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Biofuel Production*

- **Biofuel types and Process** – *Bioethanol production*: conversion of starch or sugar-rich biomass (corn (maize), other cereals, sugar cane, etc.) into sugar, fermentation, and distillation. *Advanced process*: hydrolysis of ligno-cellulosic biomass, fermentation and distillation. *Biodiesel production*: extraction and esterification of vegetable oils, used cooking oils and animal fats using alcohols. *Advanced processes*: hydrogenation of oil and fat; gasification and catalytic conversion to liquid fuels (biomass to liquid, BTL). *Biomethane*: biogas from anaerobic digestors and landfills used as compressed gas in natural gas vehicles.
- **Energy Input and Emissions** – Because of the variety of feedstocks and processes, figures vary widely and make it difficult to identify indicative values. *Sugar-cane ethanol*: fossil fuel input some 10%-12% of final energy and up to 90% CO_2 reduction compared with gasoline. *Corn ethanol*: high energy input and much smaller CO_2 reduction (15-25%). *Ligno-cellulosic ethanol*: total energy input may be higher than for corn ethanol, but most such energy could be provided from biomass itself, with CO_2 reduction up to 70% (100% with power co-generation). *Biodiesel*: about 30% energy input and up to 60% CO_2 reduction.
- **Costs** – High sensitivity to feedstock, process, land type and crop yield. Figures are only indicative (see Fig. 2). *Sugar-cane ethanol* (Brazil): $0.25-$0.35/litre of gasoline equivalent (lge), competitive with gasoline at $40-$50/bbl oil prices. Higher cost in other regions. *Ethanol from corn (US) and sugar-beet (EU)*: $0.6-$0.8/lge. *Ligno-cellulosic ethanol*: at present over $1.0/lge (feedstock price $3.6/GJ), with potential reduction to $0.50/lge in the next decade. *Biodiesel from animal fat*: $0.4-$0.5/lde; *Biodiesel from vegetable oil*: $0.6-$0.8/lde; *Biodiesel from BTL*: > $0.9/lde.
- **Potential** – *Ethanol*: Low ethanol-gasoline blends (5%-10%, E5-E10) can fuel gasoline vehicles with little if any engine modification. New flexi-fuel vehicles run on up to 85% blends. *Ligno-cellulosic ethanol* (from all kinds of biomass) may greatly increase feedstock variety and quantity, but requires further R&D. Several pilot/demo plants in operation in 2006-2007. Potential market: 45 EJ by 2050. *Biodiesel*: Low biodiesel-diesel blends (B5-B10) can fuel diesel vehicles with no engine change; low sulphur and particulate emissions. Synthetic biodiesel (BTL) is fully compatible with diesel fuel and engines. Potential market: 20 EJ by 2050. Global biomass potential is some 100-200 EJ per year by 2050 (10%-20% of total energy supply).
- **Barriers** – Cost; competition with food and fibre production for use of arable land; regional market structure; biomass transport cost; lack of well managed agricultural practices in emerging economies; water and fertiliser use; conservation of bio-diversity; logistics and distribution networks.

Process ■ **Bioethanol conventional production** – Bioethanol is the most common biofuel, accounting for more than 90% of total biofuel usage. Conventional production is a well known process based on enzymatic conversion of starchy biomass into sugars, and/or fermentation of 6-carbon sugars with final distillation of ethanol to fuel grade. Ethanol can be produced from many feedstocks, including cereal crops, corn (maize), sugar cane, sugar beets, potatoes, sorghum, cassava. Co-products (e.g animal feed) help reduce production cost. If sugar cane is used, conversion into sugar is easier. Crushed stalk (bagasse) can be used to provide heat and power for the process and for other energy applications. The world's largest producers of bio-ethanol are Brazil (sugar-cane ethanol) and the United States (corn ethanol). Ethanol is used in low 5%-10% blends with gasoline (E5, E10) but also as E-85 in flex-fuel vehicles. In Brazil, gasoline must contain a minimum of 22% bioethanol. ■ **Bioethanol advanced production** - While conventional processes use only the sugar and starch biomass components, R&D focuses on advanced processes that utilise the all available ligno-cellulosic materials. These processes hold the potential to increase variety and quantity of suitable feedstock including cellulosic wastes, maize stover, cereal straw, food-processing wastes, as well as dedicated fast-growing plants such as poplar trees and switch-grass. Cellulosic feedstock could be grown on non arable land or be produced from integrated crops, which could considerably increase land availability.

