CHEMSYSTEMS

PERP PROGRAM

Developments in Biodiesel Production Technologies

Technology & Production Costs of Esterfip-H, NExBTL, Base-Catalyzed FAME & Conventional Petrodiesel Compared; Other Renewable Biofuels Technology Processes discussed - BIOX, VERTIGRO Algae-derived, H-BIO, EcoFining (Green Diesel). Biodiesel Feedstock Options (e.g., Jatropha), Glycerin Byproduct, Performance Issues discussed. Regional Capacity & Supply/Demand Forecasts.

PERP07/08S2

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Report Abstract

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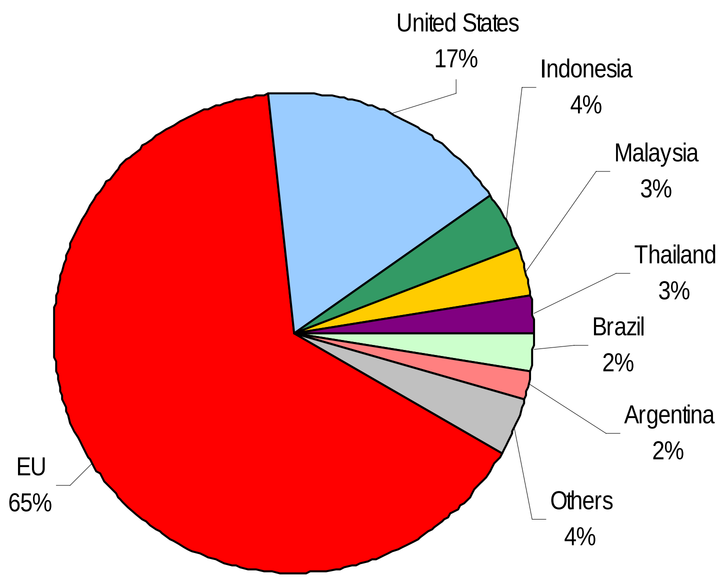
BIODIESEL

Biodiesel is a diesel-equivalent fuel processed from biologically sourced feedstocks.

Chemically it is referred to as a Fatty Acid Methyl Ester (FAME) or Ethyl Ester (FAEE). The term diesel refers to a specific fraction of a mixture of hydrocarbons that distil from crude oil within a defined boiling range. The increasing quantities of diesel-equivalents being obtained from sources other than crude oil have led to the term petroleum diesel, being used to distinguish crude oil derived diesel from diesels obtained from other sources. While biodiesel is a diesel-equivalent - meaning it can be readily used in blends with conventional diesel fuel, or neat (100 percent), in vehicles with diesel engines – it should be evident from the foregoing that it is chemically distinct from petroleum diesel.

In 2007, several million metric tons of biodiesel was produced globally. Of this production, Asia accounted for 10 percent, South America 4 percent, USA 17 percent and the European Union 65 percent, as can be seen in the figure below:

Global Production of Biodiesel
(metric tons)



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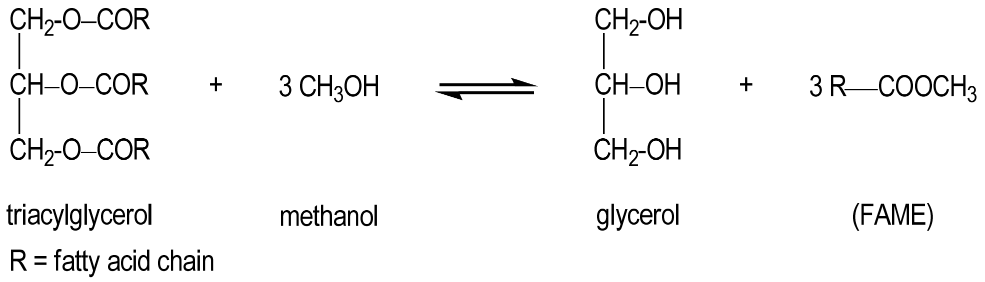
Biodiesel has many attractive features. It is a renewable source of energy, non-toxic, and biodegradable. Developments in the technology for producing biodiesel are discussed in this ChemSystems PERP report, alongside developments in alternative renewable fuels. There are also promising developments with respect to feedstocks and catalysts for biodiesel. These, along with detailed descriptions of process technology, market and economic impacts are discussed in this report. Some of these topics are briefly elucidated below.

