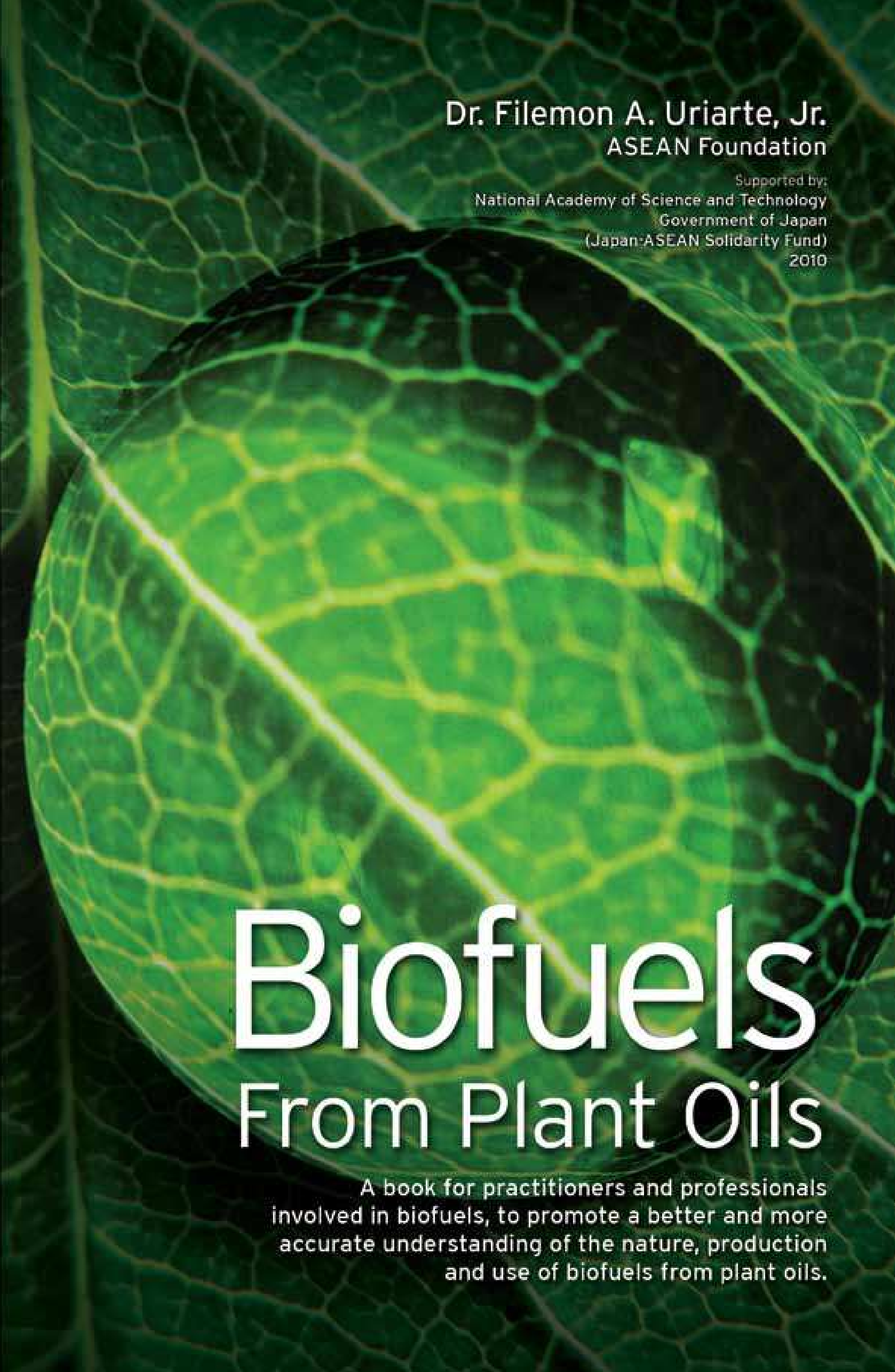

Dr. Filemon A. Uriarte, Jr.
ASEAN Foundation

Supported by:
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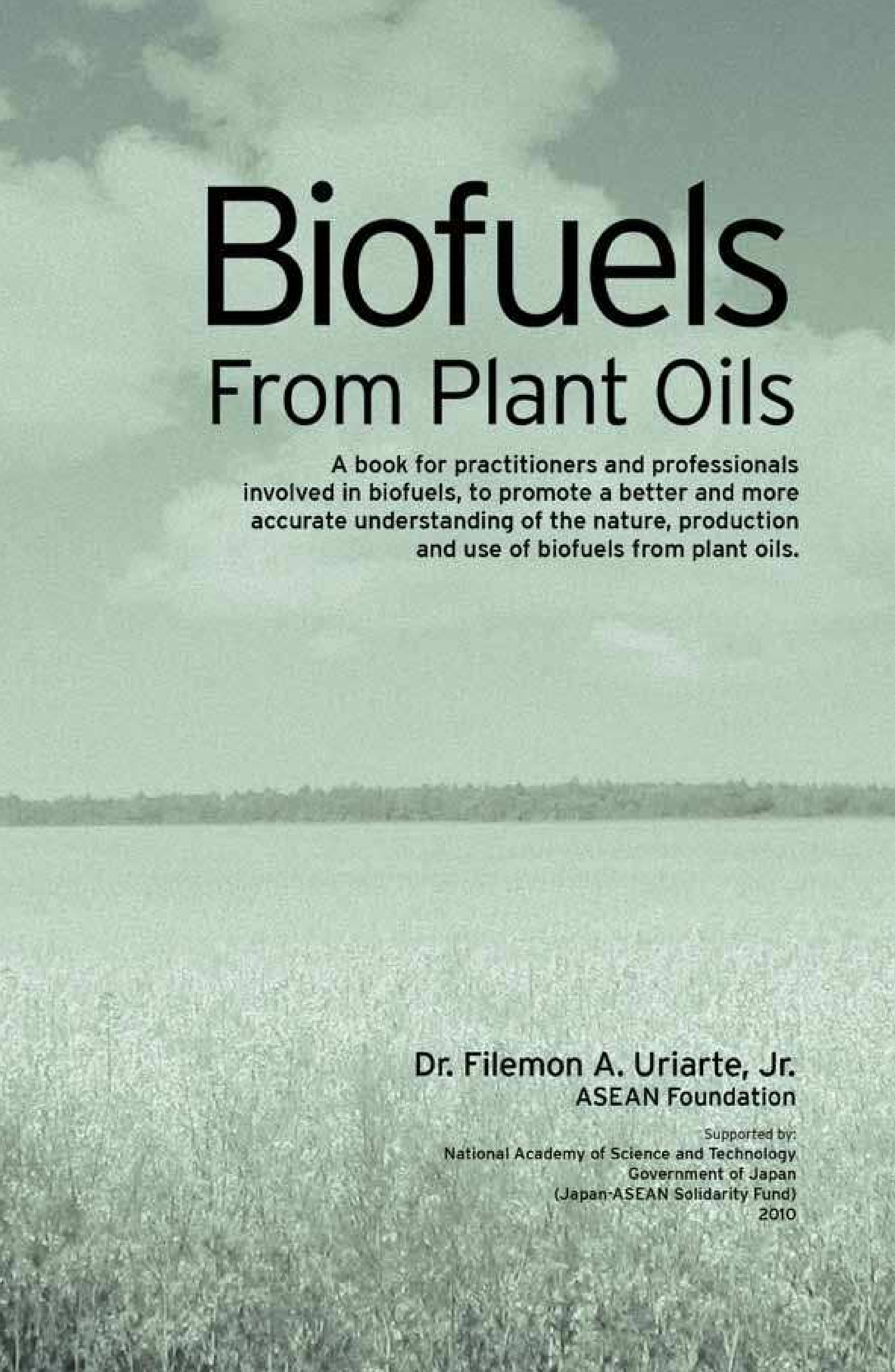
Biofuels
From Plant Oils

A book for practitioners and professionals involved in biofuels, to promote a better and more accurate understanding of the nature, production and use of biofuels from plant oils.



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Biofuels from Plant Oils

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My wife, Jean, carefully edited the various drafts of the manuscript and prepared, cleaned up and enhanced all the tables, charts, figures and boxes in this book. She conceptualized, designed and prepared the final layout and meticulously reviewed the final draft prior to printing. She should really be a co-author of this book. We dedicate this book to our seventh grandchild, James.

Dr. Filemon A. Uriarte, Jr.
Executive Director
ASEAN Foundation

Foreword

This book is intended for practitioners and professionals involved in biofuels as well as students, government officials, decision and policy makers, and civil society organizations interested in renewable energy. Its objectives are to promote a better and more accurate understanding of the nature, production and use of biofuels from plant oils and to provide a current and reliable reference and guidebook on the development, production and use of biofuels from plant oils.

In the face of rising prices of fossil fuels and the need to protect the global environment from climate change, the urgency of finding alternative sources of energy cannot be overemphasized. Cleaner fuels from renewable sources of energy including ethanol from sugar cane, corn and cassava, biodiesel from various types of plant oils such as coconut, palm and jatropha, and hybrid fuels from the microemulsification of diesel blended with varying amounts of plant oils must be developed to reduce the country's dependence on fossil fuels and contribution to global warming. The technologies for producing them must be further improved from the agricultural production phase to the industrial processing phase in order to make them viable and competitive. In line with the high priority given by the government to the development and use of biofuels, as exemplified, among others, by the passage of the Biofuels Act of 2006, it is extremely important that a reference and guidebook on the production and use of biofuels be made available widely to all the relevant sectors of society.

While the subject of ethanol from sugar cane, corn, cassava and other agricultural crops is as important as the subject covered in this guidebook, the field of ethanol production and use is a very vast and technologically different area that requires as much, if not greater, effort as is needed in preparing this book. It is thus covered only in general and is better covered in depth in a separate reference material and guidebook.

The author has been involved in numerous conferences, seminars and workshops on biofuels that provided valuable and timely reference materials and technical and economic information on the characteristics, production and use of biofuels. In addition, he is professionally and directly involved in the development and commercialization of microemulsified hybrid fuel technology using palm oil and jatropha oil, as well as in promoting investments in commercial plantations of jatropha curcas. He has incorporated the most recent technological and related developments in this field thus making parts of this book both novel and original.

This book has seven chapters. The first chapter covers the major types of biofuels including a brief description of ethanol from agricultural crops such as corn. As an introductory chapter, the coverage is not in-depth but provides the reader a good understanding of the most common biofuels, the related regulations and legislations, and the social and environmental impacts.

The second chapter covers a general survey of the various types of plant oils. The nature and characteristics of these plant oils are compared, particularly those characteristics that are important or relevant to their use as diesel fuel substitute and/or supplement.

The third chapter covers, with some degree of detail, the use of jatropha curcas for the production of biofuel as diesel substitute or supplement, starting from the agricultural production and harvesting of jatropha seeds to the processing of seeds to produce oil suitable for use in the manufacture of methyl ester and microemulsified hybrid fuel.

The fourth chapter presents various studies, trials, experiments, and actual field use of various types of straight plant oils as diesel substitute and/or supplement. It discusses the results of such studies and use, including the causes of failures and the conditions needed for success.

The fifth chapter presents the technologies available for the production of methyl ester from various plant oils, including used and recycled mixed plant oils. It discusses the use of methyl ester as a diesel substitute and/or supplement for compression ignition engines.

The sixth chapter presents the technologies available for the production of microemulsified hybrid fuel from various plant oils, including used and recycled mixed plant oils. It discusses the use of microemulsified hybrid fuel as a diesel substitute and/or supplement for diesel engines. Relevant technical data and information arising from the work of the author are presented.

The final chapter assesses the future of biofuels and presents the new and emerging technologies for their production, including the production and use of ethanol from cellulosic biomass and the production of biofuels from municipal solid wastes. A general economic assessment of the use of biofuels is also presented.

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Chapter 1:

What are Biofuels?

Biofuels are fuels derived from biomass. Biomass is organic matter taken from or produced by plants and animals. It comprises mainly wood, agricultural crops and products, aquatic plants, forestry products, wastes and residues, and animal wastes. In its most general meaning, biofuels are all types of solid, gaseous and liquid fuels that can be derived from biomass. Examples of solid biofuels include wood, charcoal and bagasse. Wood and charcoal are widely used as fuel for domestic purposes such as cooking in the rural areas of most developing countries. Waste bagasse, the fibrous material produced from sugar cane processing, is extensively used for steam and electrical power generation in raw sugar mills. Examples of gaseous biofuels include methane gas and producer gas. Methane gas is produced from the anaerobic fermentation of animal wastes, wastewater treatment sludge and municipal wastes in landfills. On the other hand, producer gas can be made from the pyrolysis or gasification of wood and agricultural wastes. Examples of liquid biofuels include methanol, ethanol, plant oils and the methyl esters produced from these oils commonly referred to as biodiesel[1].

The focus of this book is on liquid biofuels that are used primarily as transport fuel. In particular, it covers biofuels from plant oils. However, this chapter will briefly discuss the production of ethanol from sugar crops, starchy crops, and cellulosic biomass in order to provide a more complete overview of the two major types of biofuels that are commercially available, namely, ethanol and biodiesel.

Feedstock for Biofuels

The various feedstocks that can be used for the production of biofuels may be classified into three groups: cellulosic biomass, sugar and starchy crops, and oil-containing or oil-producing plants.

The first group of feedstock is cellulosic biomass. It is the type of feedstock that is increasingly becoming important for the production of biofuels. Its attractiveness as a feedstock results from the fact that it is made up of very complex sugar polymers that are not usually used as a source of human food. Cellulosic biomass includes a wide range of heterogeneous solid materials including, but not limited to, the following: (a) agricultural residues comprising leftover material from crops such as rice straw, or coconut coir, or the stalks, leaves and husks of corn plants; (b) forestry wastes such as chips and sawdust from lumber mills, dead trees, and tree branches; (c) municipal solid wastes such as paper products; (d) food processing and other industrial wastes such as slops from alcohol distilleries and black liquor from pulp and paper manufacturing; and (e) energy crops grown for fuel purposes such as fast growing trees and grasses.

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[1] Biodiesel refers to fatty acid methyl ester or mono-alkyl esters derived from plant oils or animal fats and other biomass-derived oils. The production of biodiesel will be discussed extensively in subsequent chapters.

The main components of cellulosic biomass are cellulose, hemicelluloses, and lignin. Depending on the source of biomass, cellulose may account for 40% to 60% by weight of the biomass and is thus the most common form of carbon in the biomass. It is a complex sugar polymer, or a polysaccharide, and is made from the six-carbon sugar called glucose. Because of its crystalline structure, it is resistant to hydrolysis, the chemical reaction that enables the production of simple, fermentable sugars from a polysaccharide. Hemicellulose is also a major source of carbon in biomass and may account for 20% to 40% by weight of the biomass. It is also a complex polysaccharide that is made from a variety of five-carbon and six-carbon sugars. Although it is relatively easier to hydrolyze into simple sugars compared to cellulose, the sugars that are produced, however, are not easily fermented to ethanol. Lignin comprises from 10% to 24% by weight of biomass and provides structural integrity and strength in plants. It remains as the residual material after the sugars in the biomass have been converted to ethanol. As a highly complex carbon-containing polymer, it contains a lot of energy and can be burned to produce steam and electricity for use in the biomass-to-ethanol manufacturing process.

The second group of feedstock is sugar and starchy crops. These are plants such as sugar cane and sugar beets that can store through photosynthesis the energy from the sun by converting it into simple sugars. In a similar fashion, there are plants such as corn, cassava and sweet potato that store the energy as complex sugars or starches. Although the name sugar is most often used to refer to sucrose or table sugar, in general, sugars are water-soluble carbohydrates that have relatively low molecular weight and usually characterized with having a sweet taste. Carbohydrates, on the other hand, are a group of organic compounds that include sugars, starches, celluloses and gums. They provide a major source of energy in the diet of humans and animals. These compounds are produced through photosynthesis by plants and contain only molecules of carbon, hydrogen and oxygen, usually in the ratio 1:2:1. Simple sugars are called monosaccharides. More complex sugars comprise between two and ten monosaccharides that are linked together. Thus dissacharides are those that contain two monosaccharides, trisaccharides are those that contain three and so on. These biomass products are mainly used as human or animal food. However, because of the need to find alternative sources of energy other than fossil fuels, these products are increasingly being used for the production of biofuels, particularly ethanol as gasoline substitute or blend.

The third group of feedstock is composed of oil-containing or oil-producing plants. There are a large number of plants that produce oils, in particular fixed oils, which can be processed to produce biofuels that can be used as diesel substitute or blend. The common characteristic of these oils is that they may be decomposed into glycerin and one or more acids of the type called fatty acids. The physical properties commonly found in these plant oils are the following: (a) they float on water but are not soluble in it; (b) they are greasy to the touch and have lubricating properties; (c) they are not readily volatile; and (d) they may be burned without leaving any significant residue. Most of these oils such as soybean oil, coconut oil and palm oil have been used mainly for human or animal food or the production of various types of cosmetics and pharmaceuticals but increasing amounts are now being processed for the production of biodiesel.

The recent interest in the production of energy from biomass has focused primarily on technologies and applications that produce liquid fuels for the use of the transportation industry. Since ethanol in its anhydrous form can be blended with gasoline, it has become one of the most widely used biofuel. In the same manner, since biodiesel (the methyl ester of plant oil) can be easily blended with or used as a substitute for diesel fuel, its production and use have also become widespread. Their use has the additional advantage of reducing emission of air pollutants, buildup of greenhouse gas and dependence on imported oil. At the same time, the cultivation and harvesting of the feedstocks have positive impacts on the agricultural and rural economies.

Box 1.1 – Biofuels milestones

B.C.E. (Before Common Era)

4000	Sumerians discover the process of fermentation.
10th century	Assyrians use biogas for heating bathing water.

C.E. (Common Era)

17th century	Helmont observes that organic matter emits flammable gases.
1808	Davy discovers methane as the end product of anaerobic digestion.
Mid-1800s	Transesterification of plant oils is used to distill glycerin during soap production.
1858-1864	French biologist Antoine Bechamp experiments with fermentation and concludes that ferments are living organisms.
1864	French chemist Louis Pasteur describes the process of fermentation scientifically.
1876	First successful internal combustion engine is produced.
1880s	First successful internal combustion engine using producer gas is produced.
1892-1893	Rudolf Diesel files a patent for a "Working Method and Design for Combustion Engines … a new efficient, thermal engine."
1895	Biogas is used to fuel street lamps in Exeter, Great Britain.
1897	First diesel engine suitable for practical use operates at an efficiency of 75 percent.
1908	Henry Ford's Model T is designed to run on ethanol.
1920s-1930s	Attempts to promote ethanol as motor fuel are made.
	Anaerobic bacteria responsible for methane production are identified.

