BIOFUEL YIELDS (TOE/ha):

Bioethanol (average productivity):

♦Sugar cane-sweet sorghum: 3.0/4.2
♦Sugar-beets: 3.5/4.5
♦Corn : 1.5/2
♦Wheat: 1.2
♦Potatoes: 1.8
♦Lignocellulosic crops: 3/5

Biodiesel:

♦Rape/sunflower: 1.2
♦Palm oil: 2 - 5

Biomethanol from energy crops:

♦S.R.F.: 2.4
♦Herbaceous crops: 4.5

Dimethyleter: 1.8 - 3.7

Bio – Hydrogen: 2.4 ÷ 4

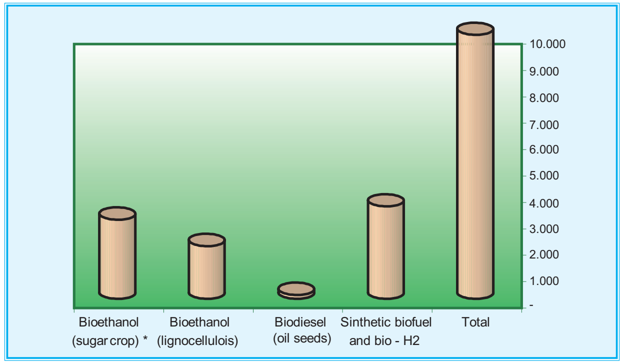
Among the different existing biofuels, **bioethanol appears to be the most promising** in short, medium and long term for the following reasons:

1. It is a refined high quality energy carrier with specific energy content ~ 70% of gasoline.
2. It can be utilized as blending component of gasoline (or diesel fuel in small amounts: 3%) or for gasoline reformulation (ETBE) acceptable in conventional vehicles as well as in the new **Flexible-Fuel-Vehicles** (FFV) able to run on any mixture of gasoline and ethanol. These FFV constitute a breakthrough in the transition towards dedicated ethanol-fuelled vehicles (under development but not yet commercial) that once optimised should present an efficiency increase of 7% in comparison with gasoline vehicles (6% if biomethanol is used).

CHARACTERISTICS OF BIOFUELS:

	Diesel engines				Otto engines				
	Diesel	Bio-diesel	DME	F-T diesel	Gasoline	Ethanol	ETBE	Methanol	MTBE
Chemical formula	$C_{12}H_6$	Methyl ester	CH_3O-CH_3	Paraf-fins	C_8H_{15}	C_2H_5-OH	$C_4H_9-OC_2H_5$	CH_3OH	$C_4H_9-OCH_3$
Cetane number	50	54	55-60	> 74	8	11	-	5	-
Octane number (MON)	-	-	-	-	86	92	105	92	100
Density (kg/l)	0.84	0.88	0.67	0.78	0.75	0.80	0.74	0.79	0.74
LHV (MJ/kg @ 15∞C)	42.7	37.3	28.4	44.0	41.3	26.4	36.0	19.8	35.2
Stoich. air / fuel ratio (kg/kg)	14.5	12.3	9.0	-	14.7	9.0	-	6.5	-
Oxygen content (wt-%)	0-0.6	9.2-11.0	-	~ 0	-	-	-	-	-
Kinematic viscosity (mm^2/s)	4	7- 4	-	3.6	-	-	-	-	-
Flash point (∞C)	77	91-135	-	72	-	-	-	-	-
Boiling temperature	-	-	-	-	30-190	78	72	65	55

TABLE VI: Biofuels long-term (2050-2100) world potential estimations (MTOE/y)



The FAO estimations of worldwide surplus land suitable for sugar-cane is ~ 1 billion ha.

ECONOMICS (estimation) €/TOE:

Bioethanol from:	NOW	LONG TERM
♦Sugar-cane	220 (Brazil)	200
♦Sugar-beets	750 (EU)	
♦Wheat	700 (EU)	
♦Corn	570 (USA)	500
♦Sweet-sorghum	350 (EU)	200-250
Biodiesel:	800 (rape seeds)	600-300
Biomethanol:	480	300
Dimethylether:	~ 600	400
F-T Diesel:	~ 700	400
Bio-H_2:	550-1,000	500

(For comparison the average industrial cost of gasoline-diesel fuel in the EU is ~ 400 €/TOE with oil at 40 $/bbl)

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LATIN AMERICA THEMATIC NETWORK ON BIOENERGY

LAMNET

BIOFUEL FOR TRANSPORT

G. Grassi

In the next 20 years the expected growth of the world economy will increase the demand of oil, in particular for transport (source Exxon) from ~85 million barrels/day to the huge value of ~ 330 million barrels/day (8 times the Saudi-Arabian capacity).

