{\underset{\underset{\displaystyle CH_3}{|}}{C}}}-CH_3}$$

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[3] MTBE stands for the synthetic compound Methyl Tertiary Butyl Ether and is a gasoline additive. MTBE is the best known oxygenate, and the one embraced by most U.S. and European oil companies although other oxygenates are used in some areas.

ETBE's octane value is near that of ethanol and higher than MTBE. It has the lowest vapor pressure of the three oxygenates and is not sensitive to water. This would enable gasoline containing ETBE to be shipped via pipeline similar to fuels containing MTBE. Since ETBE has lower vapor pressure and a higher boiling point (i.e. less volatile) than MTBE, it is the most attractive oxygenate from a technical standpoint due to its ability to contribute to lower fuel volatility. In the 1990s the primary impediment to ETBE utilization was its inability to be produced at a price competitive with MTBE. During that time frame, methanol, the primary feedstock for MTBE, experienced very low prices resulting in MTBE production costs well below those possible for ETBE. Consequently, ETBE blending in the U.S. has been limited to experimental and demonstration projects. In Europe France represents the major ETBE production capacities and market. ETBE's similarity to MTBE was once thought to be a positive. However, with recent concerns about MTBE water contamination problems, that positive has turned into a negative and interest in ETBE has waned. While ETBE's ability to impact water quality is not of as great a concern as with MTBE, it is still much greater than with ethanol. MTBE's Henry's Law Coefficient is ~ 0.018 while ETBE's is ~ 0.11. Its higher coefficient limits ETBE's ability to wash out in rain, and makes it vaporize much faster from surface water and easier to strip from water (i.e. remediation). Though less resistant to biodegradation than MTBE, ETBE is still considered fairly recalcitrant and presents water contamination risks similar to MTBE. It also has low odor and taste thresholds. Under the aura of current concerns about MTBE, it is not likely that there is any great potential for ETBE at this time.

2.2.1.3. Oxydiesel

Oxydiesel is a blend of traditional diesel fuel blended with up to 15% denatured fuel grade ethanol and special additives. It can be used in existing diesel engines without modification and delivered through the existing retail/fleet outlet system. In late 1998 Archer Daniels Midland began a fleet demonstration/test of Oxydiesel with 15% ethanol in the U. S. ADM committed three brand new Mack trucks to the test, two to operate on oxydiesel and one for a control unit. The oxydiesel blend in this test program also contained a proprietary additive supplied by Pure Energy Corporation. The engines were tested without undergoing any modification. The performance characteristics of oxydiesel are very similar to No. 2 diesel. Preliminary emissions testing on oxydiesel has been very favorable. Tests commissioned by Pure Energy Corporation at a major testing facility demonstrated significant reductions in key exhaust emission pollutants. In the tests reported in the above table, the 15% oxydiesel blend resulted in a 6% increase in fuel consumption while the 10% oxydiesel blend resulted in a 4% increase. Many ethanol industry participants feel that oxydiesel may be second only to E-10 in its ability to expand the ethanol market. Like E-10 blends, oxydiesel could be blended at the terminal and dispensed through existing equipment. It could be used in existing diesel engines without modification.

2.2.2. *Ethanol Fuel Production*

Countries, which possess favorable agricultural conditions for plants rich in carbohydrates, are the major ethanol fuel producers in the world (*Table 2*)

Table 2.

Country	Feedstock	Volume (liter/year)	Use
USA	Starch crops	3.8 billion	Gasohol, E-85
Brazil	Sugar cane	16 billion	Gasohol, E-85
France	Starch crops	210 million	ETBE

2.2.3. *Ethanol Fuel Standards*

Alcohols are more corrosive than gasoline because they are electrically conductive and may contain corrosive impurities. Alcohols may degrade materials that are commonly used with gasoline or diesel fuel. You can reduce the chance for failure or contamination of alcohol equipment and systems by selecting proper materials and by controlling fuel composition. The American Society for Testing and Materials (ASTM) and the American Automobile Manufacturers Association (AAMA) have established standards for E-85. The ASTM standard specification for fuel ethanol, designated ASTM E d 75-E d 85 (where d stands for denatured), covers fuel blends for different seasons and geographical areas. These specifications, represent the minimum commercial standards and reflect the consensus of many stakeholders. The ethanol and hydrocarbon denaturant used in making fuel ethanol must meet the requirements of ASTM D 4806.