1940s	First U.S. ethanol plant opens.
1939-1945	Extensive use of biogas to replace gasoline occurs.
1979	Commercial alcohol-blended fuels are marketed.
1984	Number of ethanol plants peaks at 163 in the United States, producing over 2.2 billion liters of ethanol during the year.
1988	Ethanol is used for first time as an oxygenate to lower pollution caused by burning gasoline.
1990	Ethanol plants begin to switch from coal to natural gas and to adopt other cost-reducing technologies.
	Ethanol plants are subsidized by the U.S. government to support farmers. Gasohol becomes commonly available in the U.S. Midwest.
1997-2002	Three million U.S. cars and light trucks that could run on E85, a blend of 85 percent ethanol and 15 percent gasoline, are produced but few gas stations sell the fuel.
	Concerns about climate change cause leading alternative energies such as biofuel, solar and wind to expand by 20 to 30 percent yearly.
2003	California becomes the first state to start replacing the oxygenate MTBE with ethanol. Several other states start switching soon afterward. California consumes 3.4 billion liters of ethanol a year – about a third of all ethanol produced in the United States.
2004	Crude oil prices rise by 80 per cent, gasoline prices rise by 30 per cent in the United States and diesel fuel prices rise by almost 50 per cent. The U.S. ethanol industry makes 225,000 barrels per day in August, an all-time record. Oil companies invest heavily in alcohol fuel.
2005	E85 sells for less than gasoline on average in the United States. More than four million flexible-fuel vehicles (vehicles that run on E85 and gasoline) exist in the United States. About 400 filling stations that sell E85 fuel exist in the United States, mostly in the Midwest. Gasoline prices rise as ethanol prices stay the same, due to rapidly growing ethanol supply and federal tax subsidies for ethanol.
2006	Indy Racing League switches to a 10 percent ethanol, 90 percent methanol fuel mixture.

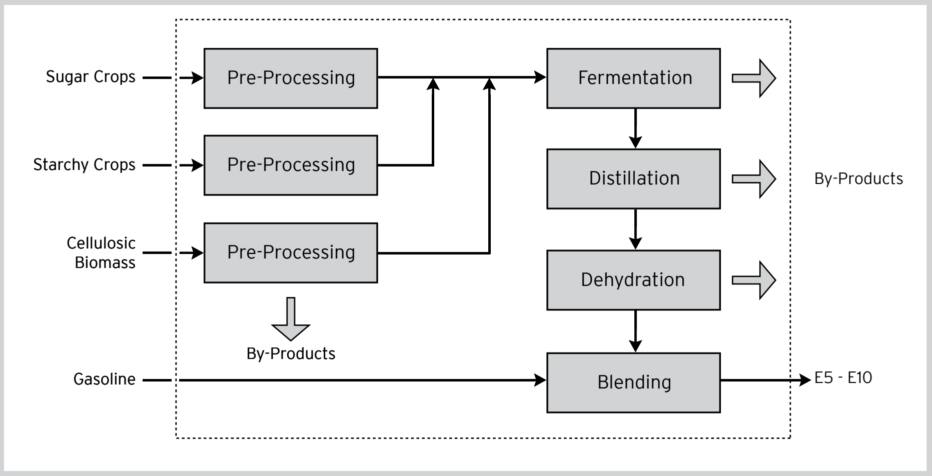
Source: Issue Brief: Biofuels, North Carolina Association for Biomedical Research, October 2006. <www.aboutbioscience.org/pdfs/Biofuels.pdf>

Production of Fuel Ethanol

Ethanol is one type of alcohol that has many properties quite similar to those of gasoline. These similarities make ethanol a highly attractive fuel for use as a gasoline substitute or as an alternative fuel for blending. The densities of ethanol and gasoline are almost identical although the energy content of ethanol is about 30% lower. On the other hand, since ethanol contains molecular oxygen that promotes more complete combustion, the difference in energy content does not become a major concern at low level of alcohol blends in gasoline.

Ethanol can be produced by the fermentation of carbohydrates from various feedstocks. The feedstocks fall under three main categories: (a) sugar-bearing feedstocks such as sugar cane; (b) starchy feedstocks such as cassava or corn; and (c) cellulosic feedstocks such as wood and agricultural residues such as bagasse. The production technologies for the first two types of feedstocks are fully mature and well-developed and are commercially available from various suppliers. However, the processing of cellulosic materials into ethanol using either acid or enzymatic hydrolysis is not yet fully developed commercially but is rapidly becoming technically and economically viable. Figure 1.1 shows schematically a simplified flow diagram for the production of ethanol from these three different feedstocks. Depending on the type and nature of feedstock, the pre-processing steps or operations may differ but there are basically three processes that are common for all three types of feedstocks: (a) fermentation of the sugars into ethanol; (b) distillation to separate the aqueous ethanol (95%) from the fermented mash; and (c) dehydration to produce anhydrous ethanol (>99.5%) suitable for blending with gasoline. In the case of starchy and cellulosic feedstocks, pre-treatment through saccharification or hydrolysis is required in order to convert them to sugars that can be fermented by yeast into ethanol.

Figure 1.1 – Production of ethanol from three different feedstocks



Fermentation is a series of chemical reactions that convert sugars to ethanol in the presence of suitable strain of yeast, which feed on the sugars. Ethanol and carbon dioxide are produced as the sugar (glucose) is consumed. The simplified fermentation reaction for a 6-carbon sugar, glucose, is as follows:

$$C_6H_{12}O_6 = 2\ CH_3CH_2OH + 2\ CO_2$$

The ethanol concentration in the fermented mash can attain a level of only 4% to 10% depending on the operating conditions and the strain of yeast being used. Ethanol is therefore recovered through distillation but only hydrous ethanol of about 95-96% can be produced through steam distillation of the fermented mash due to the formation of water-ethanol azeotrope. The product ethanol is withdrawn from the top of the distillation column while the spent fermented mash called distillery slops is withdrawn from the bottom and sent for further treatment before final disposal or reuse[2]. To make ethanol fully miscible with gasoline, it is necessary to further remove the residual water to produce anhydrous ethanol with a concentration of at least 99.5%. To attain this concentration, the hydrous ethanol has to undergo a suitable dehydration process or operation.

There are at least three widely-used dehydration processes to further remove water from the azeotropic ethanol-water solution. The first process that was used in many of the earlier ethanol plants is the so-called azeotropic distillation or ternary distillation process (as opposed to a binary or two-component distillation process). It consists of introducing a third component, benzene or cyclohexane, to the azeotropic solution which forms a heterogeneous azeotropic mixture in vapor-liquid-liquid equilibrium. When this mixture is distilled, anhydrous ethanol is produced at the bottom of the distillation column. Another early method is called extractive distillation, which consists of adding a ternary component that increases the relative volatility of ethanol. In this case, anhydrous alcohol is produced and withdrawn at the top of the distillation column.

Because distillation processes are energy intensive, a third method has been developed and accepted in majority of modern ethanol plants. This process uses molecular sieves to remove water from ethanol. In this process, ethanol vapor under pressure passes through a bed of molecular sieve beads. The pores of the beads are such that they allow the absorption of water but not ethanol. Two beds are normally used in parallel to allow the regeneration of one bed while the other is in use. This dehydration technology can save significant amounts of energy (up to 840 kJ/l) compared to conventional azeotropic or extractive distillation processes.

For the production of ethanol from corn, there are two main processes in commercial use: dry milling and wet milling. In the dry milling process the entire corn kernel is ground into flour, which is referred to as "meal." The meal is then made into slurry by adding water. Enzymes are added to the mash to convert starch to dextrose, which is a simple sugar. Ammonia is added to control the pH and to provide nutrient for the yeast, which is added later. The mixture is processed at high temperatures to reduce the bacteria levels and transferred and cooled in fermentation tanks. This is where the yeast is added and conversion from sugar to ethanol and carbon dioxide takes place.

The entire process takes between 40 to 50 hours, during which time the fermenting mash is kept cool and agitated in order to facilitate yeast activity. After the process is complete, everything is transferred to distillation columns where the ethanol is removed from the stillage. The ethanol is dehydrated to about 99.5% using a molecular sieve system. A denaturant such as gasoline is added to the anhydrous ethanol to render the product not suitable for drinking. The remaining stillage undergoes a series of processes to produce feed for livestock. The carbon dioxide released from the process is collected and processed to produce industrial or food grade product.

The process of wet milling takes the corn grain and steeps it in a dilute combination of sulfuric acid and water for 24 to 48 hours in order to separate the grain into many components. The slurry mix then goes through a series of grinders to separate out the corn germ. Corn oil is a by-product of this process and is extracted and sold. The remaining components of fiber, gluten and starch are segregated out using screen, hydroclonic and centrifugal separators.

The gluten protein is dried and filtered to make a corn gluten meals co-product, which is used as a feed ingredient for poultry broilers. The steeping liquor produced is concentrated and dried with the fiber and sold as corn gluten feed to the livestock industry. The heavy steep water is also sold as a feed ingredient. The starch and remaining water can then be processed one of three ways: (a) fermented into ethanol through a similar process as dry milling; (b) dried and sold as modified corn starch; or (c) made into corn syrup. This process is shown schematically in Figure 1.2. The production of ethanol from corn using the wet mill process has become the technology of choice since it provides more product diversity and flexibility.

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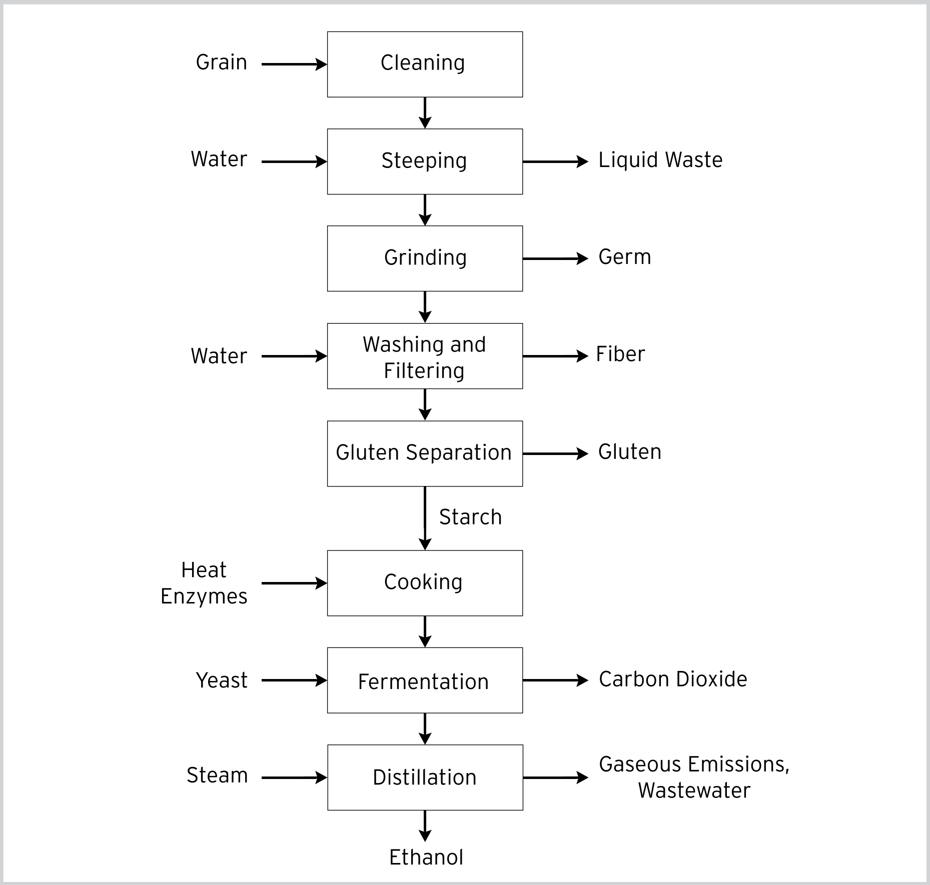
[2] There are many technologies available for the treatment or re-use of distillery slops but their detailed discussion is outside the scope of this book. The slops may be neutralized and fermented anaerobically to reduce biochemical oxygen demand (BOD) and produce methane gas for fuel. The resulting mash may be further treated to produce a suitable soil conditioner or animal feed or sent to aeration ponds, mixed with other dilute wastewater effluents and subsequently used for irrigation.

Figure 1.2 – Production of ethanol from corn using the wet mill process



To produce ethanol from cellulosic feedstocks, several pre-treatment steps are necessary to convert cellulose into simple sugars that can be converted into alcohol using the conventional yeast fermentation process. This is shown schematically in Figure 1.3.

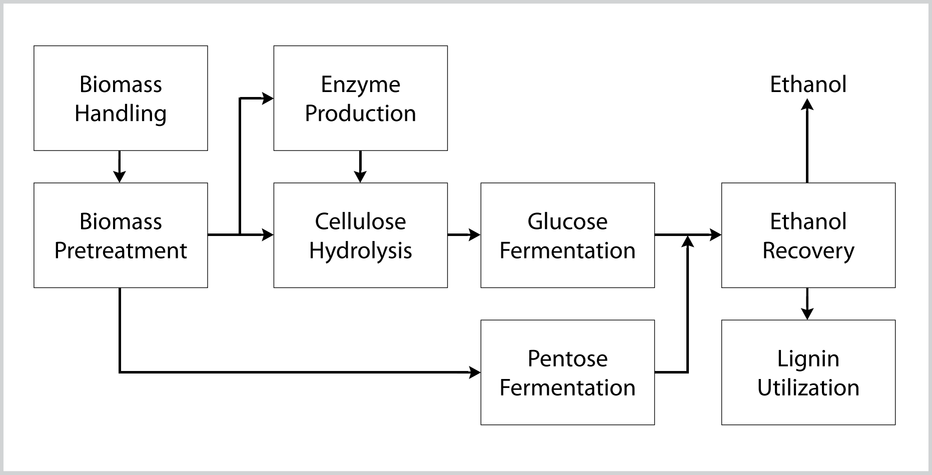
The first step is mechanical preparation through size reduction to make the material easier to handle and more susceptible to the subsequent pre-treatment steps. For example, agricultural residues go through a grinding process and wood goes through a chipping process to produce smaller and more uniform particle size. This is followed by acid pre-treatment. In this step, the hemicellulose fraction of the biomass is broken down into simple sugars. A chemical reaction called hydrolysis occurs when dilute sulfuric acid is mixed with the biomass feedstock. In this hydrolysis reaction, the complex chains of sugars that make up the hemicellulose are broken, releasing simple sugars. The complex hemicellulose sugars are converted to a mix of soluble five-carbon sugars, xylose and arabinose, and soluble six-carbon sugars, mannose and galactose. A small portion of the cellulose is also converted to glucose.

The next step is cellulose hydrolysis. In this step, the remaining cellulose is hydrolyzed to glucose. In this enzymatic hydrolysis reaction, cellulase enzymes are used to break the chains of sugars that make up the cellulose, releasing glucose. Cellulose hydrolysis is also called cellulose saccharification because it produces sugars. The cellulase enzymes needed for this process may be produced in-house in a separate enzyme production facility or may be purchased from outside suppliers. The glucose is converted to ethanol through yeast fermentation, as discussed earlier. The yeast feeds on the sugars and as the sugars are consumed, ethanol and carbon dioxide are produced.

The hemicellulose fraction of biomass is rich in five-carbon sugars, which are also called pentoses. Xylose is the most prevalent pentose released by the hemicellulose hydrolysis reaction. As glucose is converted to ethanol by yeast fermentation similar to those used in the first two types of feedstocks, the pentose (mainly xylose) is subjected to a different type of fermentation. In pentose fermentation, *Zymomonas mobilis* or other genetically engineered bacteria are used instead of yeast. Hydrous ethanol is recovered from the fermented mash through distillation and anhydrous ethanol is produced after dehydration, as in the previous processes described earlier.

Lignin and other byproducts of the biomass-to-ethanol process can be used to produce the electricity required for the ethanol production process. Burning lignin actually creates more energy than needed and selling electricity to outside users improves the economic viability of the process.

Figure 1.3 – Production of ethanol from cellulosic feedstocks



Production of Biodiesel[3]

Biodiesel is produced through a series of physical and chemical processing of the fruits, seeds, or parts of oil-containing plants. The first step usually involves the extraction of the crude oil. This step may involve several different types of operations or processes depending on the kind of feedstock. For example, the process of extracting crude oil from jatropha may involve only one or two simple mechanical operations whereas the process of extracting oil from coconut may involve many. The detailed description of the various unit operations and processes involved in the extraction of crude oil from different types of plant oils such as palm oil, soybean oil, coconut oil and others is outside the scope of this book. However, the two main processes for extracting oil from seed feedstock are mechanical press extraction and solvent extraction. In mechanical press extraction, the oil seed feedstock (e.g., jatropha seed, sunflower seed, etc.) is first heated to about 110°F. The oil seed is then crushed in a screw press. After most of the oil is removed, the remaining seed meal can be used as an animal feed. The solvent process extracts more of the oil contained in the oil seed feedstock but requires more costly equipment. The process uses a solvent to dissolve the oil. After extraction, a distillation process separates the oil from the solvent. The solvent condenses and can be recycled and reused in the process. Solvent extraction produces vegetable oil with a higher degree of purity than the mechanical press process.

The central problem in using plant oil as diesel fuel is that plant oil is much more viscous (thicker) than conventional diesel fuel. It is 11 to 17 times thicker. Plant oil also has very different chemical properties and combustion characteristics to those of conventional diesel fuel. If the fuel is too thick it will not atomize properly when the fuel injectors spray it into the combustion chamber and it will not combust properly – the injectors may get coked up, leading to poor performance, higher exhaust emissions and reduced engine life. The process of transesterification reduces the high viscosity of plant oil, resulting in a higher-quality fuel. In the transesterification process, vegetable oil reacts with alcohol (methanol or ethanol) in the presence of a catalyst (usually sodium hydroxide). The oil molecules (triglycerides) are broken apart and reformed into methyl esters and glycerin, which are then separated from each other and purified.

Biodiesel, which is a mixture of fatty acid alkyl esters, can be produced not only from plant oils, such as coconut oil, palm oil and soybean oil, but also from animal fats or recycled cooking oil and greases. Esters are compounds of alcohol and organic acids. Fatty acid methyl ester is made by bonding methanol to animal fat or plant oil. The process is relatively straightforward, but must consistently achieve prescribed standards to minimize the risk of damaging expensive diesel engines. Biodiesel can be used as a fuel for vehicles in its pure form, but it is usually used as a petroleum diesel blend to reduce levels of particulates, carbon monoxide, hydrocarbons and air toxins from diesel-powered vehicles.

Because it is oxygenated, biodiesel dramatically reduces air toxins, carbon monoxide, soot, small particles, and hydrocarbon emissions by 50% or more, reducing the cancer-risk contribution of diesel up to 90% with pure biodiesel. Air quality benefits are roughly proportional for diesel/biodiesel mixtures. Biodiesel's superior lubricity helps reduce engine wear, even as a small percentage additive. The most common use of biodiesel is as B20 (20% biodiesel, 80% diesel) and B2 (2% biodiesel, 98% diesel) or B1 (1% biodiesel, 99% diesel). The use of these blends requires no engine modifications. But because it gels at higher temperatures than petroleum diesel, however, pure biodiesel requires special management in cold climates. Biodiesel contains slightly less energy than petroleum diesel, but it is denser, so fuel economy tends to fall 7% for every 10% biodiesel in a fuel blend.