For the transport sector depending now for 100% on oil) a contribution to this immense energy supply volume will be provided by the **alternative liquid fuels** derived from natural gas (but with an energy loss for conversion of ~ 45% and thus significant decreasing CO_2 emissions) and at medium-long term from **biofuels** some of which (as can seen from the enclosed table) have the technical-economic potential to cover most of the medium term needs with a large impact on rural development (new jobs) and great benefits for the environment (zero CO_2 emissions, no SO_2 emissions for optimised closed bioenergy complexes).

Among several biofuels, **bioethanol appears to be the most promising.**

Flexible Fuel Car

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STRATEGIC ECONOMIC ENVIRONMENTAL ISSUES OF TRANSPORTATION FUELS - WORLD & EU CONTEXT:

The standard of living around the world is determined by the level and quality of energy utilisation. Currently, the main energy sources are fossil fuels. In modern societies, the transport of persons & goods (by road, railway, air, inland & sea navigation) is a critical factor for economic development, requiring increasing amount of fuel energy.
The almost total dependence on petroleum brings along increasing uncertainties in the supply, cost, durability of this economically and politically volatile resource. Any interruption in petroleum supply will generate major damage to our living conditions.

Transport in EU-15 (Eurostat) is:
- Passenger transport level: 12,755 Km/person
- Goods transport volume: 8,185 Km/person
- Total number of jobs: 7 million (57% land transport, 3% sea transport, 6% air transport, 34% for support activities)
- Total number of transport enterprise: 747,000
- Annual transport growth: 2,7% for goods, 1,7% for passengers
- Annual private household transport expenditure: 695 billion €/y

However, the use of conventional transport fuels implies a serious problem: the release of large amounts of CO_2 and other G.H.G. pollutants in our fragile atmosphere with potential risk of global climate change.

Fortunately, the significant progress in R&D aiming at producing transportation fuels from biomass (biofuels) has shown that major potential problems can be alleviated through a large scale penetration of biofuels on the conventional fuel market. Nevertheless, it will take a long period of time (20/30 years) before their market share will reach a reasonable level (10-20%) and full competitiveness is achieved.

Large investments will be needed for the biofuels sector; a reasonable part of the total future expenditure foreseen for energy infrastructures (16,000 billion € over the next 30 years) should be devoted also to the production of most promising biofuels.

In the following **table I and II** main data concerning the crude oil gross world consumption (2000) and EU–25 consumption are presented:

TABLE I: World crude oil total gross consumption (year 2000) in MTOE/y

equal to 35 % of the total primary energy consumption = 9.978 billion TOE

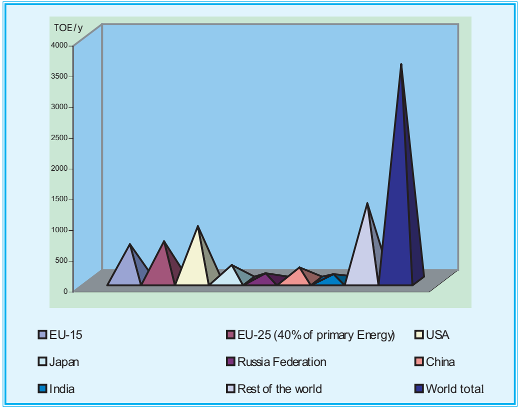
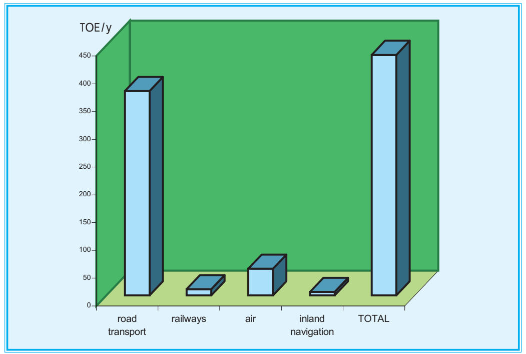