Biomass Conversion Plant

(*) For biogas production see also ETE03 *Biomass for Power Generation and CHP*

Ethanol production from ligno-cellulosic feedstock includes biomass pre-treatment to release cellulose and hemicellulose, hydrolysis to release fermentable 5- and 6-carbon sugars, sugar fermentation, separation of solid residues and non-hydrolysed cellulose, and distillation to fuel grade.. To provide better conversion, new chemical and enzymatic processes (pre-treatment, hydrolysis, fermentation) are being examined. Solid residues and co-products from the process such as lignin and other components, particularly from forest materials, may inhibit hydrolysis. They can be extracted and used as a fuel in the production process, thus reducing cost and emissions.

■ **Biodiesel production** – Biodiesel production is based on trans-esterification of vegetable oils and fats through the addition of methanol (or other alcohols) and a catalyst, giving glycerol as a co-product. Feedstock includes rapeseeds, sunflower seeds, soy seeds and palm oil seeds from which the oil is extracted chemically or mechanically. **Advanced processes** include the replacement of methanol of fossil origin, by bioethanol to produce fatty acid ethyl ester instead of fatty acid methyl ether (the latter being the traditional biodiesel). In order to expand the relatively small resource base of biodiesel, new processes have been developed to use recycled cooking oils and animal fats though these are limited in volume. **Hydrogenation of oils and fats** is a new process that is entering the market. It can produce a biodiesel that can be blended with fossil diesel up to 50% without any engine modifications. **Synthetic biofuel production** via biomass gasification and catalytic conversion to liquid using Fischer-Tropsch process (biomass conversion to liquids BTL) offers a variety of potential biofuel production processes that may be suited to current and future engine technologies. The largest biodiesel producer is Germany, which accounts for 50% of global production. Biodiesel is currently most often used in 5%-20% blends (B5, B20) with conventional diesel, or even in pure B100 form.

ENERGY INPUT AND EMISSIONS – Fossil energy inputs and emissions levels from biofuel production are sensitive to process and feedstock, to energy embedded in fertilizers, and to local conditions. ■ **Production of ethanol from sugar cane** (Brazil) is energy-efficient since the crop produces high yields per hectare and the sugar is relatively easy to extract. If bagasse is used to provide the heat and power for the process, and ethanol and biodiesel are used for crop production and transport, the fossil energy input needed for each ethanol energy unit can be very low compared with 60%-80% for ethanol from grains. As a consequence, ethanol well-to-wheels CO_2 emissions can be as low as 0.2-0.3 kgCO_2/litre ethanol compared with 2.8 kg CO_2/litre for conventional gasoline (90% reduction). Ethanol from sugar beet requires more energy input and provides 50%-60% emission reduction compared with gasoline. ■ **Ethanol production from cereals and corn (maize)** can be even more energy-intensive and debate exists on the net energy gain. Estimates, which are very sensitive to the process used, suggest that ethanol from maize may displace petroleum use by up to 95%, but total fossil energy input currently amounts to some 60%-80% of the energy contained in the final fuel (20% diesel fuel, the rest being coal and natural gas) and hence the CO_2 emissions reduction may be as low as 15%-25% vs. gasoline. ■ **Ethanol from ligno-cellulosic feedstock** – At present, the total energy input needed for the production process may be even higher as compared to bioethanol from corn, but in some cases most of such energy can be provided by the biomass feedstock itself. Net CO_2 emissions reduction from ligno-cellulosic ethanol can therefore be close to 70% vs. gasoline, and could approach 100% if electricity co-generation displaced gas or coal-fired electricity. Current R&D aims to exploit the large potential from improving efficiency in enzymatic hydrolysis. ■ Energy input and overall emissions for **biodiesel** production also depend on feedstock and process. Typical values are fossil fuel inputs of 30% and CO_2 emission reductions of 40%-60% vs. diesel. Using recycled oils and animal fats reduces the CO_2 emissions.