FAME: Conventional biodiesel is produced by processing plant or animal products or wastes through transesterification. Shown below is the formula scheme for the production of FAME from triacylglycerols. Fatty acid methyl esters today are the most commonly used biodiesel species, whereas FAEE so far have only been produced in laboratory or pilot scale.



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GLYCERINE (or glycerol): About 10 percent by weight of biodiesel production is the by-product glycerine, resulting from the separation of the backbone of the triglyceride (or triacylglcerol) by the chemical action of methoxide on the alpha carbons. Europe experienced an oversupply of glycerine compared to existing demand due to by-product glycerine from biodiesel production. A discussion about this major by-product is an important consideration in the production of biodiesel and it is covered at length in this report.

Some of the esterification-based processes leading to biodiesel that are discussed in this report are highlighted below:

The new **AXENS-IFP ESTERFIP-H™ heterogeneous (solid) catalytic, continuous biodiesel process** is aimed at producing cleaner biodiesel (VOME, vegetable oil methyl ester) and by-product glycerine at lower cost than conventional FAME processing. Using heterogeneous catalysts eliminates the need for catalyst recovery and washing steps and associated waste streams required by processes using homogeneous catalysts.

The BIOX co-solvent process is a new biodiesel process developed in North America. BIOX is reported to have been successfully demonstrated in a laboratory and pilot plant scale. The BIOX process has lower potential feed costs but somewhat higher utility costs than conventional FAME processing.

Supercritical processing uses relatively high temperatures and pressures so that the reaction times can be very short. It produces a fatty acid ester from oils and fats, but through a process quite different from conventional FAME processing.

Valcent Products, Inc. and Global Green Solutions, Inc. have developed a joint venture (Vertigro Energy) which includes the growing and harvesting of algae and extraction of vegetable oil from the algae for biodiesel production. The Vertigro technology was developed by Valcent in recognition and response to a huge unsatisfied demand for vegetable oil feedstock by biodiesel refiners and marketers.

OTHER RENEWABLE LIQUID BIOFUELS

Developments in biodiesel processes, as highlighted above are occurring concurrently with developments in other diesel-equivalent renewable biofuels. Whereas biodiesel is produced by processing natural oils and fats biomass (plant or animal products or wastes) feedstock through transesterification, a product referred to as renewable diesel is produced by processing similar biomass feedstock through a refinery-type process called hydrotreating.

There are also processes involving high temperature gasification of cellulosic biomass (e.g., crop residues, woody crops or energy grasses) to produce syngas which is subsequently catalytically converted to make diesel range fuels using Fischer-Tropsch technology. Another type of process involves anaerobic thermal cracking of cellulosic biomass into pyrolysis oil, which can be further treated (for example by hydrorefining) to give a fuel similar to diesel. These cellulosic biomass feed processes allow the use of essentially limitless biomass as feed, but have some drawbacks compared to natural oils and fats-based processes. In addition to process descriptions, the advantages/disadvantages of these alternative processes are covered in the report.

Some of the non-esterification based processes leading to diesel-equivalent biofuels that are discussed in the report are highlighted below:

Apart from feedstock flexibility, **NESTE OIL's NExBTL® renewable diesel process** includes excellent fuel properties that meet the highest requirements of automotive industry, as well as remarkably low exhaust emission levels. The first NExBTL® plant came on-stream in summer 2007. As with other biofuels already available in the market, the NExBTL® products should benefit from the tax relief aimed at encouraging production of biofuels. Rather than making a by-product of glycerol, this hydrogenation-based process makes propane by-product.

Petrobras described its in-refinery natural oil processing approach, which it calls H-BIO, as a new technique to refine low-sulfur diesel. This is fuel from vegetable oil, and is the result of research carried out by the Petrobras Research and Development Center (Cenpes).