When applied in its pure form, biodiesel has a higher flash point than fossil-based diesels, and its viscosity results in a more intense pulverization, which is another disadvantage. Nevertheless, if properly treated, these shortfalls can be abated – and the advantages of biodiesel greatly make up for its disadvantages. It is nonhazardous, nontoxic and biodegradable, and it reduces air pollutants such as particulates, carbon monoxide, hydrocarbons and air toxins. It burns more efficiently than petroleum diesel, and its higher lubricity can reduce engine wear, prolonging its lifetime.

Biofuels Legislation and Standards

In the Philippines, Republic Act No. 9367, otherwise known as Biofuels Act of 2006, was signed into law on 12 January 2007. The Implementing Rules and Regulations (IRR) were approved and signed by the Secretary of Energy on 17 May 2007. Section 2 of the IRR declares the government's policy concerning biofuels; Section 3 defines the various terms that are used in the legislation; and Section 5 states the mandatory use of biofuels in the country. The Philippine National Standards for fatty acid methyl ester is shown in Table 1.1.

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[3] This subject will be discussed in detail in the subsequent chapters but a brief overview of the main production processes is given here.

Box 1.2 – Policy on biofuels

It is hereby declared the policy of the State to reduce dependence on imported fuels with due regard to the protection of public health, the environment, and natural ecosystems consistent with the country's sustainable economic growth that would expand opportunities for livelihood by mandating the use of biofuels as a measure to:

(a) Develop and utilize indigenous renewable and sustainably-sourced clean energy sources to reduce dependence on imported oil;
(b) Mitigate toxic and greenhouse gas (GHG) emissions;
(c) Increase rural employment and income; and
(d) Ensure the availability of alternative and renewable clean energy without any detriment to the natural ecosystem, biodiversity and food reserves of the country.

Box 1.3 – Definition of terms

Bioethanol – shall refer to ethanol (C2H5OH) produced from feedstock and other biomass.

Biodiesel – shall refer to Fatty Acid Methyl Ester (FAME) or mono-alkyl esters derived from vegetable oils or animal fats and other biomass-derived oils that shall be technically proven and approved by the Department of Energy (DOE) for use in diesel engines with quality specifications in accordance with the Philippine National Standards (PNS).

Bioethanol Fuel – shall refer to hydrous or anhydrous bioethanol suitably denatured for use as motor fuel, with quality specifications in accordance with the PNS.

Biofuel – shall refer to bioethanol and biodiesel and other fuels made from biomass and primarily used for motive, thermal and power generation with quality specifications in accordance with the PNS.

Biofuel blends – shall refer to gasoline or diesel that has been blended with biofuels such as, but not limited to, bioethanol and biodiesel.

Biomass – shall refer to any organic matter, particularly cellulosic or ligno-cellulosic matter, which is available on a renewable or recurring basis, including trees, crops and associated residues, plant fiber, poultry litter and other animal wastes, industrial wastes, and the biodegradable component of solid waste.

Box 1.4 – Mandatory use of biofuels

Pursuant to Section 5 of Republic Act 9367, all liquid fuels for motors and engines sold in the Philippines shall contain locally-sourced biofuels components as follows:

5.1 Bioethanol

(a) Within two (2) years from the effectivity of the Act, at least five percent (5%) bioethanol shall comprise the annual total volume of gasoline fuel actually sold and distributed by each and every oil company in the country, subject to the requirement that all bioethanol blended gasoline shall contain a minimum five percent (5%) bioethanol fuel by volume: Provided, that the bioethanol blend conforms to the PNS.
(b) Within four (4) years from the effectivity of the Act, the National Biofuels Board (NBB) created under Section 8 of the Act is empowered to determine the feasibility and thereafter recommend to the DOE to mandate a minimum of ten percent (10%) blend of bioethanol by volume into all gasoline fuel distributed and sold by each and every oil company in the country: Provided, that the same conforms to the PNS.

5.2 Biodiesel

(a) Within three (3) months from the effectivity of the Act, a minimum of one percent (1%) biodiesel by volume shall be blended into all diesel fuels sold in the country: Provided, that the biodiesel blend conforms to the PNS.
(b) Within two (2) years from the effectivity of the Act, the NBB is empowered to determine the feasibility and thereafter recommend to the DOE to mandate a minimum of two percent (2%) blend of biodiesel by volume which may be increased after taking into account considerations including, but not limited to, domestic supply and availability of locally-sourced biodiesel component.

Table 1.1 – Chemical and physical requirements for fatty acid methyl ester

Property	Limit	Test Method
Appearance	Clear	
Acid number, mg KOH/g, max.	0.50	PNS ASTM D 664 PNS ASTM D 974 PNS EN 14104
Carbon residue on 100% sample, % mass, max.	0.050	PNS ASTM D 4530 or PNS ISO 10370
Cetane number, min.	51	PNS ASTM D 613 or PNS ASTM D 6890 or PNS ISO 5165 or PNS IP 498/03
Cloud point, ^{0}C, min.	Report	PNS ASTM D 2500
Copper strip corrosion, 3 hrs @ 50^{0}C, max.	No. 1	PNS ASTM D 130 or PNS ISO 2160
Density @ 15^{0}C, kg/L	0.86 - 0.90	PNS ASTM D 1298 or PNS ISO 3675
Distillation AET 90% recovered ^{0}C, max.	360	PNS ASTM D 1160 or PNS ASTM D 86
FAME content, % mass, min.	96.5	PNS EN 14103 modified
Flash point, Pensky-Marten, ^{0}C, min.	100	PNS ASTM D 93
Glycerin, % mass max. Free glycerin Total glycerin	 0.02 0.24	PNS AOCS Ea 6-94 (1997) PNS ASTM D 6584 (modified PNS AOCS Ca 14-56 (1997) PNS ASTM D 6584 modified
Glyceride content, % mass, max. Monoglyceride Di-glyceride Tri-glyceride	 0.80 0.20 0.20	PNS EN 14105 modified
Group Metals, mg/kg, max. Group I metals (Na+K) Group II metals (Ca+Mg)	5 5	PNS EN 14108 PNS EN 14109 PNS EN 14538
Methanol content, % m/m, max.	0.20	PNS EN 14110
Methyl Laureate (interim), % mass, min.	45	PNS EN 14331 modified
Oxidation stability, 110^{0}C, hours, min.	6	PNS EN 14112
Phosphorus, % mass, max.	0.001	PNS ASTM D 4951
Sulfated ash, % mass, max.	0.020	PNS ASTM D 874
Sulfur, % mass, max.	0.050	PNS ASTM D 2622 PNS ASTM D 5453 PNS ASTM D 4294
Viscosity, Kinematic @ 40^{0}C, mm2/s	2.0 - 4.5	PNS ASTM D 445
Water, % volume, max.	0.05	PNS ASTM D 6304 PNS ISO 12937
Water & sediments, % volume, max.	0.05	PNS ASTM D 2709

Environmental and Social Impacts

The combustion of fossil fuels such as coal, oil and natural gas has been identified as a major cause of the increase in the concentration of carbon dioxide in the earth's atmosphere. Carbon dioxide and other so-called greenhouse gases (e.g., methane) allow solar energy to enter the earth's atmosphere but reduce the amount of energy that can be radiated back into space, thus trapping energy and causing global warming.

One environmental benefit of replacing fossil fuels with biomass-based fuels is that the energy obtained from biomass does not add to the level of carbon dioxide in the atmosphere that causes global warming. Although the combustion of all types of fuel, including fuels produced from biomass, releases carbon dioxide into the atmosphere, the burning of biomass does not cause any net increase in carbon dioxide concentration. The reason for this is that plants use carbon dioxide from the atmosphere to grow (photosynthesis) and the carbon dioxide formed during combustion is balanced by that absorbed during the annual growth of the plants used as the biomass feedstock. In the case of fossil fuels, the carbon content of these fuels has been fixed and contained in the earth's crust for millions of years. By burning these fossil fuels the formerly harmless carbon buried in the earth's crust is released into the atmosphere as carbon dioxide resulting in a net increase in the carbon concentration that leads to global warming.

Although some fossil fuel-based energy may also be used to grow, produce and process the biomass feedstock, the general net result, based on a number of product life cycle studies, is still substantially reduced net greenhouse gas emissions. For example, although modern, high-yield corn production is relatively energy intensive, the net greenhouse gas emission reduction from making ethanol from corn grain can still be as much as 20%. If ethanol is produced from sugar cane where waste bagasse is used for steam and power production, the net reduction in greenhouse gas emission is even bigger. And making biodiesel from soybeans can reduce net emissions by nearly 80%. Finally, producing ethanol from cellulosic materials and using the non-fermentable lignin and other biomass for the production of steam, energy and electricity can reduce net carbon dioxide emission by close to 100%.

Since petroleum diesel and gasoline consist of blends of hundreds of different chemicals of varying hydrocarbon chains, many of these are hazardous and toxic. They include volatile compounds such as benzene, toluene and xylene that are identified as responsible for the health hazards and pollution associated with the combustion of petroleum-based fuels. Carbon monoxide (produced when combustion is inefficient or incomplete), nitrogen oxides (produced when combustion occurs at very high temperatures), sulfur oxides (produced when elemental sulfur is present in the fuel), and particulates that are generally produced during combustion are other specific emissions of concern. An important environmental and health benefit of using biofuels as an additive to or replacement of petroleum-based transportation fuels is a reduction in these harmful emissions, in particular sulfur oxides and particulates.

Since both ethanol and biodiesel contain oxygen in their chemical structure they can be used as fuel oxygenates to improve combustion characteristics. The presence of chemically-bound oxygen results in more complete combustion, which reduces carbon monoxide emissions. This is significant environmental and health benefit that can result from replacing petroleum fuels with biofuels. Ethanol is typically blended with gasoline to form an E10 blend (5%-10% ethanol and 90%-95% gasoline), but it can be used in higher concentrations such as E85 or in its pure form. Biodiesel is usually blended with petroleum diesel to form a B1 blend (1% biodiesel, 99% petroleum diesel) or B20 blend (20% biodiesel and 80% petroleum diesel), although other blend levels can be used up to B100 (pure biodiesel).

The global public debate about the use of ethanol as a world energy source has been going on for more than fifty years. On one hand, ethanol advocates have described ethanol as the "fuel of the future". But critics question the feasibility and advisability of large-scale ethanol production in terms ranging from "net petroleum energy balance" to more general environmental and agricultural impacts. The opponents of widespread use of ethanol as fuel question the use of limited edible resources to meet the world's energy needs. In the same manner, these opponents say that the need for cleaner-burning fuel sources for environmental and health reasons does not fully justify the use of edible plant oils such as soybean oil, palm oil and coconut oil. Many critics also argue that it is wrong to use grain for energy production instead of for food. In the final analysis, it is society that must decide whether the virtues and benefits of using ethanol or biodiesel as an energy source outweigh the potential negative consequences on available food supply of using grain or edible plant oils for biofuel. Society, in general, and the scientific community, in particular, must also resolve the debate about the energy balance of ethanol production, with different studies showing either a net gain or loss when the energy inputs to ethanol production are compared to the energy yield.

The future of agricultural and land use policies is complicated by this emerging potential for large-scale bio-energy production. The growing demand for cleaner-burning fuels, such as ethanol, is likely to generate changes in agricultural cropping patterns and land management practices. This will have serious impacts on the environment, possibly threatening the natural resource base. Both biofuels proponents and critics question how production decisions and policy formulation and development surrounding the rapid expansion of the biofuel industry will affect the environment, especially water quality and soil quality. In the same manner, they ask whether the long-touted climate benefits arising from the displacement of petroleum oil use will actually be realized. The answers to these questions are not yet certain. What is certain is that while energy policy will have a significant impact on how the markets for biofuels will develop, agricultural and land use policies will also significantly influence how those markets will impact the environment and the people's health.

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Chapter 2:
What are Plant Oils?

The distinction between fat and oil is mainly a physical one. If the substance is solid at ambient temperature, it is called fat. If it is liquid, it is called oil. This distinction is merely for convenience since all oils solidify when the temperature is made low enough and all fats melt if the temperature is made high enough. This temperature-based distinction between oils and fats is not precise since ambient temperatures vary depending on location. Countries in the northern hemisphere have lower ambient temperatures while countries near the equator have higher. Thus what may be usually called "fat" in a cold country may be called "oil" in a warm tropical country. In addition, it is more precise to use a melting range for plant oils rather than a melting point since the fat melts into oil within a certain range of temperatures. Oils and fats have a number of common physical and chemical properties. Their common physical properties are: (a) they float on water and are not soluble; (b) they have lubricating properties and are greasy to the touch; and (c) they leave little or no residue when burned. Their common chemical characteristic is that they may be converted into glycerin and one or more fatty acids.

When oils and fats are split into glycerin and fatty acids, the resulting mixture contain three molecules of fatty acid for each molecule of glycerin. Historically, it is because of this proportion of acid to glycerin that the chemical compounds found in the oil or fat are called triglycerides (tri = three). Fats and oils are basically mixtures of varying amounts of triglycerides. Triglyceride plant oils include not only edible, but also inedible plant fats and oils such as linseed oil, tung oil, and castor oil, which are generally used in lubricants, paints, cosmetics, pharmaceuticals and other industrial products. Although plant oils are generally thought of as esters of glycerin and a varying blend of fatty acids, they in fact contain free fatty acids and diglycerides as well.

While there are a large number of triglycerides in nature, the triglycerides of seven acids, namely, lauric, myristic, palmitic, stearic, oleic, linoleic, and linolenic, constitute the majority of natural fats and oils. In certain fats and oils, one triglyceride usually predominates, and another triglyceride in other fats and oils. But in some fats and oils, several triglycerides may be present in significant proportions. The properties of fats and oils, therefore, depend on the characteristics of the triglycerides of which they are mixtures and the relative proportion of the triglycerides present. Since fats and oils are merely physical mixtures of triglycerides, it is possible in most cases to separate them more or less completely into their component triglycerides by simple mechanical means such as chilling and application of pressure.

Types of Plant Oils

There are two distinct types of plant oils: (a) fixed oils such as coconut and castor oils, which do not readily evaporate on exposure to air; and (b) essential oils such as citronella and cinnamon oils, which readily evaporate or volatilize on exposure. Fixed oils are usually extracted by crushing and pressure, by boiling, or by chemical solvents. On the other hand, essential oils are almost always extracted by distillation, many of them from flowers such as *ilang-ilang* oil and *sampaguita* oil. Some fixed oils that are liquid at relatively high temperature become solid in ambient and lower temperatures. These fixed oils from plants are the oils of interest as possible replacement for diesel fuel or as diesel fuel extenders while essential oils are of interest as components in the production of perfumes and other cosmetics and pharmaceuticals. Soybean oil, coconut oil and palm oil are the most widely used plant oils, followed by rapeseed oil, sunflower seed oil, peanut or groundnut oil, cottonseed oil, and olive oil. Box 2.1 provides brief descriptions of various types of fixed oils.

Box 2.1 – Brief descriptions of various types of plant oils

Castor oil; Palma Christi; Endaru-tel, S; Amanaku-maram, T, *(Eicinus communis. Euphorbiaceae)*. A tall, quick-growing perennial, woody shrub or small tree, with large handsome palmate-peltate leaves, naturalized in Sri Lanka, often occurring as a weed in abandoned ground in the low-country and up to about 1,200 meters. It is cultivated in all warm countries, more particularly in India, Southern Europe, and Southern United States, generally as an annual but sometimes as a perennial crop; often planted for ornament, sometimes for shade, as in arid or desert regions. It is suited to a wide range of climate and soil.

Cultivation. The plant thrives in ordinary land, even in brackish or saline ground, but does best in rich loamy or alluvial soil. Excessive moisture is unfavorable to the crop, but a moderate rainfall in its early growth is desirable. About 450 gram of seed is sufficient to sow a 4,000 sq meter lot, allowing 3 or 4 seeds to each hole, the latter being spaced about 1.8 x 1.8 meter; the seedlings should afterwards be thinned out, leaving one to each hole. The seeds germinate in 8-10 days. The plants should be topped at a height of about 1 meter. They begin to bear fruits in about 4 months from sowing, and the harvest may be completed about 3 months later.

Yield. Planted as a pure crop, the yield under favorable conditions may be 1.7-2.2 cubic meters of seed ("beans") per hectare; as a mixed crop, 0.35-0.40 cubic meters is a fair average crop (about 600 kg = a cubic meter). A single tree may give as much as 2.7-4.5 kg. In the United States as much as 2.6 cu m or 1,570 kg per hectare is sometimes obtained. The oil is obtained from the seeds by pressure.

Coconut Palm. Pol, S; Tennai or Thenga, T. *(Cocos nucifera)*. A tall stately palm, 20-25 meters high, with a stout wavy stem, surmounted by a crown of long arching, handsome, pinnate leaves. Its cultivation and the preparation of its different products for local use or for export form an important industry in Sri Lanka and the Philippines. The kernel (endocarp) yields a valuable fatty oil. In the fresh state the kernels are shredded and made into desiccated coconut, largely exported for use in confectionery. The husk (pericarp) when retted for about 3 weeks in water yields coir fiber, which is made into mats, brushes, matting, string and ropes. Copra of commerce, the source of coconut oil, consists of the dried kernels. It is prepared by breaking the nut in two; the two cup-shaped halves, being easily separated from the shell, are then dried in the sun or in specially constructed low houses or kilns, over smoke and heat from smoldering fires made with the husks and shells. Forced hot-air driers are sometimes used for the purpose, the copra shells being placed in movable trays. Copra contains about 65% of oil.

Cultivation. The palm requires a hot and moist climate, deep alluvial or loamy soil, thriving especially near the seaboard, but also to a considerable distance inland provided climatic conditions and soil are suitable. It is propagated by the large, ovoid nuts, which are sown in the husk in nursery beds, being laid on their sides and almost covered with soil. These germinate in about 3 months, and in 10 months the seedlings, with nut attached, are ready for planting out. Or the nuts may be planted in situ in well-prepared holes. The holes should be not less than 1 meter deep by 1 meter wide, and should remain open for some time previous to planting. After planting, they should at first be only partially filled with good surface soil. In course of time the holes become filled through the process of cultivation and weathering. Planting distances depend on soil and locality; 9 x 9 meters is sometimes adopted, but 7.9 x 7.6 meters (170 to the hectare), or even closer in less favorable conditions, is more common.