COST – Costs of biofuels are highly dependent on feedstock, process, land and labour costs, credits for by-products, agricultural subsidies, food (sugar) and oil market. Ethanol energy content by volume is two-thirds that of gasoline, so costs refer to litre of gasoline equivalent (lge). ■ **Sugar cane ethanol** in Brazil costs $0.30/lge free-on-board (FOB). This cost is competitive with that of gasoline at oil prices of $40-$50/bbl ($0.3-$0.4/lge). In other regions, costs can be more than $0.40-$0.50/lge, although potential exists for cost reduction. ■ **Ethanol from maize**, **sugar-beet** and wheat cost around $0.6-$0.8/lge (excl. subsidies), potentially reducible to $0.4-$0.6/lge. ■ **Ligno-cellulosic ethanol** currently costs around $1.0/lge at the pilot scale, assuming a basic feedstock price of $3.6/GJ for delivered straw (whereas cereals for ethanol production may cost $10-$20/GJ). The cost is projected to halve in the next decade with process improvement, scaling up of plants, low-cost waste feedstock and co-production of other by-products (bio-refineries). ■ **Biodiesel** from animal fat is currently the cheapest option ($0.4-$0.5/lde) while traditional trans-esterification of vegetable oil is at present around $0.6-$0.8/lde. Cost reductions of $0.1-$0.3/lde are expected from economies of scale for new processes. The cost of BTL diesel from ligno-cellulose is more than $0.9/lde (feedstock $3.6/GJ), with a potential reduction to $0.7- $0.8/lde.

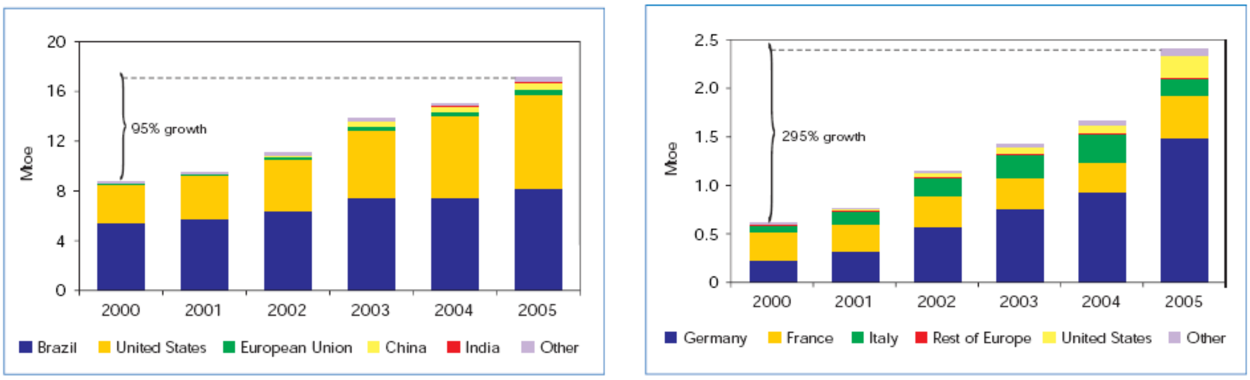
STATUS AND POTENTIAL - ■ **Ethanol** is a fuel with a high octane number and a low tendency to create knocking in spark ignition engines. Oxygen in its molecule permits low-temperature combustion with reduction of CO and

NOx emissions. Low-percentage ethanol-gasoline blends (5%-10%) can be used in conventional spark-ignition engines with almost no technical change. New *flex-fuel vehicles* of which there are over 6 million running mainly in Brazil, United States and Sweden, can run on up to 85% ethanol blends having had modest changes made during production. Ethanol combustion offers fuel and emissions savings due to the high octane number, the high compression ratio and the combustion benefits from ethanol vapour cooling which partly offsets its lower energy content per litre. Further R&D is needed to improve ligno-cellulose conversion into sugar (enzymatic hydrolysis, micro-organisms) and to improve conversion of 5-carbon sugar to ethanol. Several pilot and demonstration plants with capacities ranging from 1 to 40 million litres of ethanol a year will be operating in 2007. Fully commercial plants, however, need to scale up by a factor of 5-10 and no definite plans have been announced. Securing sufficient low cost biomass supply over a long period will need to be resolved. Ethanol could experience rapid expansion in North America and Europe by leapfrogging a number of traditional barriers faced by alternative fuels for transport. In the period 2004-2005 global ethanol production increased by 8% a year from 30.5 to 33 billion litres. By the end of 2005, there were 95 operating plants in the United States with total capacity of 16.4 billion litres per year (bnl per year). In mid-2006, 35 additional plants were under construction with further capacity of 8 bnl per year. Brazil has over 300 plants in operation, of which 80 licensed in 2005, and is expected to increase sugar cane production by 40% by 2009 as a part of a new national plan. The potential market for bioethanol is estimated at around 45 EJ by 2050. ■ **Biodiesel** offers full blending potential with conventional diesel, a high cetane number giving improved combustion in compression ignition engines, and low emissions of sulphur and particulates. Biodiesel is the fastest growing biofuel but from a lower base than ethanol. Global production passed from 2.1 bnl in 2004 to 3.9 bnl in 2005, increasing by 75% in Germany, France, Italy, and Poland and tripling in the United States. The potential market for biodiesel is estimated to be in the order of 20 EJ by 2050, assuming development of synthetic biofuel production technologies. Several countries have adopted policies such as tax exemptions, mandates and incentives for biofuels in 2005–2006. For example, France targets 5.75% biofuels by 2008 and 10% by 2015; Germany requires 2% ethanol and 4.4% biodiesel in 2007, increasing to 5.75% by 2010; Italy mandates 1% blend for both ethanol and biodiesel in 2006; and in the beginning of 2007, the European Commision proposed a 10% target by 2020. In the United States, fuel distributors are required to increase the annual volume of biofuels up to nearly 30 bnl by 2012 with the targets for "renewable and alternative fuels" raised in 2007 to 140 bnl by 2017. Targets and mandates also exist in non OECD countries (e.g., Brasil, China).