3. Environmental Impacts of Biofuels

The environmental benefits of biofuels appear during the combustion in the engine. The use of biofuels results in a closed carbon cycle, since the emitted amount of CO_2 is as much as the plant (rapeseed, corn, etc.) absorbed during its vegetation. Due to the low or zero content of pollutants such as sulfur in biofuels, the pollutant (SO_2 etc.) emission of biofuels is much lower than the emission of conventional fuels. The use of biofuels, however, has some environmental drawbacks. The raw materials of biofuels are plants produced by the agriculture having some negative impacts on the environment. *Table 3* summarizes the environmental impacts.

The only scientific way to determine the net environmental impact of biofuels (i.e. whether they are environmentally friendly or not) is the so-called life-cycle assessment.

Table 3. Environmental Pros and Cons of biofuels

Pros	Cons
Closed carbon cycle, reduced CO_2 emissions	The production of biofuels requires fossil energy
No sulfur content, no SO_2 emission, very low NO_x, CO, soot emission	Growing energy-plants bring about monocultures
Better energy balance than conventional fuels	The use of fertilizers and pesticides pollute the ground and groundwater
Biofuels are biological degradable	The production of biofuels might be more expensive than other ways of reducing CO_2 emission

3.1. Life-Cycle Assessment

The life-cycle concept is a ‘cradle-to-grave’ systems approach for thinking about technology. The concept is based on the recognition that all life-cycle stages (raw material acquisition; manufacturing, processing, and formulation; transportation and distribution; use, reuse, and maintenance; and recycling and waste management) along with all life-cycle phases (pre-operation, operation, and post-operation) result in economic, environmental, and energy impacts. Understanding all life-cycle stages and phases can yield a better understanding of the consequences of technology choices. Without consideration of life-cycle concepts, unforeseen negative consequences may be overlooked.

More specifically, the life-cycle concept is based on a recognition of the following:

- A ‘cradle-to-grave’ perspective is important to any evaluation. More site-specific, ‘end-of-pipe’, ‘within-the-plant-gate’, or ‘end-of-product-life’ perspectives may be limiting because they do not recognize the full range of upstream and downstream implications of site-specific actions.
- For any technology (product, service, or activity), material, energy, labor, and monetary demands are placed upon raw material acquisition, manufacturing, processing, formulation, transportation, distribution, use, reuse, maintenance, and recycling and waste management processes across the continent and around the world. Further, each of these processes may result in indirect economic, environmental, and energy impacts.
- Temporal and spatial dimensions to economic, environmental, and energy impacts should be considered.
- An inherently integrative concept, such as the life-cycle concept, is the best way to allow for the evaluation of economic, environmental, and energy dimensions of a problem at the same time.

Life-cycle assessment (LCA) is one type of analytical tool for implementing the life-cycle concept. Life-cycle assessment quantifies the energy use, material requirements, wastes, emissions, and potential environmental impacts that are associated with the provision of a product, service, or activity throughout its life-cycle. *Table 4* shows the impact categories of LCA.

Table 4. Impact categories of LCA[4]

Depletion of abiotic resources[5]	
Impacts of land use	Acidification
Climate change (greenhouse effect)	Eutrophication
Human toxicity	Ecotoxicity
Photochemical oxidants formation	Stratospheric ozone depletion

Life-cycle assessment:

- Contributes to a quantitative understanding of the overall and interdependent nature of environmental consequences and human activities.
- Provides decision-makers with quantitative information that describes the potential environmental effects associated with the provision of products, services, and activities and identifies opportunities for environmental improvements and highlights data gaps.
- Does not address economic considerations or social effects, although it may be used in conjunction with other quantitative tools to address these issues.

Life-cycle assessment incorporates the life-cycle concept into an analytical framework that has three quantitative elements, in addition to a goal identification and scoping exercise.

The first element is a life-cycle inventory analysis, which quantitatively evaluates the environmental and energy stressors associated with a product, service, or activity by identifying and quantifying energy and materials used and residuals produced over its entire life-cycle. The second element is a life-cycle impact assessment, which evaluates the potential impact of these energy and material uses and releases to the environment. The third element is a life-cycle improvement assessment, which identifies and evaluates opportunities to affect environmental improvements (*Fig. 6*).