TABLE II: EU-25 crude oil total gross consumption (year 2000) in MTOE/y

- The EU–25 oil import dependency is 76,5%;
- 83% of total oil consumption (535 MTOE/y) is used for energy;
- The non-energy consumption is 110 MTOE/y
- The oil consumption for transport in MTOE/y is as follows:



The present EU oil **refining capacity** is:

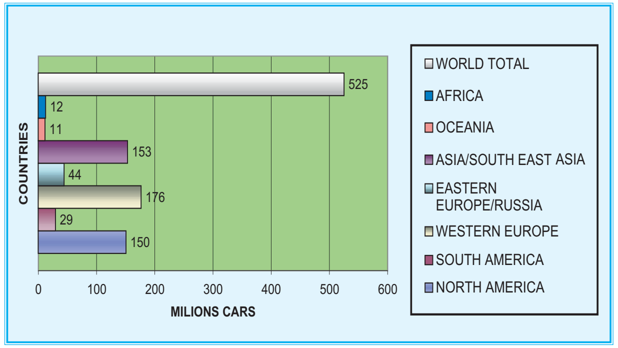
ATM distillation:	668 MTOE/y
Vacuum distillation:	256 MTOE/y
Reforming:	90 MTOE/y
Hydrocracking:	40 MTOE/y
Catalytic craking:	108 MTOE/y
Vis breaking & thermal crak:	81 MTOE/y
TOTAL:	**1,243 MTOE/y**

Energy losses for transport products refining is: ~ 10% for gasoline and ~ 20% for diesel.

Evolution of world car park and transport fuel consumption

Road transport represents a challenging future task due to its high share of total transport volume fuel consumption and to the large expected increase in number of vehicles world-wide as shown in table III:

TABLE III: World car market (year 2000)



- 390 million cars in industrial Countries: urban population, 727 million
- 135 million cars in developing Countries:rural population, 2,166 billion
- Present world car market: ~ 55 million cars/year
- **World total number of cars** (estimate for year 2020): **1.2 billion**

This huge increase (world-wide) of the number of cars will require a large increase of transport fuel consumption, from 2.1 to 3.4 billion TOE/y, as indicated in the following table.

TABLE IV: Evolution of world transport fuels consumption (MTOE/y) (source IEA / ISBN 92-64-01512-4)

	Year 2000		Year 2020	
	Gasoline	**Diesel**	**Gasoline**	**Diesel**
North-Central America	561	242	778	293
South-America	30	34	56	56
Brazil	24	3	50	61
Europe + Russia	242	333	386	439
Asia	186	253	397	469
Asian Countries	30	60	63	111
India	8	43	22	100
Africa	30	34	65	65
TOTAL world	1,111	1,002	1,817	1,594

Biofuels could provide a significant contribution

EU taxation on transport fuels (**year 2004**):
- gasoline: 0,350 €/l (minimum)
- diesel: 0,302 €/l (minimum)
- V.A.T.: 15% - 25%

Alternative Fuels for Transport

Alternative fuels are new transport energy carriers which show the potential to substitute conventional fuels (gasoline-diesel). As a consequence of the future large increase of worldwide transport activities and of the depletion of oil resources (expected around 2050), it can be anticipated for conventional fuels an approaching crisis of fundamental and structural nature, manifested by: frequent stresses on fuel market, vulnerability of supply as well as huge and increasing investments (in infrastructure) as a consequence of the lower quality and reduced accessibility. For example the extraction of oil from tar-sands with hot water beyond the high cost (~ 20 $/bbl) will pose serious environmental problems for their separation process, CO_2 emission and H_2O contamination.

The production and the introduction on the market of significative amounts of "**Alternative Fuels for Transport**" will considerably improve the general situation and in particular the security of fuel supply for transport which is vital for all modern societies. These **Alternative Fuels** can be subdivided in two categories:

- **New transport fuels** derived from natural gas (or coal);
- **Biofuels** (fuels derived from biological resources) having large worldwide availability and being expected to become competitive (in a longer term) with low environmental impact.