UOP and ENI have developed a technology for converting vegetable oils to renewable diesel (so called "Green Diesel"). The Ecofining™ process hydrogenates triglycerides and/or free fatty acid feedstocks such as pretreated vegetable oils (e.g., rapeseed, canola, soybean, palm, and jatropha) and animal fats (e.g., tallow). The resulting paraffins are then isomerized to create a high quality hydrocarbon known as green diesel.

Shell has entered into a partnership with CHOREN to provide advanced biofuels for both gasoline and diesel engines. Shell is providing its version of the Fischer-Tropsch technology. Separately, Carbo-V technology is aimed at Fischer-Tropsch production of biodiesel fuel branded "SunDiesel®".

The Canadian firm Dynamotive is the chief proponent of the anaerobic thermal pyrolysis process. Such processes typically produce complex mixtures of light and heavy oxygenated materials and other compounds, and char residues. Various developers are working on upgrading fuel quality.

As a long-range fermentation alternative to crop, gasification or pyrolysis-based oils for biodiesel, one company has been investigating the possibility that yeasts, molds, fungi, or bacteria can be genetically optimized to produce oils in closed manufacturing systems fed inexpensive biomass substrates.

Choosing a process technology for a biofuel plant largely depends upon the quality of the feedstock, the plant capacity, and the quality requirements for the finished product and its by-products. Feedstock is the largest cost component in the manufacturing of biodiesel.

FEEDSTOCKS

Biodiesel, either as FAME from transesterification of natural triglycerides as exemplified by Axens-IFP's new Esterfip-H™, or as the emerging hydrocracked natural triglyceride products such as are being introduced by Neste Oil and Petrobras, can be made from a wide range of natural fats, oils and greases (or FOG). These include Virgin refined vegetable oils, crude vegetable oils, rendered fats (which are co-products of animal slaughtering and processing), post-consumer waste oils such as from commercial or industrial food frying operations ("yellow grease"), so called "brown grease" (the waste greases that accumulate in public sewers and waste treatment systems), and fish oils.

The best plants for biodiesel feedstocks are those efficient at converting solar energy into chemical energy. Some experts believe that algae is set to eclipse all other biofuel feedstocks as the cheapest, easiest, and most environmentally friendly way to produce liquid fuel.

Jatropha curcas (a tropical/subtropical plant) is seen by many to be the perfect biodiesel crop. Unlike other biodiesel crops, jatropha can be grown almost anywhere including deserts, trash dumps, and rock piles. The latter point means environmentalists and policy makers don't have to worry about whether jatropha diverts resources away from crops that could be used to feed people.

Feedstock options are assessed at length, the advantages/disadvantages and cost considerations, as well as a detailed discussion of the food versus fuel issue.

ECONOMIC ANALYSIS and BIODIESEL MARKET

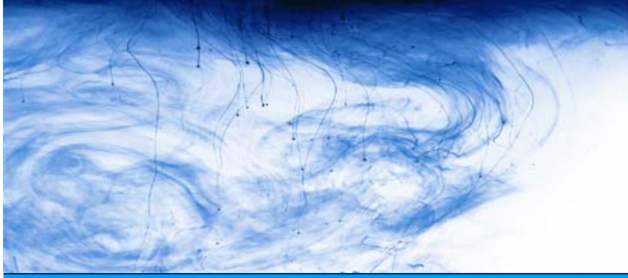
There is a trade off between feedstock cost and investment cost that needs to be evaluated on a case-by-case basis.

Comparisons of the cost of production estimate for the following are detailed and calculated in the report:

- Biodiesel (fatty acid methyl esters) via conventional transesterification of vegetable oil (base-catalyzed) technology
- Biodiesel (fatty acid methyl esters) via Axens' Esterfip-H™ technology
- Renewable diesel via Neste Oil's NExBTL® technology
- Conventional petrodiesel

Various sensitivities have been explored to illustrate the effects of variations in certain parameters on the base case economics presented. These results can also be used to make approximate comparisons between cases for which detailed economics have not been provided, by adjusting for capacity differences, alternative feedstock valuation etc. The sensitivities examined include the cost of raw materials, capital investment, and economy of scale.

The biodiesel market is multi-faceted, presenting varied opportunities for market entry and distribution modes. Generally, all of these could use various blends of bio- and petro-diesel.



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