3.2. *Life-Cycle Assessment of Biofuels*

In Europe, there have been published 2 biofuel LCA studies of a high standard. The first one was published in Belgium in 1997. This study was conducted at VITO,

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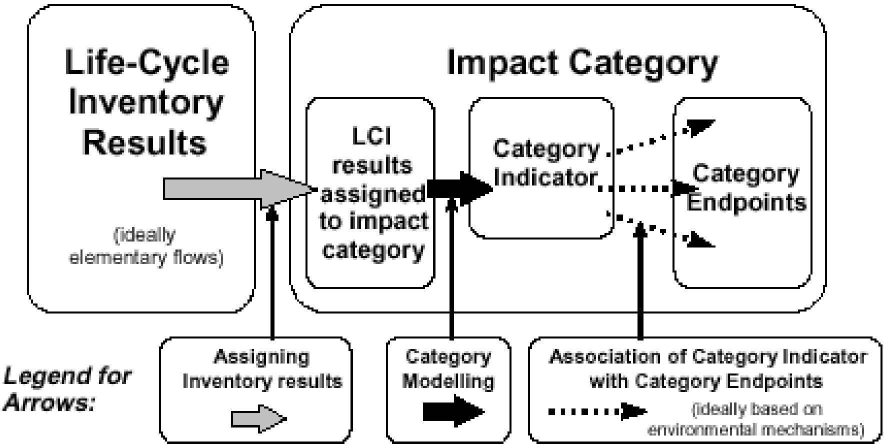
[4] Source: SETAC, 1995

[5] Fossil fuels, inorganic raw materials, water etc.

the Flemish Institute for Technological Research and sponsored by the Belgian Office for Scientific, Technical, and Cultural Affairs and the European Commission. The Belgian scientists drew a comparison between the environmental impacts of biodiesel made of winter-rapeseed and those of conventional diesel. The second study was conducted in Germany by the University of Stuttgart, the University of Heidelberg, and the University of Bochum. The German scientists compared the environmental impacts of biodiesel made of winter-rapeseed with those of conventional diesel, the environmental impacts of ethanol made of sugar-beet, winter-wheat, and potato added to gasoline by 5% (e.g. E5 ethanol blend) with those of conventional gasoline.

In the Belgian study the authors adjusted the general LCA impacts categories to the local conditions. Instead of using the impact category depletion of abiotic resources, they only evaluated the relevant component use of fossil fuels. Within the impact category human and ecotoxicity they focused on radioactive and nonradioactive waste.

In the European Union it is a widespread belief that the use of biodiesel is environmentally friendly. Unfortunately, the findings of the Belgian study indicate a different opinion. *Fig. 7* and *Table 5* show a comparison of the environmental profiles developed for biodiesel and diesel fuel. The fuel with the highest impact is shown as representing 100% and the impact of the other fuel is shown as a percentage of that value. As can be observed, biodiesel had less impact in only two of the nine categories considered, namely Fossil Fuels and Greenhouse Effect. The advantage of biodiesel in the Fossil Fuels category was a recognition that biodiesel has a positive energy balance and provides more energy than is contained in the fossil fuels used to produce it. This advantage carries through to the Greenhouse



Source: SETAC, 1995

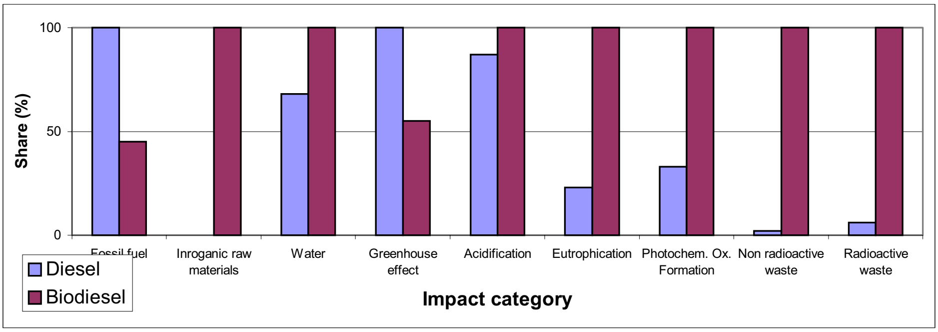
Fig. 6. The elements of LCA

Effect category where biodiesel is only assessed by the CO_2 emissions associated with the fossil fuel required to produce it since the CO_2 released when the biodiesel burns was originally extracted from the atmosphere.