Yield. A small crop may be obtained when the palms are 7-8 years old; but they may not be in full bearing until about the age of 15 years. They continue to yield profitable crops until about 50 years old, fruiting all the year round. The crop per tree may vary from 40 to 80 nuts a year, and an average of 7,500 nuts to a hectare is considered a satisfactory yield, though it may be as much as 10,000 or more. With good cultivation, under favorable conditions, 10,000 nuts should give 2.5 tons of copra. It is usual to make six rounds of plucking a year, i.e., once in two months. The palms attain a height of 18-24 m, with an unbranched, wavy stem.

Oil Palm. *(Elaeis guineenis)*. A stately, erect handsome palm, 18-21 m high, with a stout stem and large pinnate leaves, native of W. Trop. Africa, where it forms the principal natural product

Cultivation. The palm thrives in a hot, humid climate and low-lying alluvial soil. It requires similar climatic conditions to cacao, and a somewhat lower rainfall than the coconut palm. Extensive areas have been planted in Malaysia and Indonesia.

Propagation and Planting. Fresh seeds may germinate in about 4 or 5 months after sowing, but often take 8 months or longer. Germination may be hastened by soaking the seeds in hot water for a few days, or by placing them between layers of stable manure so as to set up fermentation. Seedlings may be planted out about 8 months after germination or when about 60 cm. high, being spaced 8.5 x 8.5 m (136 palms to a hectare) or, as is more usual, 8 x 8 m. Wide spacing has the effect of developing stout and short stems, thereby facilitating harvesting of the crop besides being more productive. The palms begin to bear when 4-6 years old, and should be in full bearing at the age of 12-15. After the age of about 30 years the yield gradually declines. The outer covering (pericarp) of the fruit yields "palm pulp", or "pericarp-oil". Distinct from this is the "kernel" or "white-oil", obtained by machinery or solvents, which is the more valuable and is largely used for margarine and cooking-fats.

Yield. The average annual yield of fruit per mature tree in an uncultivated state is variously estimated at from 27 to 36 kg or more, but cultivated palms may give double these figures. It is estimated for Sumatra plantations: 5th-10th year, average 24 kg of nuts per tree; 11th-30th year, 75 kg; 31st-50th year, 30 kg. Each mature palm produces from 5 to 10 bunches a year, each weighing from 9 to 18 kg or more according to age. A hectare of mature trees is considered to yield 10 tons of fruit, or 1.25 to 1.75 tons of kernels.

Gingelly-oil; Sesame, Til, Sim-sim, Bene, Beni-seed, Mafuta, Tala-tel, *(Sesamum indicum. Pedaliaceae)*. An erect annual, 60-120 cm high, indigenous to Sri Lanka, India, and Africa, long cultivated in the tropics and sub-tropics for the small seed, which is largely exported for its oil, of which it yields by expression about 45-50%. There are several varieties, the seeds of which there are black, yellow, red, and white, the latter yielding the finest oil.

Cultivation. The plant is grown as a summer crop in warm or subtropical countries, as in Italy, United States, and India and thrives in light friable soil with moderate rainfall. After the land is well tilled the seed is sown broadcast, or in drills about 45 cm apart, at the rate of 9-11 kg per hectare. The crop is ripe in about 4 months, and is then cut, tied in bundles and stocked. If allowed to become fully ripe the pods will burst and disperse the seed. The usual yield is about 450-675 kg per hectare, producing about 95 liters oil.

Cottonseed Oil. One of the most important sources of commercial oils is cotton seed after it has been separated from the fiber. It is extracted from the seeds of cotton plant of various species, mainly *Goddypium hirsutum* and *Gossypium herbaceum*. The best seed yields 20% or more of oil. The oil has a 2:1 ratio of polyunsaturated to saturated fatty acids. Its fatty acid profile generally consists of about 70% unsaturated fatty acids, 18% monounsaturated (oleic acid), 52% polyunsaturated (linoleic acid), and about 26% saturated fatty acids (primarily palmitic and some stearic). The oil is valuable as a cooking oil, or for margarine manufacture, and the protein residue is a valuable animal feed. Linters, the short cellulose fibers left on the seed after the staple cotton is removed by ginning, are used to make coarse yarns and many cellulose products. The hulls, or outer seed coverings, are used in ruminant animal feed as roughage.

Groundnut or Peanut. *(Arachis hypogaea)*. The pod or legume belongs to the family Fabaceae, which has the peculiar habit of ripening underground. It is a concentrated food; pound for pound, peanuts have more protein, minerals and vitamins than beef liver; more fat than heavy cream; and more food energy (calories) than sugar. The plant is an annual, ranging from an erect or bunch form 450-600 mm high, with short branches, to a spreading, or runner, form 300-450 mm high with branches up to 600 mm long. Groundnut has an outer thick woody shell. Inside normally there are 2 or 3 embedded seeds (kernel). The seed consists of two cotyledons and the germ covered by an outer thin skin called the testa. The color of the testa may be red, brown, purple or white depending upon the type and variety. Testa constitutes about 4-5% of the weight of the kernel. The cotyledons constitute the bulk of the seed in the range of around 92-94%. The testa protects the seed against pests and diseases. Peanut oil is appreciated for its high smoke point relative to many other cooking oils. Its major component fatty acids are oleic acid (56.6%) and linoleic acid (26.7%).

Linseed Oil. *(Linum usitatissimum)*. This valuable and well-known oil is obtained from the seed. The plant is largely grown in India, yielding at the rate of about 400-450 kg per hectare.

Olive Oil. *(Olea europaea)*. Olive is a subtropical, broad-leaved, evergreen tree that belongs to the family Oleaceae. The tree ranging in height from 3 to 12 meters or more has numerous branches. Its leaves, leathery and lance-shaped, are dark green above and silvery on the underside and are paired opposite each other on the twig. In the late spring, small flowers appear on the olive trees. Wind pollination results in the blossoming of the olives, which reach their peak oil content about six months later. Thus, the olives are harvested from November to March, after they have progressed in color from green to reddish violet to black. It is often necessary to harvest olives from the same trees several times in order to gather olives at the same stage of maturation. The wood is resistant to decay. If the top dies back, a new trunk will often arise from the roots. The wild olive tree originated in Asia Minor (modern Turkey) and spread from there as far as southern Africa, Australia, Japan and China. Considered the best of all salad or culinary oils, olive oil is obtained by pressure from full-grown but unripe fruit. Olive oil is composed mainly of the mixed triglyceride esters of oleic acid and palmitic acid and of other fatty acids, along with traces of squalene (up to 0.7%) and sterols (about 0.2% phytosterol and tocosterols). The composition varies by cultivar, region, altitude, time of harvest and extraction process.

Rapeseed. *(Brassica napus).* A plant of the mustard family (Brassicaceae), native to Europe. Rape is an annual, 30 cm or more tall, with a long, usually thin taproot. Its leaves are smooth, bluish green, and deeply scalloped, and the bases of the upper leaves clasp the stem. Rape bears four-petaled, yellow flowers in spikes. Each round, elongated pod has a short beak and contains many seeds. These seeds, known as rapeseeds, yield an oil – rapeseed oil or canola – that is variously treated for use in cooking, as an ingredient in soap and margarine, as a lamp fuel and other uses. Natural rapeseed oil contains 50% erucic acid. Processing of rapeseed for oil production provides rapeseed animal meal as a by-product.

Sunflower Oil. *(Helianthus annuus. Compositae).* A tall, quick-growing coarse annual, 1.5-2.5 m high or more, native of Mexico, extensively cultivated in parts of India, China, and South America, the seed of which yields a valuable edible oil. The plant thrives in ordinarily good soil with a warm and moderately moist climate. Different varieties are commonly grown in warm countries, thriving in the tropics at medium and high elevations. The seed may be sown in rows 1 m apart, about 9-11 kg being required to sow a hectare. The seedlings are afterwards thinned out to about 30 or 40 cm apart.

Yield. A crop is obtained in about 4 months after sowing, yielding 2.6-3.5 cu m of seed per hectare, which should give about 100 liters of oil per cu m of seeds. The method of harvesting is similar to that of maize, the heads being gathered, dried, and then threshed; or the seeds are rubbed out by hand over a coarse grater. The oil, which is obtained by pressure, is edible and of a pleasant flavor.

Shea Butter. "Butter-tree" or "Emi". *(Butyrospermum Parkii. Sapotaceae).* A medium-sized or large tree with a stout trunk, bearing rather leathery, oval leaves about 15-23 cm long by 8-10 cm broad, crowded at the ends of the branches, native of Africa. The large fleshy nuts, of which each fruit usually contains only one, yields a large percentage of stearine fat. The tree is a slow grower.

Soybean. *(Glycine max).* A species of legume native to East Asia. It is an annual plant that may vary in growth, habit, and height. It may grow prostrate, not growing higher than 20 cm, or even stiffly erect up to 2 meters in height. The pods, stems, and leaves are covered with fine brown or gray pubescence. The leaves are trifoliolate, having 3 leaflets per leaf, and the leaflets are 6-15 cm long and 2-7 cm broad. The leaves fall before the seeds mature. The small, inconspicuous, self-fertile flowers are borne in the axil of the leaf and are white, pink or purple. The fruit is a hairy pod that grows in clusters of 3-5, with each pod 3-8 cm long and usually containing 2-4 (rarely more) seeds 5-11 mm in diameter. To produce soybean oil, the soybeans are cracked, adjusted for moisture content, rolled into flakes and solvent-extracted with commercial hexane.

Tung or Wood-Oil. *(Aleurites Fordii. Euphorbiaceae).* A small tree of China, suited to high elevations or subtropical conditions with moderate rainfall. The kernels yield a valuable drying oil, largely used in the paint, varnish and linoleum trades. An average Tung tree may produce 45-68 kg of nuts a year, yielding about 35-40% of oil. The seeds may take about 2 to 3 months to germinate. It is said to give 12 tons seed (2,000 kg oil) per hectare of 150 mature trees.

Vegetable- or Chinese-Tallow. A product of *Stillingia (Sapium) sebifera (Euphorbiaceae)*, a small tree, about 9 m high, native of China and Japan. The fatty oil obtained from the layer surrounding the seed is used in China in place of animal tallow for the manufacture of candles and soap. The kernels yield a yellowish oil used by the Chinese in the preparation of varnishes and for lighting, and a mixture of the oil and fat is stated to form a good substitute for lard for industrial purposes.

OTHER FIXED OILS

Amoora Rohituka. Hingul, S. *(Meliaceae)*. Moderate-sized tree of Sri Lanka and India. Oil from seed used for lighting.

Argania Sideroxylon. Argan-oil. *(Sapotaceae)*. Medium-sized tree of Morocco, where it is largely cultivated. Seeds yield an oil used in cooking and said to be almost equal to olive oil. Leaves and fruit are a valuable food for stock in Africa.

Attalea Cohune. Cohune-nut. *(Palmae).* Kernels, the size of a hen's egg, yield an oil similar to coconut-oil and suitable for use in margarine manufacture. Charcoal made from the fruits is largely used for gas masks.

Azadirachta indica. *Margosa (Portuguese); Nim- or Neem-tree of India; Kohomba, S; Vempu, T. (Meliaceae).* A tall tree of India and Sri Lanka. The strong-smelling, aromatic oil obtained from the fruit is much valued in native medicine, being a well-known application for leprosy and rheumatism and is taken internally by women in pregnancy. It is commonly used for animals, both internally and externally.

Balanites Manghamii. Manduro. *(Simarubaceae)*. A tree of East Africa. The nuts yield a clear oil, burning with a bright flame, much used locally. *B. aegyptiaca.* "Desert Dates". A tree found in drier parts of West and Central Africa. Fruit is edible and yields a clear oil called Betu- or Zachun Oil.

Bassia butyracea. Indian Butter-tree. *(Sapotaceae)*. A medium-sized deciduous tree of India, occurring at 300-1,500 m. The seeds yield by expression a thick oil or fat used locally for burning and externally for rheumatism. **B. latifolia.** Mahua or Mahwa ; Mowra. A large, spreading tree with broad leaves, common in India up to 1,200 m, often cultivated. From the seeds is obtained a thick, yellow oil or fat known as "mowra fat", commonly used in India for cooking. **B. longilfolia.** Mi or Mee, S.; Ilippi or Illupai, T. A large tree of Sri Lanka, Malaysia and India. Often cultivated for the fleshy seeds, which yield an oil esteemed locally for cooking. The tree is deciduous for a short period in the dry season.

Brassica juncea. Aba, S.; Kaduga, T.; Indian Mustard or Rai. *(Crucifereae)*. An erect annual, of which there are several varieties, 60-120 cm high, naturalized in Ceylon, etc., commonly cultivated in N. India and elsewhere, usually as a catch-crop, the small seeds yielding an oil used in cooking, medicine, etc. Seed is sown broadcast in well-tilled soil at the rate of about 7-9 kg per hectare, which yields from 280-340 kg of seed.

Calophyllum Inophyllum. Punnai-nuts; Domba, S.; Dommakottai, T. Medium-sized or large, handsome tree of Sri Lanka and India. The nuts yield abundant dark green, thick and strongly scented oil, employed locally in medicine and for burning. They are collected in Ceylon as a "forest produce", under licence. **C. tomentosum.** Keena, S.; Pongu, T. A tall tree with straight trunk and quadrangular twigs, native of the moist low-country of Sri Lanka, India and Malaysia. Seeds yield an orange-colored oil (Keena-tel), used for medicine, lighting and other domestic purposes. This is the Kina or Keena Tree of the lower hill-country which is not so striking as the larger Keena (G. Walkeri) of higher elevations.

Carapa-, Crapa or Crab-oil. *Carapa guianensis.* The large fruit contains numerous seeds which yield an oil used in Guiana for medicine, lighting and other purposes.

Carthamus tinctorius. Safflower Oil. Kusuma. Largely cultivated in India, Egypt and Caucasus for the seeds, which yield safflower oil by pressure. The oil

is used in India for culinary purposes, but chiefly in the manufacture of paint and soap and for dressing leather. A dye is obtained from the flowers.

Diospyros Embryoptefis. Tunka Oil. Timbiri. Used medicinally in India.

Dipterocaipus glandulosus. Dorana-tel, S. *(Dipterocarpeae)*. A tall, erect tree of Sri Lanka. A resin which exudes naturally from the stem and is collected at the base, yields an oil used in medicine.

Dumoria Heckeli. Bako-nuts. *(Sapotaceae)*. The large, ovoid, smooth seeds, with a large oval scar along one side, are obtained from a large tree, 30-45 m high, of Africa and are rich in oil, edible and valued for soap-making.

Garcinia echinocarpa. Madol-tel, S. Small tree of Sri Lanka. Seeds yield an oil used in medicine.

Guizotia abyssinica. Ramtil-, Inga-, Black-til- or Niger seed-oil. *(Compositae)*. An annual, largely cultivated in India and Africa for the oil obtained from the seed; used locally for cooking, lighting, and medicine, and exported for use in margarine, etc. Seed commonly used as food for cage birds. Yield, 340-450 kg per hectare.

Gynocaidia odorata. *(Bixaceae)*. Large tree of Sikkim, etc. Bears large globular fruits, the seeds of which yield a drying oil of good quality, known as Gynocardia-oil. This was formerly supposed to be the source of Chaulmugra oil.

Hemp-seed Oil. Obtained by pressure from the seed of Cannabis sativa or Indian Hemp. It is of a greenish-yellow color and used chiefly in paints and varnishes; produced largely in China and Algeria. It is also used for bird-food.

Hydnocarpus anthelminticus and **H. wightiana.** "Kavatel". *(Bixaceae)*. Medium-sized trees of India and Myanmar. An oil similar to Chaulmugra oil is obtained from the seed.

Illipe. Edible fat- or oil-yielding seeds of *Bassia* (in India), *Shorea* (in Indonesia), *Isoptera* (in Malaysia).

Irvingia Olivera. Cay-cay or Dika. *(Simarubaceae)*. A slow-growing, straggling tree of Indochina, the kernels of which are edible and rich in fatty matter.

Jatropha Curcas. Physic-nut; Pulsa- or Purqueira-oil; Rata-endaru, S.; Kaddamanakku, T. A well-known shrub, commonly planted as a fence around farms or gardens, being readily propagated from large cuttings. Grown in India, West Africa and Southeast Asia. A strong purgative oil obtained from the seed is used in native medicine and in soap and candle manufacture. Residual cake is poisonous.

Kokoona zeylanica. Kokun-oil; Potha-eta-tel, S. *(Celastraceae)*. Large tree of Sri Lanka and India. Seeds yield oil used for lighting and medicine.

Lophira alata. Scrubby Oak. *(Dipterocarpeae)*. A small ornamental tree, native of Sierra Leone; yields an edible fat known as Kiam- or Meme-butter.

Moringa pterygosperma. *Moringae*. Horse-radish Tree; Drumsticks; Murunga, S.; Murunga-kai, T. A short, slender tree, about 8 m high, with small tripinnate leaves, cultivated in gardens throughout Sri Lanka and India. The roots are used as a substitute for horse-radish, the leaves for vegetable curries as well as for seasoning and in pickles, and the 60-120 cm long unripe pods ("drumsticks") as a curry vegetable, the latter being boiled and sliced like beans. The seeds yield a fine oil known as Oil-of-Ben used by watchmakers and in cosmetics. Propagated by seeds or cuttings.

Pentadesma butyracea. Tallow- or Butter-tree; Okoto- or Koma-nut Oil. *(Guttiferae)*. A large tree with long, straight, regularly radiating branches, native of West Tropical Africa. The large, oblong fruit (13-15 cm long by 9 cm diameter) and large fleshy seeds (8-10 cm each fruit) contain a quantity of yellow, waxy juice which is used by the natives for the extraction of an edible oil. An average tree bears 700-900 fruits or about 70 kg of seeds a year. Bears a heavy crop of fruit each year, during April to May.

Poppy-seed Oil. Derived from the seed of *Papaver somniferum* used in artists' paints.

Quillai Bark or Soap-bark Oil. *(Quillaja saponaria. Rosaceae)*. Small tree of Chile with saponine bark, readily raising a lather in water; used locally as vegetable soap.

Sapindus emarginatus. Penela, S.; Neyk-kodan, T.; Soap-nut. *(Sapindaceae)*. A large tree of Sri Lanka, India, and Myanmar. Fruits, dry or fresh, are saponine in water and used as a substitute for soap.

S. Saponaria. Soapberry. Small tree of Jamaica. Fruit strongly saponaceous.

Schleichera trijuga. Ceylon Oak; Kusumb of India. *(Sapindaceae)*. A large tree of Sri Lanka, India and Myanmar. Seeds, edible and rich in oil, are said to be the original Macassar oil.

Taraktogenos Kurzii. Kalaw or Kalaw-ni. *(Bixaceae)*. A large or medium-sized tree of Myanmar and Thailand. The large fleshy seeds yield a thick yellowish oil or fat of the consistency of butter, valued in the treatment of leprosy and other skin diseases.

Trichilia emetica. Malfura or Mafureira-nut. *(Meliaceae)*. A handsome African deciduous tree, yields 27-36 kg dry nuts per tree. Nuts rich in fatty oil, edible and used in the manufacture of soaps and candles. The residue from the seed is considered poisonous.