■ **Global potential for biomass production -** Present global modern bio-energy production is estimated at some 9 EJ/year of which industrial biofuel production is only 1 EJ per year (around 1% of transport fuels from crops grown on some 1% of all arable land - 14 million hectares). Estimates of global potential for industrial biomass production by 2050 vary considerably. Estimates of 100-200 EJ per year (roughly 10%-20% of 2050 primary energy supply) are based on the assumption of no water shortage and increased food agriculture yields in the coming decades, partly due to genetically modified crops. In this case, large amounts (20%-50%) of arable land would be available for biomass production. Some 50 EJ per year could be produced from ligno-cellulosic feedstock. The possible use of marginal, non-arable land could also play a role. The IEA's *World Energy Outlook* 2006 Reference Scenario projects the world biofuels output to climb at a rate of 7% per year to meet 4% of road-transport fuel demand by 2030. In the WEO Alternative Scenario, annual growth is 9% and output reaches 7% of road-fuel use in 2030. The IEA's *Energy Technology Perspectives* (2006) suggests bioethanol and biodiesel could meet some 13% of global transport fuel demand and contribute some 6% of global emission reductions by 2050. Projections are very sensitive to assumptions. Yields of biofuels from purpose grown crops depend on the species, soil type and climate. Cereals and maize can yield around 1500-3000 lge/ha; sugar cane 3000-6000 lge/ha; sugar beet 2000-4000 lge/ha, vegetable oil crops 700-1300 lde/ha, and palm oil 2500-3000 lde/ha.

BARRIERS - ■ **Ethanol** supply is constrained by arable land availability. Competition with food production for land use could drive possible increases in both ethanol and food prices (already occurring in the sugar market). Ethanol markets still have a regional structure (ethanol shipping $0.02-$0.03/l). Transport of biomass remains a logistics barrier that limits the size of ethanol production plants and economies of scale. A more liberalised market would create opportunities and incentives for producers in emerging economies especially Brazil, India, and Thailand. Transfer of advanced agricultural practices to developing countries could considerably help. Conversely, producing more biofuels from conventional feedstocks could conflict with conservation of bio-diversity and call for increased amounts of water, pesticides and fertilisers, thus raising sustainability issues. In scenarios having 25% of transport fuels derived from biomass, the use of fertilisers increases by about 40%. On a fuel-cycle basis, ethanol, with its high vapour pressure, reduces NOx and volatile organic compound (VOC) emissions but this is partly offset from increased N2O emission from increased use of nitrogenous fertilisers. Developing cost-effective ethanol production from ligno-cellulose via enzymatic hydrolysis would therefore increase the variety and availability of feedstocks and hence expand the production of biofuels. Other ethanol drawbacks include miscibility with water, aldehyde emissions, compatibility issues with some plastics or metals (Al-alloys, brass, zinc, lead) and high latent vapourisation heat (cold start issues). Ethanol use in compression ignition engines needs additives due to the low cetane number and is impractical. ■ **Biodiesel** production depends on feedstock and land availability even more than bioethanol production. The Fischer-Tropsch BTL technology and other advanced processes hold the potential to increase biofuels production basis.

Fig. 1 – World Production of Biofuels



Source: IEA analysis based on F.O.Lichts – IEA *World Energy Outlook* 2006

Fig. 2 – Current and projected costs of biofuels compared with conventional wholesale gasoline and diesel prices (fob).