Table 5. Summary of the results

Fossil Fuels: The study indicated that the fossil fuel consumption to produce biodiesel was only 45% that of diesel fuel. Most of this fossil fuel input for biodiesel is due to the natural gas required for methanol production and fertilizer production.
Inorganic Raw Materials: According to the Belgian study this category consists primarily of the mineral feedstocks for fertilizer production including phosphate rock, sylvinite (for potassium), kieserite (for magnesium), and limestone.
Water: The two major areas for the higher water consumption associated with biodiesel production were the esterification process with methanol and the production of chemical fertilizers. Most of the water used during esterification is for washing the product to remove soap and catalyst. Again, if fertilizer application rates were cut back, the second major source would also be reduced.
Greenhouse Effect: The greenhouse effect calculated for biodiesel was only 55% that for diesel fuel. This biodiesel advantage was primarily attributable to the fact that rapeseed assimilates CO_2 as it grows. This effect should track the fossil fuel impact fairly closely and if the fossil fuel required to produce biodiesel decreases due to lower fertilizer usage, then biodiesel's contribution to the greenhouse effect should decrease proportionately.
Acidification: Acidification is mainly caused by nitrogen and sulfur oxides and ammonia which are released during the growing of the rapeseed. Reducing fertilizer rates would reduce this contribution so that biodiesel's contribution to acidification would be less than diesel fuel's. About a third of the acidification is attributed to the NOx emissions from the tailpipe of the diesel engine which burns the fuels. The authors assumed that diesel fuel only contributed about 70% as much as biodiesel in this category.
Eutrophication: Eutrophication refers to the excessive growth of algae in surface water due to nitrate and phosphate fertilizer runoff. The decay of the algae depletes oxygen from the water and renders it unsuitable for other organisms. The impact of this problem should be reduced at least in proportion to the reduction in fertilizer application rates. With German, other EU, or U.S. fertilizer rates, it should be a non-issue.
Photochemical Oxidants Formation: This category comes primarily from volatile organic compounds that are released during the production of biodiesel. A major source of these is the hexane released by solvent-based oil extraction plants. Recent developments in extraction technology have reportedly reduced these emissions.
Nonradioactive Wastes: Nonradioactive wastes consist primarily of gypsum which is a by-product of the production of phosphate fertilizer. Lower fertilizer application rates would reduce this impact proportionately.
Radioactive Waste: This impact is primarily due to radioactive waste from nuclear power plants. When a product requires more electricity it is charged with a higher level of radioactive waste since a large fraction of the electricity in Europe is produced in nuclear plants (France is over 80%!). Much of the higher electricity input is from fertilizer production, which will be lower in other countries such as Germany and the U.S. In addition, the U.S., Germany and other countries derives a lower fraction of their power from nuclear sources than Belgium.

In this case, the analysis is based on agricultural cultivation of winter rapeseed in Belgium. Any generalization of results beyond this scope must be done very carefully to make sure that conditions are the same. In fact, this appears to be the primary reason the authors produced results that are different from those found in similar studies conducted in the United States and Germany. *Table* 6 shows the amounts of fertilizer (that must be applied to maintain a steady state of nutrient balance in the soil) assumed in the Belgian and the German studies.



Source: CEUTERICK, SPIRINKX, 1997

Fig. 7. Comparison of the two environmental profiles

Table 6. Belgian study[6]

	Belgian study	German study
N	200 kg/hectare	145 kg/hectare
P_2O_5	70 kg/hectare	54 kg/hectare
K_2O	130 kg/hectare	30 kg/hectare
MgO	80 kg/hectare	–
CaO	500 kg/hectare	50 kg/hectare

Clearly, the Belgian study assumed much higher levels of fertilizer application than would be common practice for rapeseed cultivation in Germany. This great disparity in fertilizer application rates provides the primary factor for negative conclusions about the environmental impact of biodiesel in Belgium.

The findings of the German study were much more favorable (*Table* 7).

The German study indicated that the use of biodiesel induces much more environmental benefits than drawbacks. The reasons for that are the truly favorable German (rapeseed growing) agricultural conditions (much better conditions than in Belgium). Only the stratospheric ozone depletion impact is considered to be rather negative, due to the N_2O emission coming from fertilizer production and the combustion of biodiesel in vehicles without oxidizing catalyst. However, the

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[6] Source: CEUTERICK, SPIRINKX, 1997; STELZER, 1999

Table 7. Summary of the results of the German biofuel LCA study[7]

		Relevant LCA impact categories				
	Feedstock	Depletion of abiotic resources	Climate change	Stratospheric ozone depletion	Acidification	Human and ecotoxicity
Biodiesel vs. diesel	rapeseed	☺	☺	☹	😐	☺
Ethanol (E5) vs. gasoline	sugar-beet	☺	☺	☹	😐	😐
Ethanol (E5)	winter wheat	☺	☺	☹	😐	😐
vs. gasoline	potato	😐	😐	☹	☹	😐

Explanation:
☺ : Lower impact of the biofuel than the conventional fuel
😐 : approx. the same impact of the biofuel and the conventional fuel
☹ : higher impact of the biofuel than the conventional fuel

intensification of fertilizer production and the equipping of vehicles with oxidizing catalyst can compensate this impact entirely.