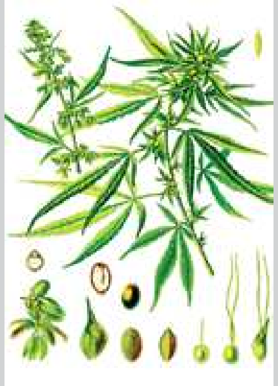

Castor Oil Plant


Oil Palm


Coconut Palm


Sesame

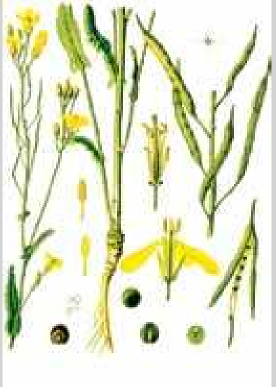

Moringa


Hemp-seed Oil

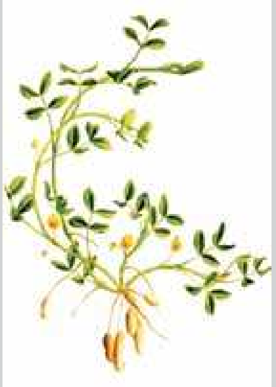
Brassica

Groundnut Oil

Soybean



Rapeseed



Peanut

Olive

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2. Chemical composition of groundnut, <www.fao.org>
3. Macmillan, H.F., Oil and Vegetable Fat, <www.herbdatanz.com/oils_and _vegetables_fats.htm>
4. Soyatech Growing Opportunities, <www.soyatech.com>

Concentration and Composition of Plant Oils

The oil from oil-bearing and oil-producing plants is usually concentrated mainly in the fruits and seeds. The roots, stalks, branches, and leaves may also contain some oil but, in general, the amount is very much lower. The oil content of some seeds and fruits can be as high as 35 per cent. For example, in dried coconut meat (commonly termed copra) the oil content can be as much as 60 to 65 per cent. In some seeds the oil is mainly found in the germ or embryo, which normally constitutes only a small part of the seed. In the case of the olive, however, a major portion of the oil is found in the pulp surrounding the kernel and only a small portion in the kernel itself. But in the case of the oil palm, both the pulp and the kernel contain large amounts of oil. In general, the oil from the pulp may have characteristics somewhat different from the fat from the kernel.

Table 2.1 presents the typical amounts of oil that can be extracted from some plants or crops. It shows that copra (dried coconut meat), castor seed and sesame seed yield the highest percentages of oil per unit weight of material (50 to 62%) while cotton seed and soybean have the lowest percentages (13 to 14%). The kernel of the oil palm also yields more oil (36%) compared to its fruit (20%). This parameter – the oil yield per unit weight of material being processed – is important in assessing the relative magnitude or cost of processing or extraction required to produce the desired product, which is the oil. The higher the oil concentration in the seed or fruit to be processed, the greater the oil produced per unit weight of seed or fruit, and generally the lower the cost of processing. However, these numbers should be understood as merely indicative and useful only as general guidelines. For example, copra is shown with the highest yield of 62 kg oil per 100 kg of material. But to produce copra from the fresh nut of the coconut, several pre-processing steps are required. On the other hand, other fruits or seeds may require fewer pre-processing steps prior to the extraction of oil, thus compensating for the lower oil yield per unit weight of fruit or seed.

Table 2.1 – Typical oil extraction

Crop	kg oil / 100 kg crop
Castor Seed	50
Copra	62
Cotton Seed	13
Groundnut Kernel	42
Mustard	35
Palm Fruit	20
Palm Kernel	36
Rapeseed	37
Sesame	50
Soybean	14
Sunflower	32

Source: Calais, Philip and Clark, A. R., Waste Vegetable Oil as a Diesel Replacement Fuel, Environmental Science, Murdoch University and Western Australian Renewable Fuels Assn, Inc., Perth, Australia, <http://www.shortcircuit.com.au/warfa/paper/paper.htm>

Another commercially important parameter is the amount of oil that can be produced or extracted per unit area of land planted to the oil-containing crop. Although the fruit or seed of some plants may yield more oil per unit weight of seed or fruit, it may turn out, however, that the amount of seed or fruit produced per hectare of land is low – and thus yield a lower amount of oil per hectare of cultivated land. The ideal situation would be to have a crop that yields seeds or fruits with high oil concentration while at the same time producing more seeds or fruits per hectare of cultivated land. Table 2.2 shows the typical yields of various plant oils per unit area of cultivated land. Oil palm produces the highest amount of oil per hectare of cultivated land, yielding 5,000 kg oil per hectare followed by coconut with 2,260 kg oil per hectare. Corn has the lowest yield with only 145 kg oil per hectare. Jatropha typically produces 1,590 kg oil per hectare. It must be noted, however, that this is just one parameter and overall productivity must be assessed taking into consideration other needed agricultural inputs such as water, fertilizer, labor and energy requirements, particularly for harvesting and processing.

Table 2.2 – Typical yields of various plant oils

Crop	kg oil / ha	liters oil / ha
Corn	145	172
Cashew Nut	148	176
Oats	183	217
Lupine	195	232
Kenaf	230	273
Calendula	256	305
Cotton	273	325
Hemp	305	363
Soybean	375	446
Coffee	386	459
Linseed	402	478
Hazelnuts	405	482
Euphorbia	440	524
Pumpkin Seed	449	534
Coriander	450	536
Mustard Seed	481	572
Camelina	490	583
Sesame	585	696
Safflower	655	779
Rice	696	828
Tung Oil Tree	790	940
Sunflowers	800	952
Cocoa	863	1026
Peanuts	890	1059
Rapeseed	1000	1190
Olives	1019	1212
Castor Beans	1188	1413
Pecan nuts	1505	1791
Jojoba	1528	1818
Jatropha	1590	1892
Macadamia Nuts	1887	2246
Brazil Nuts	2010	2392
Avocado	2217	2638
Coconut	2260	2689
Oil Palm	5000	5950

Source: Calais, Philip and Clark, A. R., Waste Vegetable Oil as a Diesel Replacement Fuel, Environmental Science, Murdoch University and Western Australian Renewable Fuels Assn, Inc., Perth, Australia, <http://www.shortcircuit.com.au/warfa/paper/paper.htm>

The oils from different plants or crops contain fatty acids in varying proportions. Table 2.3 lists the names and chemical formulas of the seven most common fatty acids while Table 2.4 gives the proportion of these acids in several plant oils. Coconut oil and palm kernel oil contain mainly lauric and myristic acids; olive oil, peanut oil, cottonseed oil, and corn oil contain mainly oleic and linoleic acids, although cottonseed oil also contains significant amount of palmitic acid; and linseed oil and soybean oil contain mainly linoleic acid, although soybean oil also contains significant amount of oleic acid. Rapeseed oil comprises mainly oleic acid and moderate amount of linoleic acid.

Table 2.3 – The seven most common fatty acids

Acid	Elementary Formula	Constitutional Formula
Lauric	$C_{12}H_{24}O_2$	$CH_3(CH_2)_{10}COOH$
Myristic	$C_{14}H_{28}O_2$	$CH_3(CH_2)_{12}COOH$
Palmitic	$C_{16}H_{32}O_2$	$CH_3(CH_2)_{14}COOH$
Stearic	$C_{18}H_{36}O_2$	$CH_3(CH_2)_{16}COOH$
Oleic	$C_{18}H_{34}O_2$	$CH_3(CH_2)_{14}(CH)_2COOH$
Linoleic	$C_{18}H_{32}O_2$	$CH_3(CH_2)_{12}(CH)_4COOH$
Linolenic	$C_{18}H_{30}O_2$	$CH_3(CH_2)_{10}(CH)_6COOH$

Source: E. T. Webb, *Oils and Fats in Soap Manufacture,* Soap Gazette and Perfumer, October 1, 1926, xxviii, 302.

Table 2.4 – Fatty acid composition of some plant oils

Plant oil	Lauric	Myristic	Palmitic	Stearic	Oleic	Linoleic	Linolenic
Coconut	45[1], 46.5[2]	20[1], 19.2[2]	5[1], 9.8[2]	3	61, 6.9[2]	2.2[2]	0.0[2]
Cotton-seed	0.1[2]	0.7[2]	23.4[1], 20.1[2]	2.6[2]	31.6[1], 19.2[2]	45.0[1], 55.2[2]	0.6[2]
Maize	-	-	6.0	2.0	44.0	48.0	-
Linseed	-	3	6.0	-	-	74.0	17.0
Olive	-	-	14.6	-	75.4	10.0	-
Palm	0.1[2]	1.0[2]	42.8[2]	4.5[2]	40.5[2]	10.1[2]	0.2[2]
Palm Kernel	55	12	6	4	10	-	-
Peanut	-	-	8.5	6.00	51.6	26.0	-
Rapeseed	0.6[2]	0.6[2]	0.6[2]	2.02	62.2[2]	22.0[2]	9.0[2]
Soybean	0.1[2]	0.2[2]	11.0[1], 10.2[2]	2.0[1], 3.7[2]	20.0[1], 22.8[2]	64.0[1], 53.7[2]	3.0[1], 8.6[2]

Sources:
1. Farid, M.M., Behzadi, S., Department of Chemical and Materials Engineering, University of Auckland, New Zealand, Paper on "Innovation in the Production of Biodiesel" during the 16th ASEAN Regional Symposium on Chemical Engineering, Manila, Philippines, Dec 2009.
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When the molecule of the fatty acid contains the maximum possible amount of hydrogen, the acid is called a saturated fatty acid. Myristic, lauric, palmitic and stearic acids are saturated fatty acids. These fatty acids are usually solid at ambient temperature. For example, crude palm oil is normally solid at ambient temperature since it contains significant amount of palmitic acid. On the contrary, when the molecule of the fatty acid does not contain the maximum possible amount of hydrogen, the acid is called an unsaturated fatty acid. Oleic, linoleic and linolenic acids are unsaturated fatty acids. These fatty acids are usually liquid at ambient temperature. For example, linseed oil contains over 70% linoleic acid. An index of the degree of unsaturation of fats and oils is called the iodine value. The iodine value is a number that reflects the percentage by weight of iodine absorbed by the oil or fat in the natural state. Plant oils with low iodine value are more saturated with fewer double-bonds, e.g., palm oil and coconut oil. On the other hand, plant oils with high iodine value are more unsaturated with more double-bonds, e.g., linseed oil and soybean oil. The iodine value of some plant oils are given in Table 2.5.

Table 2.5 – Iodine values of plant oils

Plant Oil	Iodine Value
Linseed oil	173 - 201
Soybean oil	137 - 143
Sunflower oil	119 - 135
Corn oil	111 - 130
Cottonseed oil	108 - 110
Sesame oil	103 - 108
Rapeseed oil	94 - 102
Peanut oil	83 - 100
Olive oil	79 - 88
Palm oil	52 - 57
Cacao oil	32 - 41
Palm kernel oil	13 - 17
Coconut oil	8 - 10

Source: J. Lewkowitsch, *Chemical Technology and Analysis of Oils, Fats, and Waxes,* pp. 419-24.

Fuel-Related Characteristics of Plant Oils

There are a number of physical and chemical characteristics of plant oils that affect their suitability as fuels. These include the heating value, pour point, cloud point, flash point, iodine value, viscosity, density, and cetane number. The characteristics that directly affect the efficiency of the fuel and the performance of the engine are summarized in Box 2.2. The typical values of these physical and chemical parameters for a number of plant oils are given in Table 2.6 while Table 2.7 compares the properties of canola oil with diesel and biodiesel.

The heating values of most plant oils vary within a narrow range, ranging from only 39,310 kJ/kg for linseed oil to 40,480 kJ/kg for crambe oil. These values compare well with diesel fuel with a heating value of 45,340 kJ/kg. On the other hand, the flash points of most plant oils, ranging from 241^{0}C for linseed oil to 277^{0}C for corn oil, are much higher than that of diesel fuel, which is only 52^{0}C. In addition to these physical and chemical characteristics, there are also other characteristics that do not have direct bearing on the actual performance of the engine, but are similarly important for environmental and other reasons. These include the ash, sulfur and potassium contents of the plant oil.

Plant oils with low iodine value are generally more combustible and more efficient fuels than oils with high iodine value. The disadvantage is that oils with low iodine value also have higher melting points and are usually solid at room temperature. For example, crude palm oil is usually solid at ambient temperature. As a consequence, biodiesel that is produced from oils with low iodine value also has a higher melting point and might only be suitable for use as fuel in warm tropical countries or during the summer months in temperate countries. High iodine value oils have lower melting points and make better cold weather biodiesel. The drawback, however, is that with high iodine value oils there is more risk of the biodiesel oxidizing and polymerizing (drying) into a tough, insoluble plastic-like solid. Therefore, biodiesel made from oils with high iodine value, such as linseed oil, soybean oil and sunflower oil, should be stored appropriately and used quickly.

Viscosity is one of the critical parameters in the use of plant oils as fuel since it affects injector lubrication and fuel atomization. Castor oil, for example, has a very high viscosity and therefore not suitable diesel fuel substitute or blending. Other plant oils have viscosities ranging from 31 mm^2/sec for safflower oil to 54 mm^2/sec for crambe oil. With proper processing, these viscosities can be reduced to a level close to that of diesel fuel, which is 3-5 mm^2/sec. Viscosity is, of course, highly dependent on temperature – the higher the temperature, the lower the viscosity. Fuels with high viscosity may not provide sufficient lubrication for the precision fit of fuel injection pumps, resulting in leakage or increased wear. Pre-heating these types of fuels may render them suitable as diesel fuel substitute. Fuel atomization is also affected by fuel viscosity. Fuels with high viscosity tend to form larger droplets on injection which can cause poor combustion, increased exhaust smoke and emissions.

In the same manner, fuels with low cetane numbers, such as linseed oil (35) and rapeseed oil (38) will cause difficult starting and produce noise and thick exhaust smoke. In general, diesel engines will operate better on fuels with cetane numbers of around 50 or higher. Palm stearine (85), palm kernel oil (70), and palm olein (65) all have cetane numbers higher than 50. Ash content is also important. High concentrations of ash can cause injector tip plugging, combustion deposits and injection system wear. The ash content is important for the heating value, as heating value decreases with increasing ash content. The ash content of biofuels is typically lower than for most coals, and sulfur content is much lower than for many fossil fuels. Unlike coal ash, which may contain toxic metals and other trace contaminants, plant oil ash may be used as a soil conditioner to help replenish the nutrients removed by harvest.

Box 2.2 – Characteristics of plant oils affecting suitability as fuel

Ash Percentage. Ash is a measure of the amount of metals contained in the fuel.

Cetane Number (CN). A relative measure of the interval between the beginning of injection and autoignition of the fuel. The higher the cetane number, the shorter the delay interval and the greater its combustibility.

Cloud Point (CP). The temperature at which an oil starts to solidify. While operating an engine at temperatures below an oil's cloud point, heating will be necessary in order to avoid waxing of the fuel.

Density. The weight per unit volume. Oils that are denser contain more energy. For example, gasoline and diesel fuels give comparable energy by weight, but diesel is denser and hence gives more energy per liter.

Flash Point (FP). The flash point temperature of fuel is the minimum temperature at which the fuel will ignite (flash) on application of an ignition source. Flash point varies inversely with the fuel's volatility. Minimum flash point temperatures are required for proper safety and handling of fuel.

Heating Value, Heat of Combustion. Heating Value or Heat of Combustion is the amount of heating energy released by the combustion of a unit value of fuels. One of the most important determinants of heating value is moisture content. Air-dried biomass typically has about 15-20% moisture, whereas the moisture content for oven-dried biomass is negligible.

Iodine Value (IV). The amount of iodine, measured in grams, absorbed by 100ml of a given oil. The degree of saturation is indicated by the Iodine Value of the oil.

Melt Point or Pour Point. Melt or pour point refers to the temperature at which the oil in solid form starts to melt or pour. In cases where the temperatures fall below the melt point, the entire fuel system including all fuel lines and fuel tank will need to be heated.

Potassium Percentage. The percentage, by weight, of potassium in the fuel

Sulfur Percentage. The percentage, by weight, of sulfur in the fuel. Sulfur content is limited by law to very small percentages for diesel fuel used in on-road applications.

Viscosity. Viscosity refers to the thickness of the oil, and is determined by measuring the amount of time taken for a given measure of oil to pass through an orifice of a specified size.

Table 2.6 – Fuel-related properties of plant oils

Oil	CN	IV	HV (kJ/kg)	CP (°C)	PP (°C)	FP (°C)	Viscosity (mm^2/s) at 38°C
Babassu	38						
Castor[a]		85	39,500		-32 to -18	260	297
Coconut[a]	70	8-10			20-25		
Corn[a]	38-53	115-124	39,500	-1.1	-40 to -5	277	35
Cottonseed[a]	42-55	100-115	39,470	1.7	-15 to 0	234	34
Crambe	45		40,480	10	-12	274	54
DF No. 2	47		45,340	-15	-33	52	3
Lard[a]	65	60-70			32 to 36		
Linseed	35		39,310	1.7	-15	241	27
Olive[a]	60	77-94			-12 to -6		
Palm oil[a]	42-65	44-58			30-38		
Palm kernel oil[a]	70	12-18			20-26		
Palm olein[a]	65	85-95			20-25		
Palm stearine[a]	85	20-45			35-40		
Peanut[a]	42	93	39,780	13	-7 to 3	271	40
Rapeseed[a]	38	97-115	39,710	-3.9	-32 to 5	246	37
Safflower	41		39,520	18	-6.7	260	31
Safflower (high-oleic)	49		39,520	-12	-21	293	41
Sesame	40		39,350	-3.9	-9.4	260	36
Soybean[a]	38-53	125-140	39,620	-3.9	-12	254	33
Sunflower[a]	37-52	125-135	39,580	7.2	-15 to -18	274	37
Tallow[a]	75	50-60			35 to 40		

CN = cetane number, IV = iodine value, CP = cloud point, PP = pour point, FP = flash point

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1. Calais, Philip and Clark, A. R., Waste Vegetable Oil as a Diesel Replacement Fuel, Environmental Science, Murdoch University and Western Australian Renewable Fuels Assn, Inc., Perth, Australia, <http://www.shortcircuit.com.au/warfa/paper/paper.htm>
2. Liberty Vegetable Oil Company, <http://www.libertyvegetableoil.com/products.html>

Table 2.7 – Comparison of properties of diesel, canola oil and biodiesel

	Diesel	Canola Oil	Biodiesel
Density (kg/l) at 15.5⁰C	0.84	0.92	0.88
Calorific value (mJ/l)	38.3	36.9	33-40
Viscosity (mm²/s) at 20⁰C	4-5	70	4-6
Viscosity (mm²/s) at 40⁰C	3-4	37	4-5
Viscosity (mm²/s) at 70⁰C	-	10	-
Cetane number	45	40-50	45-65

Sources:

1. Beer, T., Grant, T., Brown, R., Edwards, J., Nelson, P., Watson, H., Williams, D. (2000), *Life-Cycle Emission Analysis of Alternative Fuels for Heavy Vehicles*, CSIRO, Australia.
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Chapter 3:
Jatropha Curcas as Feedstock

The growing concern regarding the possible diversion of plant oils from their use as food for humans and animals to their use as fuel for compression ignition engines has sparked the search for suitable plant oils that fall outside the "food or fuel dilemma". As population grows and per capita consumption rises, the price of traditional feedstocks such as coconut oil, palm oil and soybean oil rises sharply making their use as fuel both uneconomical and impractical. It is impractical because as more of these plant oils are diverted to fuel production, their price go up even more thus rendering them uneconomical for fuel use. In addition, this causes further increase in the price of many food products. One of the consequences of this food or fuel dilemma is the growing interest in the use of oil from jatropha curcas as feedstock for the production of biofuels. The principal reasons for this are first, jatropha oil is not suitable for human consumption, and second, the plant is found to grow fairly well in marginal soils.