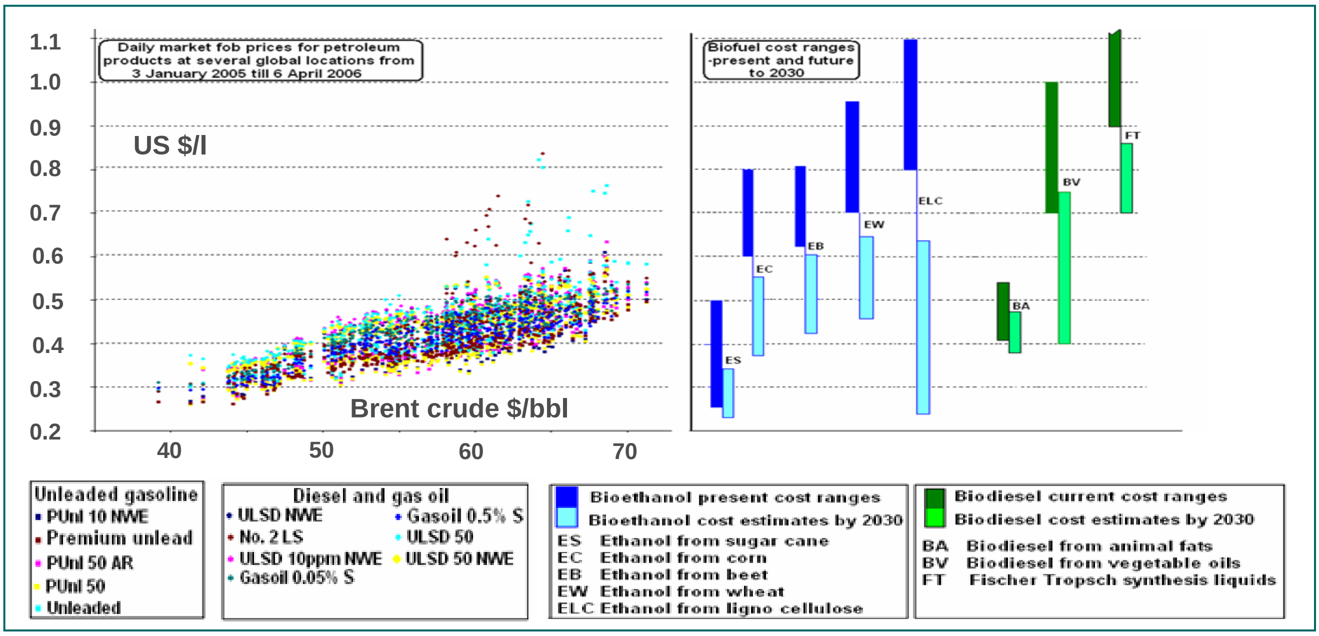


Table 1 –Feedstock production, costs, and emissions data for bioethanol and biodiesel production

Data Confidence – Bio-ethanol and biodiesel production from conventional feedstocks are already commercial in some countries, but subject to further improvement and optimisation. Data refer to typical, current technologies. Biofuels produced from ligno-cellulosic feedstocks are still in the demonstration phase and require further R&D to reduce cost and increase efficiency.

Performance	**Bioethanol**				**Biodiesel**
Feedstock	Cereals, maize	Sugar beets	Sugar cane	Ligno-cellulosic	Vegetable oils
Fossil energy input (%)	60-80	na	10-12	([a])	30-40
Co-products			Heat and power	Heat and power	
Installed capacity (bn l /yr)	19.5 US, 5 China	na	18 Brazil		1.9 Germany; 2.1 rest of world
Cost					
Production cost ($/lge)	0.6-0.8	0.6	0.3-0.5	1.0 ([b])	0.7-1.0 ($/lde)
Environmental Impact					
CO_2 reduction (%[c])	15-25	50-60	90	70	40-60
Pollutant abatement	CO	CO	CO	CO, NOx	SOx, particulates
Land use (lge/ha)	1500-3000	2000-4000	3000-6000	Na	700-1300 lde/ha (3000 palm)
Further Information	www.iea.org; www.ieabioenergy.com; International Bio-Energy Partnership (www.fao.org); *Energy Technology Perspectives* (IEA, 2006); *World Energy Outlook* (IEA, 2006); REN21 – Global Status Report 2005, 2006 (www.ren21.net)				

(a) Energy input may be higher than final ethanol energy, but most such energy comes from the biomass itself.
(b) Twice gasoline cost at $ 60/bbl. (c) Compared with gasoline (2.8 kg CO_2/l) or conventional diesel.