The results of ethanol blends made of various feedstock are also positive, but less favorable. The agricultural circumstances in Germany are less advantageous for wheat, sugar-beet and potato than for rapeseed (less sunshine, more humidity etc.). Consequently, higher fertilizer rates are necessary for good yield, yet causing more pollution.

The LCA results proved the environmental benefits of biofuels during the combustion in the engine, but at the same time they emphasized the environmental drawbacks of biofuels occurring in the agricultural phase of the life-cycle. To sum up, it is apparent from both studies that the net environmental impact of biofuels significantly depends on the agricultural conditions. Provided the feedstock of biofuels is produced under appropriate agricultural and climate conditions, the net environmental impact of biofuels is sure to be advantageous supporting sustainable agriculture and sustainable development.

4. Biofuel Policy

The development of a biofuel policy is the task of the government and the legislation in each country. The production of biofuels is at present more expensive than the production of conventional fuels all around the world. Yet, an appropriate bio-

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[7] Source: STELZER, 1999

fuel policy is able to make biofuels marketable and in addition to that bring about such macroeconomic benefits (the reduction of agricultural surplus stock, the mitigation of unemployment and the dependency on imported oil, rural development, sustainable agriculture) that exceed the necessary costs by far.

In the United States the Congress passed Energy Policy Act (EPAct), or Public Law 102–486, on October 24, 1992, to accelerate the use of alternative fuels in the transportation sector. With EPAct in place, the primary goals are to decrease the nation's dependence on foreign oil and increase energy security through the use of domestically produced alternative fuels. The overall mission is to replace 10% of petroleum-based motor fuels by the year 2000 and 30% by the year 2010.

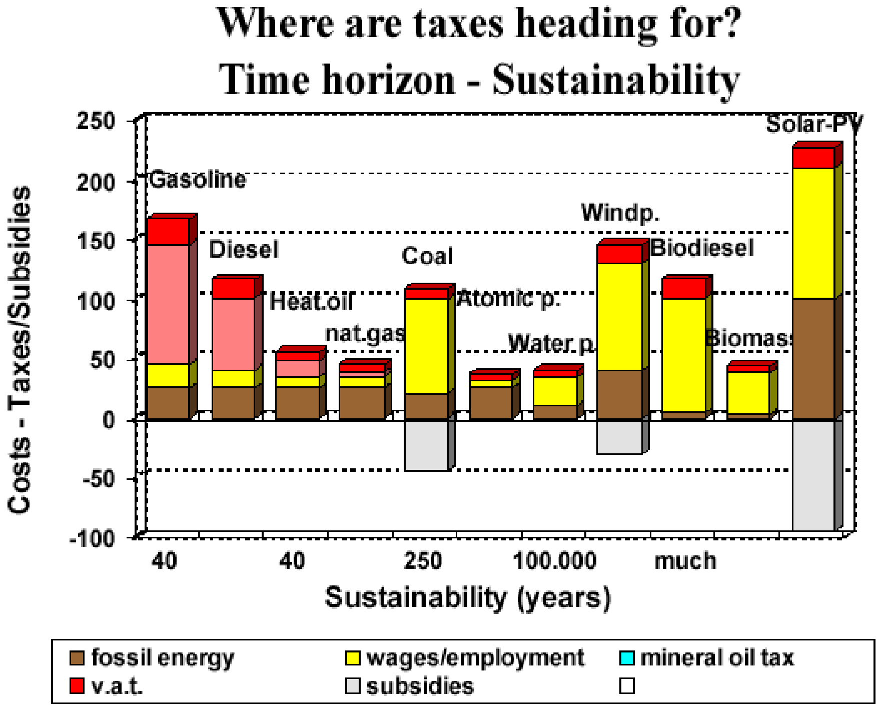
According to EPAct, alternative fuels include ethanol, methanol, and other alcohols; mixtures containing 85% or more by volume of methanol, ethanol, or other alcohols with gasoline or other fuels; natural gas; liquefied petroleum gas; coal-derived liquid fuels; hydrogen; fuels (other than alcohols) derived from biological materials; electricity; and any other fuel the Secretary of Energy determines is substantially not petroleum. EPAct established the purchase requirements for alternative-fueled vehicles (AFVs) for Federal, state government, and fuel-provider fleets. If the Secretary of Energy determines that EPAct goals will not be met with only the above requirements, municipal and private sector fleets may be required to purchase AFVs. Also established were tax incentives for purchasing AFVs, for converting gasoline vehicles to operate on alternative fuels, and for installing refueling or recharging facilities.