Characteristics of Jatropha Curcas

Jatropha is a genus of about 175 succulent plants, shrubs and trees from the family Euphorbiaceae, subfamily Crotonoideae, and tribe Jatropheae[1 2 3]. There are at least four important species, namely, J. curcas, J. gossrifolia, J. podarica, and J. multifada. It was botanist Carl Von Linne who first classified the plants in 1753 and gave the botanical name "Jatropha curcas" from the Greek word "Jatros" meaning doctor and "trophe" meaning nutrition. Originally a native of Central America and the Caribbean, it has become naturalized in many tropical and subtropical areas and now thrives throughout Africa and Asia brought by Portuguese traders. It is widely grown in Tamil Nadu, India, growing as weeds in Brazil, Fiji, Honduras, Jamaica, Panama, Puerto Rico, and El Salvador. Jatropha is easy to establish, grows relatively quickly and is hardy. Being drought tolerant, it can be used to reclaim eroded areas and grown as live hedge in arid or semi-arid areas. In the Philippines, it is commonly used for fencing, hence the name *tubang bakod* (*bakod* = fence). Jatropha curcas is known to tolerate a wide range of rainfall (48 cm to 238 cm annually), grows in a wide range of temperature (18-28°C), but requires full sun. It thrives in any soil type, sandy, gravelly, saline, provided it is well drained. The trees are fast growing, easily propagated either by seeds or stem cuttings, and are adapted to marginal soils with low nutrient content.

Known in the Philippines as *tuba-tuba*, *tubang bakod* (Tagalog), or *galumpang* (Pampanga), the oil plant *Jatropha curcas* (L) (Jatropha) or physic nut is a multipurpose and drought-resistant large shrub or small soft wooded

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tree with smooth gray bark that yields a whitish colored, watery latex when cut. It normally grows between 3 to 5 meters high, but can attain a height of up to 8-10 meters under favorable conditions. It has spreading branches and stubby twigs, with milky and yellowish exudates. Its leaves are deciduous, green to pale-green, alternate but apically crowded, ovate, acute to acuminate, basally cordate, 3-5 lobed in outline, 6-40 cm long and 6-35 cm broad[4]. The mature tree bears male and female flowers, with female flowers usually slightly larger and occurring during the hot season. The flowers are greenish cymes, yellowish and bell shaped. The petiole length ranges between 6-23 mm[5]. The inflorescence is formed in the leaf axil. In conditions where continuous growth occurs, an imbalance of pistillate or staminate flower production results in a higher number of female flowers. The fruit capsule is approximately 2.5 cm to 4 cm in diameter[6].

Jatropha grows readily from cuttings or seeds. Use of fresh seeds improves germination and with good moisture conditions, germination takes 10 days. The seed shell splits, the radicula emerges and 4 small peripheral roots are formed. Soon after development of the first leaves, the cotyledons wither and fall off. Seedlings (3-4 month old) can be planted with the following distances: square planting: 2m x 2m (2,500 trees/ha) or 2m x 3m (1,666 trees/ha). The best time of planting is during the start of the rainy season. Caring for the plants is simple, involving only ring weeding during the first year and under brushing in later years to control vines and other competitive weeds. Seed production from plants propagated from seeds can be expected within 3-4 years. The use of branch cutting for propagation is also easy and results in rapid growth. The plant can be expected to bear fruit within one year of planting. The recommended spacing is 15-25 cm x 15-25 cm in one or two rows, respectively, for hedgerows or soil conservation, and 2m x 2m or 2m x 3m for plantations[7]. With this spacing, there will be between 4,000 to 6,700 plants per km for a single hedgerow and double that when two rows are planted. The number of trees per hectare will range from 1,600 to 2,500. Wider spacing is reported to yield more fruits of up to about 794 kg/ha[8]. When established, the trees need little attention or management and minimal fertilizer application. No insect pests are known to attack the crop and it is not palatable to ruminants (cattle or sheep, goat) making it a desirable plant for the fence lines.

Plants start bearing fruits within two years after planting and may produce several crops during the year if soil moisture is good and temperatures are sufficiently high. However, maximum productivity is attained only after 5 years[9].

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[9] Jones, N, and Miller, J. H., *Jatropha curcas*: A Multipurpose Species for Problematic Sites, The World Bank, Washington DC, USA, 1992.

The fruits are produced when the shrub is leafless. Each inflorescence yields a bunch of approximately 10 or more ovoid fruits. A three, bi-valved cocci is formed after the seeds mature and the fleshy exocarp dries. The fruits are harvested at yellow stage with each fruit containing 3-4 black color seeds 2 cm long and 1 cm thick. The yield per tree (fresh weight) ranges from 4-12 kg. The usual average yields by year are in the following order of magnitude: 0.4 tons/ha during the first 2-3 years, 2-3 tons/ha in 3-4 years, 5-6 tons/ha in 5 years to 50 years[10]. The dry seed is about 15% of the fresh weight of the fruits and generally contains 32% meal, 30-38% crude oil, and 30-38% seed coat[11].

Pruning of jatropha during the first two years is important but this is a highly labor- intensive operation. The availability of relatively inexpensive labor is therefore a key factor in the profitability of a jatropha plantation. The top of the sapling must be cut in the nursery before sending it for planting. It is then pruned twice or thrice during the first two years. As a result of pruning, there will be less flowering and fruiting in the first two years but this will be compensated by bigger harvests in subsequent years. After every pruning, four branches emerge from the earlier node. In order to produce one kilogram of seeds after 2 to 3 years from a plant, it should have at least 24 to 30 secondary or tertiary branches[12].

Jatropha plantation in April 2004

Source: Jatropha plantation of Tree Oils India Ltd., Technical document of Shivrai Technologies, Pune, India, <www.svlele.com/jatropha_plant.htm>

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[12] Technical document of Shivrai Technologies, Pune, India, <www.svlele.com/jatropha_plant.htm>

Same Jatropha plantation in June 2005

Source: Jatropha plantation of Tree Oils India Ltd.,
Technical document of Shivrai Technologies, Pune, India,
<www.svlele.com/jatropha_plant.htm>

Planting materials in a Jatropha Nursery Development Project at Pampanga Agricultural College, Magalang, Pampanga, Philippines
(Photo by LAUDS Technologies, Inc., 2007)

Jatropha flowers

Jatropha fruits

Jatropha fruits

Harvested Jatropha fruits

Jatropha seeds ready for oil extraction

Box 3.1 – What is jatropha curcas?

- It is known in the Philippines as *tubang bakod, tuba-tuba, kasla, tubang aso, tibang silangan, tawa-tawa*
- Planted in fences for hedges, thus the term *tubang bakod*
- Seeds are grounded and used to poison fish thus the term *tuba*
- Leaves are used as herbal medicine for fractures
- Can reach a height of up to 5 meters
- 500-600 mm of rainfall limit of growth
- Can grow in areas of up to 500 meters above sea level
- Can grow in marginal or poor soil condition (semi-arid to tropical condition)
- Can be planted as intercrop with banana and coconut
- Can be planted under old and widely spaced coconut trees
- Bears flowers and fruits as early as 6 months and can live up to 50 years
- Can bear fruit throughout the year
- From seedling: flowering starts at 7 to 8 months after planting
- From cuttings: flowering could be as early as four months after planting
- Typically planting density of 2,500 trees per hectare (2 meters x 2 meters)

- Yields 2,000-5,000 kg seeds/hectare/year depending on the quality of jatropha seed, planting density and soil quality
- 3-4 bunches per branch per fruiting season
- 7-10 fruits per bunch
- Average of 2.66 seeds per fruit
- Average of 36 branches per tree
- Average of 1,200 seeds per kilogram
- 0.3-0.9 kg/tree seed production
- Seeds yield 30-40% crude non-edible oil
- Typically produces 0.75-2 tons biodiesel/hectare

Source: Villancio, V. T., From Seed to Blend: Jatropha Curcas for Biodiesel, Integrated R&D Program on Jatropha curcas (Tubang bakod) for Biodiesel, University of the Philippines Los Baños, Philippines, 2007.

Box 3.2 – How to grow jatropha for biodiesel

Plant's description. Jatropha curcas L. is found throughout the Philippines. In fact, different regions have their own common name for jatropha. In the Tagalog region, it is known as *tubang bakod, tuba* and *sambo*. Among the Bicolanos, it is called *tuba* and *tuba-tuba*; in Pangasinan and Nueva Ecija, it is called *tagumbao*; *tawa-tawa* in Ilocos and *kalunay* in Cagayan Valley. In the Visayas and Mindanao, it is also known as *tuba-tuba*; *kasla* among the Ilongos and *tangan-tangan* in Lanao region.

Jatropha is a drought resistant perennial shrub or small tree that has an economic life of up to 35 years and can live for 50 years. It grows fast, with little or no need for maintenance and can reach a height of 3 to 8 meters. It has a smooth gray bark which exudes whitish color, watery latex when cut. The size of the leaves ranges from 6-15 cm in length and width. The leaves are green to pale, alternate to sub-opposite with 3 to 5 lobes. It sheds leaves in the dry season and rejuvenates during rainy season. Flowers are formed terminally, individually, with female flowers usually slightly larger. It is pollinated by insects especially honey bees. Two flowering peaks are often observed and occur during the wet season. Each inflorescence yields fruits. After the seeds mature, 3 bi-valved cocci are formed. The seeds become mature when the capsule changes from green to yellow about three months after flowering.

Site requirements. Jatropha curcas is a tropical and subtropical plant. It grows almost anywhere even on sandy, gravelly and saline soils and does well on high temperatures. Select a site with well-drained soils and good aeration. Jatropha is well adapted to marginal soils with low nutrient content but the use of organic fertilizer would result to higher yield. Its water requirement is extremely low and can stand long periods of drought by shedding most of its leaves. It grows best when planted at the start of the rainy season.

Land preparation. For commercial plantation, prepare the planting site by weeding, cultivation and digging holes, with spacing of 2 x 2 m apart. For hedges, a distance of 1 x 1 m is recommended.

Seeds (Sexual propagation). For reproduction purposes, harvest the fruits when already yellow to dark brown in color. Two to four months after flowering, seeds should be collected when capsules split open. Experience shows that drying seeds in direct sunlight has negative effect on viability. The number of seeds per kilogram ranges from 600 to 1,600. De-hull the dried seeds using a hollow wooded plank then winnow to separate the hulls from the seeds. The seeds are orthodox and should be dried to 5-7% moisture content and stored in air-tight containers. The seeds can last for one year at room temperature. However, seeds that are oily cannot be stored for a long period.

For seedling production, select the seeds and treat them with water eight hours before sowing. This is done to soften the seed coat for easy germination. Then put the seeds in the mixture of soil, sand and manure prepared in plastic bags with water. It is best to avoid removing or breaking the seed coat before sowing due to risk of abnormal seedlings. To sow the seeds, pour water while pressing it lightly on the soaked soil. The first shoot is expected after 6 days. Water the plants twice a day for seven days and once for the succeeding days. After 2 months, the sapling is ready for plantation.

Stem cuttings (Asexual propagation). Cuttings should be obtained from at least 8 month-old mature plants, as much as possible 45-100 cm from the base of the stem. Use a saw or sharp bolo to cut it. The plant should be about 3-4 cm thick and has short internodes with many eyes. Cuttings serve as an immediate source of planting material that can produce seeds in less than 1-2 years.

Tissue culture. Tissue culture is a laboratory-based procedure which uses artificial and sterilized propagation media. Tissues from various parts of the plant can be used in this procedure. This method allows choosing desirable characteristics of the mother stock and improving the variety of jatropha.

Nursery operation. One of the most important components of plantation development is nursery operation since it increases the rate of survival of the planting material. The nursery should be accessible to the planting site, preferably on non-sloping area and near the source of water.

Planting jatropha. Transplant the two-month old seedling or cutting in holes 2 x 2 meters apart, or any preferred spacing. Cover the hole with topsoil in a hill-up manner to avoid erosion. Water the plants up to two weeks after transplanting. For cuttings, the same procedure can be adapted provided that the stalk is transplanted within 5 days after cutting.

Fertilizer application. To have higher yield and better quality seed, application of fertilizer is recommended. After applying, water the plants to avoid wilting. In highly rain-fed areas, fertilizers can be applied during the rainy days. Apply the fertilizer in a depth of 5-10 cm and 15-20 cm away from the plant. The use of organic fertilizer is highly recommended.

Harvesting. Seeds can usually be harvested one year after planting. Seeds for replanting can be gathered when the fruits are already yellow to dark brown. Seeds that are black and dry can already be used for oil extraction.

Yields. Potential yield ranges from 1.25 to 12.5 tons per hectare depending on the site, climate and tending operations. Based on the experience in India, 3 kilograms of jatropha seeds can produce one liter of crude jatropha oil.

Source: A Primer, How to Grow Jatropha for Biodiesel, Philippine Forest Corporation, 2007.

Box 3.3 – Jatropha fruit yield characteristics

Under Calauan, Laguna, Philippine conditions, *tubang bakod* (the local name of Jatropha curcas L.) bears harvestable fruit from April to July. Hence the harvesting for jatropha fruit is priming (harvesting the fruit as they mature). Matured fruits are yellowish and turn blackish as they dry. As presented in Table 1, four samples represented the conditions when fruits were harvested. Samples 1 and 4 were harvested at the same time and on a sunny day, hence the fruits were relatively dry. Samples 2 and 3 were harvested on a rainy week, therefore they are relatively wet. These are the weather conditions during the harvesting period of jatropha fruits.

Black- and yellow-colored fruits differ in moisture condition, with the yellow-colored having higher moisture, thus, they are heavier than the black-colored fruits. Yellow fresh fruits at 12.34 g per fruit are 3 times heavier than black fruits at 4.52 g per fruit. Extracted seeds from yellow fresh fruits at 1.27 g per seed are also heavier than seed extracted from black fruits which weigh 0.844 g per seed. Moisture content, as indicated by the color of the fruit, is important as it determines the percent seed recovery (%SR).

If the exocarp (the technical term for the fruit cover) has more moisture as in the yellow fruit, the %SR would be lower. Yellow-colored fruits have only 10.35% SR while black-colored fruits have 20.97% SR. Fruit color or its moisture content is also related to the number of seeds per unit weight. Using 1 kg as reference weight, the number of seeds per one kg seed lot was estimated:

1.0 kg of yellow-colored fruits = 797 seeds
1.0 kg of black-colored fruits = 1,227 seeds

The seed number as influenced by moisture content status is important as it determines the equivalent quantity of fruits to obtain 1.0 kg seeds. Based on estimates, the following data were obtained:

1.0 kg seed = 9.71 kg fresh yellow fruits
1.0 kg seed = 5.11 kg fresh black fruits
1.0 kg seed = 7.41 kg of fresh fruit (average of yellow and black fruits)

These fruit yield characteristics are important data for the following reasons: (a) Field conditions at harvesting time is related to the moisture condition of the fruit and seed. The fruit moisture in turn determines the number of seeds per kilogram, the % seed extraction and the weight (in kg) of fresh fruits that yields a kilogram of seed; (b) The fruit yield data, especially the conversion from kg fruit to kg seed is important in buying jatropha fruit at the farm level; (c) Data/technical coefficients are needed in establishing jatropha farms for production and constructing mills for processing seeds into various products (crop and mill planning).

Table 1 – Jatropha fruit yield characteristics*

Sample No.	Features of sample	Average weight of fruits (g)	Average number of seeds per fruit	Average weight of seeds (g)	% Seed Recovery (SR)	Number of seeds in 1.0 kg	Kg fruits per 1.0 kg seeds
1	Yellow fresh fruits	11.43	2.20	1.09	9.50	672	10.52
2	Yellow fresh fruits (wet)	13.26	3.00	1.49	11.22	921	8.91
Average (1+2)		12.34	2.60	1.27	10.35	796.5	9.71
3	Black fruits (wet)	6.45	2.85	1.00	15.50	1,000	6.45
4	Black fruits (dry)	2.60	2.40	0.69	26.44	1,454	3.78
Average (3+4)		4.52	2.62	0.84	20.97	1,227	5.11
Average (1+2+3+4)		5.93	2.61	1.06	15.66	1,011	7.41

* Data were obtained from Jatropha fruiting trees at Brgy. Bangyas, Calauan, Laguna (April to July 2006).

Source: Mendoza, Teodoro C., Castillo, E., and Aquino, A. L., Towards Making Jatropha "Tubang Bakod" a Viable Source of Biodiesel in the Philippines, College of Agriculture, University of the Philippines, Los Banos, College, Laguna, Philippines, 2007.

Chemistry, Composition and Uses

The oil of the jatropha plant comes mainly from its seeds. The proximate analysis of jatropha seed shows that it contains 38-47% crude fat, 18-25% crude protein and 10-16% crude fiber (Table 3.1). The kernel has the highest heating value of over 30 MJ/kg and the highest percentage of lipid and crude protein of around 79-86% by weight indicating that this is where the oil is mainly concentrated (Table 3.2). Jatropha oil has a heating value of 31-36 MJ/kg and a relatively high iodine value (96-105) comparable to that of sesame oil (103-108) and cottonseed oil (108-110) indicating a fairly high degree of unsaturation (Table 3.3). The predominant fatty acids are oleic and linoleic acids with moderate amount of palmitic acid. The oleic acid content of jatropha oil and palm oil are comparable. However, jatropha oil contains more linoleic acid while palm oil has more palmitic acid (Table 3.4). The heating value and cetane number of jatropha oil are comparable to that of diesel fuel but as with other plant oils, the flash point of jatropha oil is considerably higher compared to that of diesel fuel (Table 3.5). The bark, fruit, leaf, root, and wood of jatropha are all reported to contain hydrocyanic acid (HCN) and the seed contains the dangerous toxalbumin curcin as well as diterpene esters, rendering it potentially fatally toxic[13]. For this reason, the cake that remains after the oil has been extracted cannot be used as animal feed, but it is valuable as a soil conditioner or as solid fuel, particularly if it is briquetted. As a fertilizer supplement or soil conditioner, the jatropha press cake contains the following nutrients: N: 5.7-6.48%, P_2O_5: 2.6-3.1%, K_2O: 0.9-1.0%, CaO: 0.6-0.7%, and MgO: 1.26-1.37%[14].