The transport biofuels of major interest, are the following:

BIOETHANOL (BIO - ETOH): is a colourless, liquid fuel with the chemical formula: C_2H_5OH. This biofuel is a refined product and it is a suitable transport fuel for gasoline and diesel fuel blending, reformulation or substitution for **flexible fuel vehicles** (equipped with a compromise designed engine but able to run with any gasoline-alcohol mixture) or for optimised ethanol engines commercially not yet available. The incremental cost for mass-production of FFV is estimated to be ~ 150 € which is much lower than for compressed natural gas vehicles. Bioethanol is 30% less energetic than gasoline to future optimised ethanol engines should be ~ 7% more efficient than present gasoline engines. Bioethanol can be produced frm sugar, starch, ligno-cellulosic biomass as well as from town sludge/MSW (~ 20 li/kg of solid residue).

BIO-ETBE (Bio-Ethyl Tertiary Butyl Ether): is a colourless, flammable, oxygenated hydrocarbon with the chemical formula: $C_2\ H_5\ OC_4\ H_9$. This biofuel is produced by mixing bioethanol (48% in volume) and tertiary butanol (or bioethanol with iso butylene) and reacting them with heat over a catalyst. This biofuel (octane rating: 112) can be used in existing gasoline engine without any modification shows excellent performance and environmental benefits replacing aromatics and benzene. Bio-ETBE is acceptable for direct refinery blending and for common pipeline transport.

BIODIESEL: At world level the average diesel - oil consumption is ~ 145 l / person. The interest for substitution with vegetal - oils locally produced is significant. In Europe there is a specific crop (rapeseed with a productivity of 1 - 1,5 t/ha of oil extracted from the seeds) of particular interest for farmers. Because vegetal - oils are not very good fuels for direct injection engines (high viscosity and thermal instability) it has been found to be a good solution by transforming the vegetal - oil in ester (Biodiesel) as follows: 1 t (oil) + 100 Kg methanol = Biodiesel + 100 K (glycerine). The best solution is blending (~ 5%) of Biodiesel in diesel fuel, but existing diesel engines can run with 100% biodiesel. Currently in Germany there are 1600 Biodiesel refuelling stations.

BIOMETHANOL (BIO - MEOH): might become a preferred fuel for fuel cell vehicles (with on board hydrogen reforming) because of its high hydrogen content. Biomethanol (CH_3OH) can be produced from bio-syn-gas, mixtures of H_2 and CO derived from biomass via a well - known oxygen/allothermal gasification process, by steam reforming of charcoal and subsequent process by catalytic synthesis process of CO_2 and H_2. At present, methanol is mostly produced from natural gas (world production 27 mio t/year) with a conversion efficiency of ~ 55%. Biomethanol has in a longer term the economic potential of substituting the methanol derived from natural gas. Experiments of biomethanol direct synthesis by electrolysis of supercritical CO_2-water solution (over GA as cathalist) show positive results with a current efficiency of ~100%.

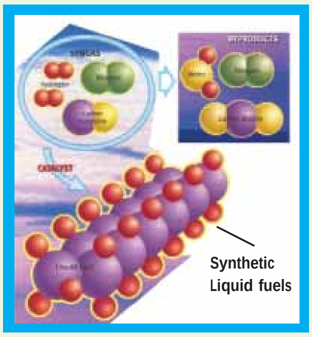
BIO-MTBE (Bio-Methyl-Tertiary Butyl Ether): is similar to Bio-ETBE and obtained by mixing biomethanol (36% in volume) and tertiary butanol with heat over catalyst.

BIOGAS (a mixture of ~ 60% methane and ~ 40% CO_2): is produced mostly by anaerobic fermentation of very humid biomass (livestock liquid manure, sludges, wastes, etc...). Small size plants are widely diffused in developing countries (~ 10 mio units in China), large plants are deployed mostly in industrial countries for treatment of urban sludges or for disposal of agro-industrial wastes.