There is no harmonized European policy on biofuels, and each producing and consuming Member State implements its own domestic regulations. After several years of discussion, the European Commission approved the French tax exemption system for biofuels in 1997. However, in September 2000, BP Chemicals company, which is the leading European company producing synthetic ethanol, filed an appeal in an EU court against the Commission's approval of the TIPP exemption for biofuels. The Court rejected the appeal for RME, but annulled the Commission's decision for ETBE. The GOF and the EU Commission are currently discussing the ETBE regime.

In 1999, the European Commission released a White Paper on renewable energies which sets the objectives of 5 million MT in 2003 (i.e., 2 percent of the total EU fuel consumption) and 18 million MT in 2010 of biofuels to be consumed in the EU. In the European Commission, biofuels are discussed in the Permanent Group for Renewable Energies in the General Direction for Agriculture. The EU Member States faced blockades in response to sharp fuel price increases in summer 2000. Consequently, the Ministers of Transportation met on September 20, 2000 in a special session and invited the European Commission and the Member States to take new actions to limit energy consumption, and to promote alternative fuels. The EU Commission released a communiqué on October 11, 2000 on the EU's petroleum supply, where it suggested strengthening the measures favoring biofuels, for which there is no short supply risk, and which open new economic opportunities in agriculture. The EU Commission is also working on drafting a Directive on energy products, or may propose a Directive specifically on biofuels.

In Europe we have rather high excise duties for fuels for transportation. For biodiesel there are exemptions in some countries e.g. in Germany, France, Italy, Sweden, Austria and Czechia. The EU Commission intends to develop a 5% market share for biofuels up to the year 2005 and recommends time-limited exemptions or reductions of taxes on biofuels to 0–10% of normal amounts for the first 10 years, then to increase stepwise. With *Fig. 8* another view is given, which in a simplified manner tells:

Short-running energy carriers (the fossils) have to be taxed, long-running energy carriers (the renewables) have to be developed as fast as possible to gain a certain percentage (10–20%) of total supply.



Source: CONNEMANN, 1999

Fig. 8. Taxation of energy carriers according availability

5. Biofuels in Hungary

The production of biofuels in Hungary is in the state of establishment. The supervisory authority is the Hungarian Regional Development Center in the Ministry of Agriculture and Regional Development. Presumably the first Hungarian biodiesel plant will be inaugurated in December 2001 in Kunhegyes. This plant will have a capacity of 4 million liter biodiesel/year, processing biodiesel from rapeseed. Initially the produced biodiesel will not be sold at petrol stations, but it will be retailed as fuel for tractors etc. among farmers.

In Hungary there are two ethanol plants with enough capacity to process the surplus amount of wheat and corn. The first one is located in Győr, the second one in Szabadegyháza. The Hungarian oil company MOL produces annually 40 000 tons of MTBE. The substitution of MTBE by ETBE would require 18800 tons of ethanol/year. These two plants could provide MOL with the required amount of ethanol without any investment. Unfortunately, neither the Parliament, nor the Government has established policies or directives regarding the introduction of ethanol as biofuel in Hungary.

6. Summary

The world's oil reserves are getting used up and their exploitation is getting more and more expensive. One possible way to substitute conventional fuels is to produce so-called biofuels using agricultural feedstock. The two most important biofuels are biodiesel and ethanol. The life-cycle assessment of biodiesel and ethanol has proved that their impact on the environment during the entire life-cycle is much more favorable than those of the conventional fuels (diesel, gasoline), provided the agricultural, climate conditions are advantageous. Beyond environmental benefits, an appropriate biofuel policy is able to capitalize on the economic benefits of biofuels such as the reduction of agricultural surplus stock, the mitigation of unemployment and the dependency on imported oil, rural development, sustainable agriculture etc. The U.S. and several EU member states already pursue successful biofuel policy. Fortunately, Hungary has already taken the first measures in this field, as well.

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