The leaves contain isovitexin and vitexin[15]. They show anti-leukemic activity and contain α-amyrin, β-sitosterol, stigmasterol, campesterol, 7-keto-β-sitosterol, stigmast-5-ene-3-β, 7-α-diol, and stigmast-5-ene-3β, 7β-diol[16]. They also yield a dark blue dye that have been used for coloring cloth, fishing nets and lines and are believed to have a number of ethno-medicinal applications or folk remedies. The leaves are also burned to fumigate houses against insects and bedbugs. The latex of jatropha curcas contains an alkaloid known as jatrophine, which is believed to have anti-cancerous and anti-microbial properties and can be used to heal wounds and some skin diseases or applied topically to bee and wasp stings[17].

Table 3.1 – Proximate analysis of jatropha seed

Parameter	Composition (wt %)		
	Akintayo	Shivrai	Duke/Atchley
Crude fat	47.2	38.0	38.0
Crude protein	24.6	18.0	18.2
Crude fiber	10.1	15.5	15.5
Moisture	5.5	6.2	6.6
Ash	4.5	5.3	4.5
Carbohydrate	8.0	17.0	33.5

Sources:
1. Akintayo, E.T., Characteristics and Composition of Jatropha Curcas Oils and Cakes, 2003 (quoted in an unpublished paper of the project "Development of Small Distributed Power Plant Generation Using Jatropha in Indonesia", Institute of Technology Bandung, Indonesia)
2. Technical document of Shivrai Technologies, Pune, India, <www.svlele.com/jatropha_plant.htm>
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Table 3.2 – Analysis of jatropha fruit

Parameter	Kernel	Shell	Meal
Dry matter (wt%)	94.2 - 96.9	89.8 - 90.4	100
Constituents (% in dry matter)			
Crude protein	22.2 - 27.2	4.3 - 4.5	56.4 - 63.8
Lipid	56.8 - 58.4	0.5 - 1.4	1.0 - 1.5
Ash	3.6 - 4.3	2.8 - 6.1	9.6 - 10.4
Neutral detergent fiber	3.5 - 3.8	83.9 - 89.4	8.1 - 9.1
Acid detergent fiber	2.4 - 3.0	74.6 - 78.3	5.7 - 7.0
Acid detergent lignin	0.0 - 0.2	45.1 - 47.5	0.1 - 0.4
Heating value (MJ/kg)	30.5 - 31.1	19.3 - 19.5	18.0 - 19.3

Source: Trabi, M., Die Gifstoffe der Purglemuss (Jatropha curcas L.) MSc Thesis, Graz University of Technology, Germany, 1998 (quoted in an unpublished paper of the project "Development of Small Distributed Power Plant Generation Using Jatropha in Indonesia," Institute of Technology Bandung, Indonesia)

Table 3.3 – Physical and chemical characteristics of jatropha seed oil

Parameter	Akintayo/Gubitz	ITB-MRI
Density (g/cm^3) at 15^{0}C	0.920	0.918
Viscosity (cSt) at 30^{0}C	17 - 52	50.8
Flash point (^{0}C)	240	290
Sulfur content (ppm)	n.a.	<1
Iodine value	105	96.5
Heating value (MJ/kg)	30.7	35.6

Sources:
1. Akintayo, E.T., Characteristics and Composition of Jatropha Curcas Oils and Cakes, 2003.
2. Gubitz, G.M., Mittelback, M., Trabi, M., Exploitation of the Tropical Seed Plant Jatropha Curcas L., Bioresource Technology, 67, 1999.
3. Project on "Development of Small Distributed Power Plant Generation Using Jatropha in Indonesia," Institute of Technology Bandung, Indonesia, and Mitsubishi Research Institute, Japan, 2004.

Table 3.4 – Fatty acid composition of jatropha seed oil and palm oil

Fatty acid	Jatropha	Palm
Miristic 14:0	0.0 – 0.1	0.9 - 1.5
Palmitic 16:0	14.1 – 15.3	39.2 – 45.8
Stearic 18:0	3.7 – 9.8	3.7 – 5.1
Arachidic 20:0	0.0 – 0.3	0.0 – 0.04
Palmitoleic 16:1	0.0 – 1.3	0.0 – 0.4
Oleic 18:1	34.3 – 45.8	37.4 – 44.1
Linoleic 18:2	29.0 – 44.2	8.7 – 12.5
Linolenic 18:3	0.0 – 0.3	0.0 – 0.6

Source: Gubitz, G.M., Mittelback, M., Trabi, M., Exploitation of the Tropical Seed Plant Jatropha Curcas L., Bioresource Technology, 67, 1999.

Table 3.5 – Comparison between jatropha oil and diesel fuel

Parameter	Jatropha oil	Diesel fuel
Specific gravity, g/ml	0.918	0.841
Sulfur, wt%	0.13	1.2
Heating value, kcal/kg	9,470	10,170
Flash point, ^{0}C	240	50
Cetane Number	51	50

Source: Kandpal, J.B., Mira Medan, Jatropha Curcas: A Renewable Source of Energy Meeting Future Energy Needs, Technical Note, Renewable Energy, vol. 6, no. 2, 1994.

Production and Use of Jatropha Oil

The process of biodiesel production involves two phases. The first phase is the extraction of crude oil from seeds and the second is the transesterification of the crude oil into biodiesel. The extraction process involves the use of machines to extract the oil from the seed. This produces crude jatropha oil, and hull and press cake as by-products. Laboratory results show that around 2.9 kg of seeds can produce 1 liter of crude oil. On the other hand, the transesterification of crude oil is a process that uses chemicals like methanol and catalysts such as caustic soda[18]. This produces jatropha methyl ester (JME) as its main product and glycerin as its by-product. Ten liters of crude jatropha oil produces 8.5 liters of JME. The results of laboratory tests show that JME passes the American standard (ASTM D6751) and European standard (EN 14214) for biodiesel. Moreover, analysis of crude jatropha oil shows that it is comparable to bunker fuel[19].

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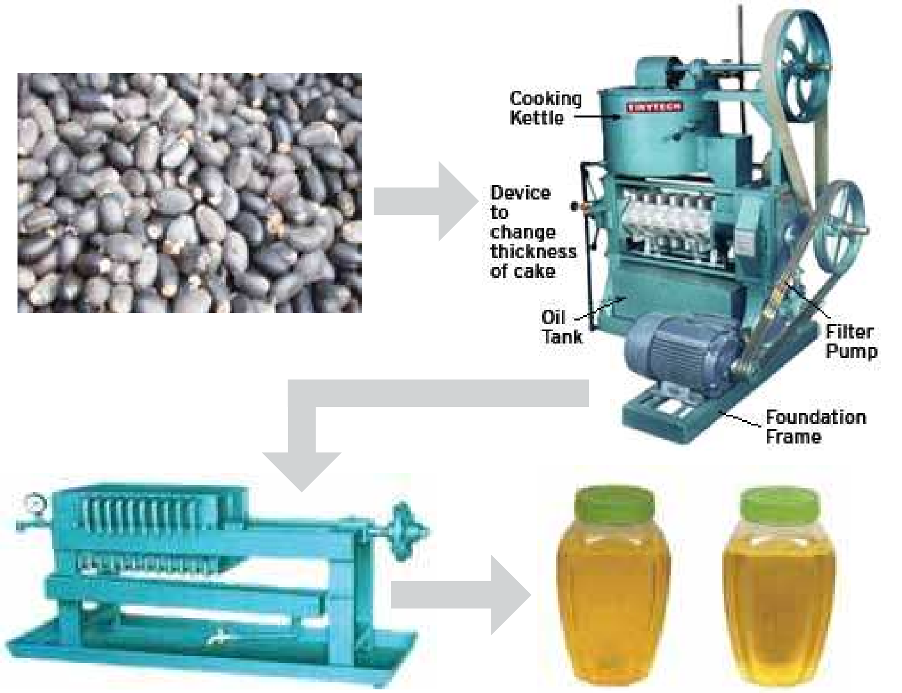
[18] The process of transesterification to produce biodiesel will be described in detail in another chapter.

[19] Technical Bulletin, Tuba-Tuba (Jatropha Curcas L.): An Alternative Source of Energy, Philippine Forest Corporation, Philippines, 2007.

The use of small scale mechanical press for the extraction of oil from jatropha seeds, combined with the microemulsification of jatropha oil to produce fuel for compression ignition engines, appears to be a viable option for wide application in many parts of most developing countries, including the Philippines[20]. In the countryside where land is available and labor is plentiful and relatively cheap, jatropha curcas may be grown and the seeds manually harvested. Small scale jatropha oil extraction facilities may be installed together with a microemulsification plant. The extraction process using a small mechanical press followed by filtration is shown schematically in Figure 3.1. The fruits are sun-dried, manually dehulled, and the seed further dried under the sun. The sun-dried seeds are then sent to a mechanical press for the extraction of oil. The press cake is removed from the bottom of the equipment and may be used as fuel for cooking and other purposes. The crude jatropha oil is sent to a plate-and-frame filter press to remove residual solids. The filtered jatropha oil is ready and suitable as feedstock in a small-scale microemulsification plant. The MHF that is produced can be used to run farm tractors, trucks, cars and jeepneys, and to operate compression ignition engines to supply electricity to the community or run irrigation pumps.

Figure 3.1 – Processing of jatropha seeds to produce oil



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[20] The process of microemulsification to produce diesel substitute or blend will be described in detail in another chapter.

A pilot plant for the production of jatropha microemulsified hybrid fuel comprising a mechanical extractor (green colored equipment on the right) and a small MHF machine (silver colored equipment on the center) located at Philippine Forest Corporation. (Photo by LAUDS Technologies, Inc., 2007).

A small MHF machine owned by LAUDS Technologies, Inc. and Nippon Ecosolutions, Ltd. located at the pilot jatropha oil extraction plant owned by Philippine Forest Corporation. Jatropha oil is processed through the reactor (silver-colored, rectangular-shaped machine) and the five-micron tubular filter (silver-colored vertical tube in the middle) while a proprietary additive is added (green drum fitted with a mixer). (Photo by LAUDS Technologies, Inc., 2007).

An Indian-made mechanical oil extractor (front) with a plate-and-frame filter press (behind the oil extractor, partly hidden) located at the jatropha oil pilot plant owned by Philippine Forest Corporation. (Photo by LAUDS Technologies, Inc., 2007).

Sun-dried jatropha seeds are fed into the mechanical extraction equipment (green-colored equipment shown on the right side of the top picture and also in the bottom picture). Crude jathropha oil is sent to a plate-and-frame filter press to remove residual solids (not shown in the top picture but shown behind the mechanical press in the bottom picture) and the filtered jatropha oil is stored in a stainless steel cylindrical storage tank (shown to the left of the jatropha press in the top picture). The filtered jatropha oil is then sent to the MHF machine (shown as the silver-colored equipment in the middle of the photo and also in the middle photo) for processing. A proprietary additive is added and the solution recirculated for two hours through the machine. The final product is filtered through a 5 micron filter (shown as a small cylindrical tube located below the MHF machine, top and middle photo).

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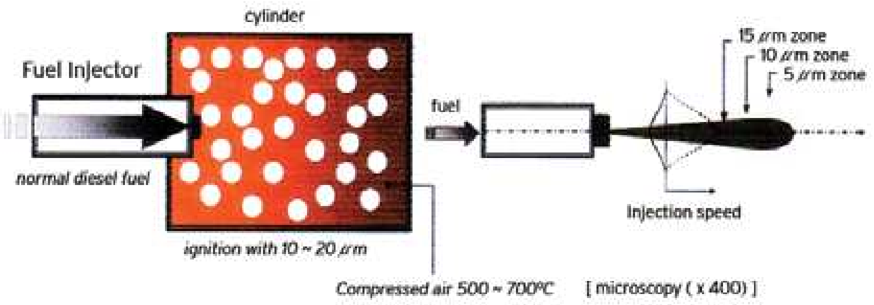
Chapter 4:

Straight Plant Oil as Diesel Substitute

The use of pure or straight plant oil as fuel in diesel engines is an old idea. In fact it was the fuel of choice when the diesel engine was invented and first demonstrated. The only reason straight plant oil (more commonly referred to in literature as straight vegetable oil or SVO) cannot be used to run a diesel engine is if the oil is too thick to flow at the required rate through the fuel lines and filters of the engine. This, of course, is the case for most plant oils at ambient temperature. The diesel engine was named after Dr. Rudolph Diesel, a German engineer who filed the patent for a compression ignition (CI) engine in 1894. He then successfully operated a prototype engine in 1897. Then in 1900 the diesel engine was first demonstrated to run on peanut oil during the world fair in Paris by the Otto Company at the request of the French Government. At that time the French Government was interested in using peanut oil as an energy source for its colonies in Africa. Thus the current interest in running a car or truck using straight or pure plant oil could be viewed as merely going back to what the inventor of the CI engine had originally intended. Unfortunately, the design and operating characteristics of modern CI engines are nowhere near those of the first CI engine that ran on peanut oil. Mainly as a result of the economics favoring fossil fuels, the developments in the design and engineering of the CI engine have been geared towards the use of a distillate of crude oil commonly known as diesel fuel instead of peanut oil or other plant oils. For this reason, most modern CI or diesel engines, including the combustion chamber and fuel supply and injection systems, are engineered to optimize the burning of diesel fuel, rather than plant oils.

As a consequence of the manner the design and engineering of the compression ignition engine evolved, plant oils that are generally much more viscous than diesel fuel cannot be injected into the cylinders as effectively and efficiently as diesel fuel. And even if the plant oil can be successfully injected, the injector, which was carefully engineered to the specifications of the diesel fuel, cannot provide a fuel mist as fine as when plant oils are used. When larger fuel droplets are formed upon injection, the fuel does not burn efficiently causing difficulty with starting and incomplete combustion, which leads to build-up of carbon residue. As deposits build up inside the engine, they can cause poor engine performance resulting from low compression due to sticking piston rings or coked valves. In addition, deposits on the injector nozzle produce poor injection spray pattern resulting in even more incomplete combustion and possible piston damage due to increased heat on piston surfaces. Figure 4.1 shows a typical spray pattern inside the cylinder. When injected, diesel fuel normally produces fine mist ranging in size from 5 to 20 microns. The finer the mist and the more uniform the mist size, the better is the combustion inside the cylinder.

Figure 4.1 – Spray pattern inside the cylinder



Source: Technical paper, Nippon Ecosolutions, Ltd., Japan, 2007.

Appearance of fuel injection nozzles removed from the engine of a truck that runs on diesel fuel. (Photo by LAUDS Technologies, Inc. and Nippon Ecosolutions, Ltd.)

Box 4.1 – Basic principles of diesel engine

The Direct Injection Engine (DI)

The engine uses the heat caused by compressing air in a cylinder, with a piston, to ignite fuel oil which is injected into the cylinder. This oil burns and creates an increase in pressure which forces the piston back down the cylinder, providing the power. The burnt gasses are exhausted from the cylinder and replaced by fresh charge through valves, commonly positioned above the piston in the cylinder head.

The fuel oil is pushed into the engine under high pressure at the correct time by an injector pump. The oil is sprayed into the engine cylinder as a very fine mist from the nozzle of an injector. The fine fuel oil mist readily mixes with hot air in the cylinder, ignites and provides an efficient burn. The injector pump also meters the amount of fuel delivered. The more fuel the more power/faster the engine.

The Indirect Injection Engine (IDI)

A later development was the IDI engine that utilizes a separate combustion chamber, connected to the engine cylinder, into which the fuel is injected and combustion is initiated.

A heat resistant insert with low heat conductivity is located within the combustion chamber so it quickly heats up and retains heat from combustion, providing extra heat to enable quicker ignition. The fuel is injected into the hot combustion chamber as a jet at a low pressure compared to the fine high-pressure spray of a DI engine. The fuel jet hits the hot insert where ignition is initiated; the fuel is distributed around the combustion chamber as combustion continues. The expanding burning fuel, along with partially burnt and unburnt fuel, is carried into the hot engine cylinder where further oxygen is available and combustion continues.

The most common prechamber format utilized is the Ricardo Comet design developed by Ricardo and Company of Shoreham, Sussex, UK. With this design, air is pushed from the cylinder into a circular 'swirl chamber' through a tangentially aligned throat. The bottom half of the chamber along with the throat is constructed from a nimonic alloy designed to maintain high temperatures during engine operation. The temperature of the compressed air is raised further while passing through the throat. A vigorous swirl motion is initiated as the air is forced into the circular swirl chamber. The fuel is injected into the swirl chamber and rapidly atomized within the mass of hot turbulent air.

The advantage of IDI engines is that they can operate at higher engine speeds as the more efficient fuel and air mixing provides faster combustion. Cars and small commercial vehicles require a small, light engine which must be able to operate at higher speeds to provide the necessary power, and with the advent of the IDI engine the use of diesel engines in such vehicles became widespread.

The heat lost due to the increased surface areas of the combustion chamber and the pressure drop between cylinder and combustion chamber make it necessary for the engines to operate at higher compression ratios to provide enough heat for ignition. The lost heat and force required to push the air into the combustion chamber is wasted energy making IDI engines around 10-15% less efficient than DI units.

IDI engines became the engine of choice in small vehicle applications as a small engine could produce more power at higher speed providing a suitable power/weight ratio for such applications. Recent advances in fuel injection technology, which provide more precise fuel delivery, allow faster combustion within a DI engine. The improved efficiency of the DI cycle has spurred the fitment of such engines to become more common in small vehicles.

Source: Darren Hill, "Vegetable Oil as a Fuel", <http://vegeburner.co.uk>

Box 4.2 – Fuel injection equipment

Timing, pressure and quantity of fuel delivery are crucial for efficient combustion. The important task of fuel delivery is performed by the fuel injection equipment.

Mechanically-Controlled Fuel Injection

Fuel is supplied to the injector by an injector pump. The injector pumps are mechanically driven from the crankshaft. The drive from the crankshaft is set so that the injector pump delivers fuel at the correct time in the engine operation cycle.

Single Element Injection Pump (Jerk Pump)

The simplest type of injection pump found on single cylinder engines. The single pumping element delivers fuel to the injector via a high pressure pipe. Multi-cylinder engines sometimes utilize multiple single element pumps. This is most often seen in stationary or marine applications.

In-Line Injector Pump

In-line pumps use a similar design to the single element pump, for a multi-cylinder engine. A number of jerk pumps are combined into a single component. The pumps are driven by a camshaft held within the pump body.

Rotary Injector Pump

Rotary pumps are similar in appearance to a petrol engine distributor. A single pumping mechanism rotates and supplies fuel to each cylinder in turn.