BIO-DIMETHYL ETHER (Bio-DME): is promising fuel for diesel engines due to its combustion and emission properties and could become of great interest for very low GHG vehicles. This biofuel is liquid once pressured at ~ 5 bar. It is similar to LPG (a mixture of propane and butane) in terms of physical characteristics. It can be used as substitute for LPG or as oxygenated addictive in gasoline or as blending component of diesel fuel (easily soluble) or as diesel-fuel substitution for modified diesel engines. A potential 2% contribution to the diesel-oil pool is considered possible in a medium term but biomass must compete with DME derived from natural gas. DME can be produced from bio-syn-gas. At present DME is produced from pure methanol by an acid catalyst (Aluminium Oxide or Aluminium Silicate) in a fixed bed of low pressure and temperature (260 °C - 350 °C). The resulting mixture (DME + methanol + water) is separated by distillation. Direct conversion of CO in DME (now under development) will be more economical.

BIOSYNTHETIC FUELS: A wide range of very clean synthetic fuels can be obtained from "biosyngas" derived from biomass through the "Fisher - Tropsch" (FT) process, by building different polymer chains from the CO and H_2 basic molecules. The FT stands out as the most attractive process because:

- It can produce a wide range of high quality fuels, some of high value, like: FT bio-diesel oil (sulphur free), Bio-Middle Distillates, Bio-nafta (basic gasoline), Bio-methane, etc...; now the problem of how much sulfur should be allowed in gasoline is emerging worldwide due to refining difficulties and to environmental constraints.
- However is an expensive process;
- The market for its products is well established;
- There is no need of new refuelling infrastructure;
- There is no need of major engine modification;
- The production costs are higher than for biomethanol and there is the need to develop the market for co-products.



SCHEME OF BASIC PROCESS FOR SYNTHETIC FUELS PRODUCTION

BIOHYDROGEN: is defined as the hydrogen derived from biomass resources. It is an excellent clean fuel, very energetic (~ three times that of oil per unit weight) and does not emit CO_2 in combustion processes. It can be obtained in several ways:

- By water electrolysis utilising bioelectricity. This is a very efficient process but the investment cost and the H_2 production cost is relatively high (2,000 ÷ 3,000 €/t of H2 with ~ 4.5 KWhe/m3 of H_2)
- By catalytic shifting of "biosyngas", CO-H_2 mixture derived from solid biomass. From trials it seems that it could also be produced at reasonable cost (~ 1700 €/t) via steam reforming of charcoal/pellets obtained from low cost biomass residues (30 €/d ton)
- By membrane separation from biosyngas
- From bioethanol-water solution (99% mass conversion efficiency - 75% energy conversion efficiency)
- From biomethanol via **Steam Reforming**.

Cost estimations of conventional hydrogen production and supply at refuelling stations obtained from natural gas (3 € / MMBTU), via steam reforming process, are ~ 1,600 €/t for plants of 240 t H_2/day requiring an Investment of ~ 220 mio €. However, it is estimated that **for the next 20 years the price of natural gas will fluctuate around 7 $/MMBTU** with very large increase for the hydrogen production.

Biofuels for transportation

TABLE V: Production targets of biofuels in the EU (EU Directive 2003/30/CE)

YEAR	Targets (not mandatory) in MTOE/y
2000	~ 0.9
2005	~ 5 (2% of total)
2010	~ 17 (5.75% of total)
2020	~ 37 (new target under evaluation)

The long-term world-wide technical estimated potential of biofuels for the transportation sector are indeed very large i.e. **7-10 billion TOE/y** (Table VI), but their penetration on the transportation fuel market will depend mostly of their competitiveness (in energy terms) in comparison with conventional fuels (gasoline-diesel); their industrial cost in the EU is (in July 2004 for oil at 40 $/bbl):

350 – 450 €/TOE
(variation according to the EU Countries)

with a structure of average supply final cost at refuelling station (before taxes) as follows:

0.20 €/l	(cost of oil)
0.05 €/l	(transport by ship)
0.09 €/l	(refining cost & loss of fuel)
0.07 €/l	(delivery by truck to refuelling St.)
0.41 €/l	(~ 540 €/TOE) **(1 bbl=159 l)**

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The activities of LAMNET include the analysis of available bioenergy technologies and systems as well as the development and implementation of policy options for the promotion and deployment of bioenergy.

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