Electronically-Controlled Fuel Injection

Recently developed electronically controlled injectors can provide exact amounts of fuel at very high pressure, very precise timing and even multiple injections within each cycle to give greatly improved combustion and in turn increased fuel economy and lower engine noise and toxic emissions. Both in-line and rotary injection pumps have been developed with electronic components to help achieve more accurate injection timing and metering. By monitoring the engine using a number of sensors the electronic controller can modify the fuel injection characteristics to improve combustion.

Common Rail Injection Systems (CDI)

With this system a pump constantly supplies fuel at a very high pressure to the common rail – a tube with thick walls. From the common rail fuel is supplied to electronically controlled injectors. The higher pressure injection gives a finer spray and improved combustion.

Unit Injector System and Unit Pump Systems

Unit injector systems combine the pump and injector into one unit. The pump is driven from the engines camshaft. Fuel delivery is timed and metered by electronically-controlled valves. Unit pump systems are similar with the pump and injector separated and connected by a short high pressure fuel line.

Source: Darren Hill, "Vegetable Oil as a Fuel", <http://vegeburner.co.uk>

Use of 100 Per Cent Plant Oil as Fuel

An excellent review of literature concerning the use of various kinds of plant oils as a replacement for diesel fuel was made by Jones and Peterson of the University of Idaho[1]. Pryde (1982) also reviewed the results of a number of studies on the use of plant oils as a diesel substitute and reported that whole short-term engine tests showed promising results, long-term engine tests revealed serious problems resulting from carbon build up and lubricating oil contamination[2]. It was concluded that plant oils must either be chemically altered or blended with diesel fuel to prevent premature engine failure. Quick (1980) also surveyed the work on over 30 different plant oils that had been used to operate compression engines[3]. It was found that while plant oils showed great potential as diesel fuel substitutes, extended operation resulted in serious carbonization of critical engine components. Blending the plant oil with diesel fuel was found to yield better results, reducing coking and extending engine life.

Seddon (1942) studied the performance of different plant oils as fuel using a Perkins P6 diesel engine with good results[4]. The experiments showed that plants oils could be used to power diesel engines under normal operating conditions. It was noted, however, that much more work would be needed to fully ascertain the reliability of plant oils as substitute for diesel fuel since problems tend to surface as the trials lasted longer periods. Bruwer et al (1980) examined the use of 100% sunflower seed oil as a diesel fuel substitute in running a farm tractor[5]. A power loss of 8% occurred after 1,000 hours of operation, which was corrected by replacing the fuel injectors and injector pump. After 1,300 hours of operation, the carbon deposits in the engine were measured to be equivalent to an engine fueled with 100% diesel except for the injector tips, which exhibited excessive carbon build-up.

Goering et al (1981) studied the performance of eleven plant oils to determine which oils could be used as an alternative fuel source[6]. Of the eleven plant oils used in the experiments, corn, rapeseed, sesame, cottonseed, and soybean oils showed the most favorable fuel properties. Similarly, Bacon et al (1981) evaluated the use of several plant oils as diesel fuel substitute[7]. Short 2-hour tests were conducted to visually compare the effects of using different plant oils in place of diesel fuel. The initial engine performance tests showed acceptable performance although there was noticeable carbon build up in the combustion chamber. As the tests progressed with the continuous running of the diesel engine at part-load and mid-speeds, it was observed that carbon deposits accumulated rapidly on the injector tips. Although short-term engine test results were promising, it was recommended that long-term engine testing would be necessary to ascertain the overall effects on diesel engines of using plant oils as fuel.

Schoedder (1981) obtained mixed results using rapeseed oils as a diesel fuel replacement in a series of studies[8]. Although short-term engine tests indicated that rapeseed oil had similar energy outputs compared to diesel fuel, the results of long-term engine tests revealed operating difficulties arising from deposits on piston rings, valves and injectors, particularly after 100 hours of continuous operation. The study recommended further long-term testing to determine how these difficulties could be avoided. Nearly similar results were obtained by Yarbrough et al (1981) when testing six sunflower oils as diesel fuel replacements[9]. The tests showed that raw sunflower oils were unsuitable for use as diesel fuel substitute but refined sunflower oil was found to give acceptable performance. They further showed that degumming and dewaxing of the plant oils would be required to prevent engine failure.

Reid et al (1982) conducted injection studies and engine tests to evaluate the chemical and physical properties of 14 plant oils related to their use as alternative fuels[10]. The injection studies showed that the plant oils dispersed differently compared to diesel fuel due to their much higher viscosities. The engine tests showed that the level of carbon deposit varied even for plant oils with nearly similar viscosities, indicating that oil composition was also an important factor. The tests also revealed that pre-heating the oil prior to injection could reduce the amount of carbon deposits in the engine. Auld et al (1982) evaluated the suitability of rapeseed oil as an alternative fuel in diesel engines and showed that there is a relationship between viscosity and fatty acid chain length[11]. Although the engine power and torque results using rapeseed oil were similar to that of diesel fuel during short-term tests, the study clearly indicated the need for further long-term testing to better evaluate engine durability.

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[11] Auld, D. L., Bettis, B. L. and Peterson C. L., 1982, Production and Fuel Characteristics of Vegetable Oilseed Crops in the Pacific Northwest, *Vegetable Oil Fuels: Proceedings of the International Conference on Plant and Vegetable Oils Fuels,* St. Joseph, MI: ASAE.

Bettis et al (1982) evaluated sunflower, safflower and rapeseed oils as possible sources for liquid fuels[12]. These plant oils were found to contain approximately 95% of the energy content of diesel fuel but were about 15 times more viscous. As with earlier findings, short-term engine tests indicated that the plant oils could deliver power nearly equal to that of diesel fuel, but long-term durability tests revealed serious problems related to carbonization of the combustion chamber. Tahir et al (1982) tested sunflower oil in farm tractors as a diesel fuel substitute[13]. Although the viscosity of sunflower oil was 14% higher than diesel fuel at 37^{0}C, the test showed engine performance comparable to that of diesel fuel, but with slightly higher fuel consumption. Furthermore, the oxidation of the sunflower oil left heavy gum and wax deposits on test equipment that, with continued use, could lead to engine failure.

Engler et al (1983) used raw sunflower and cottonseed oils as fuel in a series of engine performance tests and obtained poor results[14]. However, when processed or refined sunflower and cottonseed oils were used, the tests produced results slightly better than similar tests for diesel fuel. There was, however, the occurrence of carbon deposits and lubricating oil contamination problems, indicating that these oils were acceptable only for short-term use as diesel fuel substitute. Pryor et al (1983) conducted short-term and long-term engine performance experiments using 100% soybean oil in a small diesel engine[15]. The results confirmed the findings of similar earlier studies – short-term use gave performance equivalent to that of diesel fuel, but long-term use would result in severe power loss due to carbon buildup in the injectors.

The studies on the use of various types of plant oils as replacement for diesel fuel indicate that a diesel engine can be successfully run with 100% refined or processed plant oil but only on a short-term basis. The long-term use of 100% plant oil can cause engine failure due to engine oil contamination, stuck piston rings, and excessive carbon build-up on internal engine components. It can, therefore, be concluded that 100% unmodified plant oils are not acceptable diesel fuel replacements.

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Plant Oil-Diesel Blends as Fuel

With the preponderance of evidence from numerous studies showing the unsuitability of using pure or straight plant oil for long-term use as diesel fuel substitute in unmodified modern CI engines, researchers have focused on using various blends of different plant oils with diesel fuel. There are basically two parameters that can be changed or adjusted: first, the type of plant oil; and second, the ratio of plant oil to diesel fuel in the blend. A summary of the results of a number of tests and field trials is presented here using varying blends of various plant oils such as soybean, rapeseed, sunflower, peanut, palm and others.

Engelman et al (1978) conducted a series of performance tests using 10% to 50% soybean oil blended with diesel fuel in diesel engines with initially encouraging results[16]. The carbon build-up in the combustion chamber was minimal at the end of the 50-hour test run and the power delivered was only slightly lower compared to 100% diesel fuel. However, fuel blends containing 60% or higher concentrations of plant oil caused the engine to sputter due to fuel filter plugging. The tests showed that among the plant oils used, waste soybean oil gave the most promising results.

Sims et al (1981) showed that rapeseed oil-diesel fuel blends could be used as a replacement for diesel fuel[17]. Short-term engine tests showed that a 50:50 rapeseed oil-diesel fuel blend had no adverse effects although long-term tests resulted in injector pump failure and cold starting problems. The amount of carbon deposits on combustion chamber components was found to be nearly the same as that found in engines operated on 100% diesel fuel. Worgetter (1981) used a 50:50 blend of rapeseed oil and diesel fuel to operate a 43-kW tractor[18]. Initial results were good but after 400 hours of continuous operation the test had to be aborted due to serious engine problems resulting from heavy carbon deposits on the injector tips and pistons.

Van der Walt and Hugo (1981) examined the long-term effects of using sunflower oil-diesel fuel blends as a replacement for 100% diesel fuel in direct- and indirect-injected diesel engines[19]. The indirect-injected diesel engines were

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[16] Engelman, H. W., Guenther, D. A. and Silvis, T. W., 1978, Vegetable Oil as a Diesel Fuel, Diesel & Gas Engine Power Division of ASME Paper Number 78-DGP-19, New York, NY: ASME.

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run for over 2,000 hours using varying blends of de-gummed, filtered sunflower oil with no adverse effects. However, the direct-injected engines were not able to complete 400 hours of operation using a 20:80 sunflower oil-diesel fuel blend due to severe power loss resulting from severely coked injectors, carbon buildup in the combustion chamber, and stuck piston rings. There was also considerable wear of the piston, liner and bearing as indicated by the analysis of the lubricating oil. Barsic and Humke (1981) also studied the effects of mixing sunflower oil and peanut oil with diesel fuel in a single cylinder engine[20]. The fuel blends were found to have lower heating value compared to diesel fuel and were observed to increase the amount of carbon deposits on the combustion side of the injector tip. In addition, there was serious fuel filter plugging when crude sunflower oil and crude peanut oil were used as diesel fuel extenders. In a much later study, Fuls (1983) reported similar findings for indirect- and direct-injection engines using 20:80 sunflower oil-diesel fuel blends where injector coking occurred in direct-injected diesel engines[21].

McCutchen (1981) compared engine performance of direct-injection engines to indirect-injection engines when fueled with a 30:70 soybean oil-diesel fuel blend[22]. The results showed that the indirect-injection engine could be successfully operated on this fuel blend but the direct-injection engine could not without severe engine problem occurring due to injector coking and piston ring sticking. Bartholomew (1981) reported that plant oils mixed with diesel fuel in small amounts did not cause engine failure[23]. Short-term tests of plant oil-diesel fuel blends of up to 50% plant oil yielded acceptable results but reducing the blend to only 20% plant oil gave better and more consistent engine performance. Other studies by Hofman et al (1981) and Peterson et al (1981) confirmed earlier findings that while plant fuel blends yielded encouraging results in short-term testing, problems occurred in long-term performance tests[24][25]. The most common problems encountered were carbon build-up, ring sticking, and lubricating oil contamination.

Fort et al (1982) reported that cottonseed oil-diesel fuel blends functioned reasonably well during short-term performance and emissions tests, particularly in terms of power, fuel consumption, and quality of emissions[26]. However, long-term engine durability was always a concern during extended use due to the formation of carbon deposits and clogging of the fuel delivery system. Similar studies by Baranescu and Lusco (1982) using three blends of sunflower oil and diesel fuel indicated that the sunflower oil caused premature engine failure due to carbon buildup and that cold weather operation caused fuel system malfunction[27]. Engine testing by Ziejewski and Kaufman (1982) using a 50:50 blend of sunflower oil and diesel fuel was unsuccessful due to significant carbon buildup on the injectors, intake ports and piston rings[28].

Wagner and Peterson (1982) reported severe engine damage during short-term engine testing using 100% rapeseed oil as a substitute fuel and heating the oil prior to combustion exhibited no measurable improvement[29]. However, a long-term test using a 70:30 rapeseed oil-diesel fuel blend was successful for 850 hours with no significant wear, contamination of lubricating oil, or loss of power. Peterson et al (1982) also used a 70:30 rapeseed oil-diesel oil blend to successfully operate a small single cylinder diesel engine for 850 hours[30]. In a much later study, McDonnell et al (2000) used a 25:75 semi-refined rapeseed oil-diesel fuel blend[31]. The results showed that the injector life was shortened due to carbon buildup but there were no signs of significant internal engine wear or lubricating oil contamination.

Ryan et al (1984) showed that the atomization and injection characteristics of several plant oils were significantly different from that of diesel fuel due primarily to the higher viscosity of the plant oils[32]. A series of engine performance tests also showed that power output slightly decreased when using blends of plant oils and diesel fuel and that injector coking and lubricating oil contamination were the dominant problems associated with the use of plant oil-based fuels with high viscosities. Pestes and Stanislao (1984) used a 50:50 plant oil-diesel fuel blend to study the formation of piston ring deposits and found that the most severe carbon deposits occurred on the thrust face of the first piston ring[33]. It was suggested that to reduce piston ring deposits a fuel additive could be used or the concentration of plant oil in the blend could be lowered.

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German et al (1985) used six farm tractors averaging 1,300 hours of operation to study the formation of carbon deposits[34]. It was found that carbon deposits on the internal engine components were greater for the tractors using a 50:50 sunflower oil-diesel fuel blend than for those using a 25:75 sunflower oil-diesel fuel blend. And all test engines using plant oil blends had more carbon buildup than the engine using 100% diesel fuel. The results of the study indicated that plant oil-diesel fuel blends could not be used to completely replace petroleum-based fuels on a long-term basis without adversely affecting engine life.

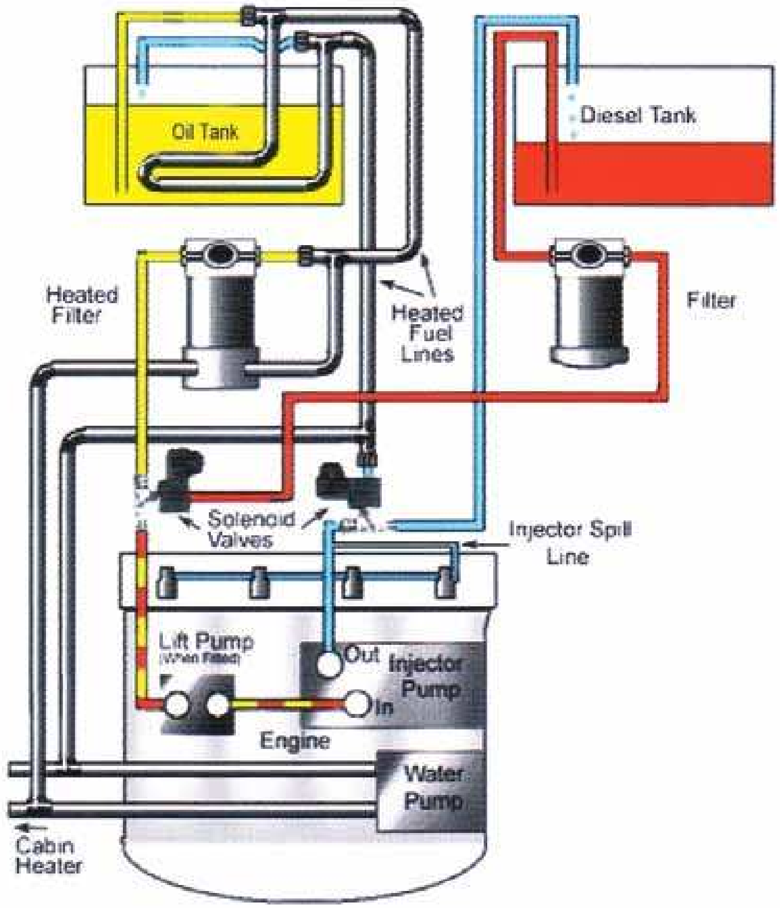
Nag et al (1995) conducted studies in India using fuel blends as high as 50:50 of oil from the Indian Amulate plant and diesel fuel and found no loss of power, knock-free performance, and no significant carbon deposits on the functional parts of the combustion chamber[35]. Sapaun et al (1996) reported that studies in Malaysia with palm oil-diesel fuel blends exhibited encouraging results[36]. Short-term performance tests indicated that power outputs were nearly the same for various blends of palm oil and diesel fuel and 100% diesel fuel with no signs of adverse combustion chamber wear, increase in carbon deposits, or lubricating oil contamination.

The various studies on the use of plant oil-diesel fuel blends indicate that they can be used in diesel engines for short periods with no significant decline in performance provided that the concentration of the plant oil in the blend is less than 20%. Long-term engine performance tests show that plant oil concentrations higher than 20% can have adverse effect on the engine due to accumulation of carbon deposits, fuel line clogging, and lubricating oil contamination. Degumming is suggested as a way to improve the characteristics of plant oils in low level blends. The use of suitable additives has also been suggested to overcome many of the problems associated with the use of higher concentrations of plant oil in the fuel blends.

Twin Tank or Dual Fuel System

A simple and effective way to run on pure plant oil is to use a twin tank or dual fuel system. The engine is started on the conventional diesel fuel and the waste heat generated by the engine is used to heat the plant oil. This avoids running viscous plant oil through a cold engine at start up. A temperature gauge in the fuel line determines when the plant oil is hot enough for the fuel supply to be switched to 100% plant oil. The fuel supply is switched by a three-way valve. Before shutting down for extended periods, the fuel supply is switched back to conventional diesel fuel and the engine is allowed to run for about 3 to 5 minutes so that any residual plant oil is flushed from the fuel system. The vehicle or engine is then ready to be restarted on diesel fuel. A schematic diagram of a twin tank or dual fuel system is shown in Figure 4.2. Various types of conversion kits are available commercially to convert existing single tank/single fuel systems into twin tank or dual fuel systems. One example is the Greasecar Vegetable Oil Conversion System described in Box 4.3.

Figure 4.2 – Schematic diagram of a twin tank fuel system



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Box 4.3 – Greasecar vegetable oil conversion system

The Greasecar Vegetable Oil Conversion System is an auxiliary fuel modification system that allows diesel vehicles to run on plant oil in any climate. The Greasecar kit comes with everything needed to convert a diesel vehicle to run on straight plant oil, including an aluminum heated fuel cell, quick-flush switching, and 10 micron filter. The kit includes: fuel valves (2), wire harness and connectors, fuse and harness, lighted in-dash fuel gauge, lighted 3-position switch, heater hose, window decal, instruction manual, 5-micron bag filter, hardware, hose brackets, heated fuel line, fuel hose, hose clamps, t-fittings, large hose clamps, heated plant oil tank, and heated 10 micron filter.

Source: <www.greasecar.com/product_detail.cfm?prodID=17>

Conclusion

Majority of the studies conducted on the use of straight plant oils or of varying blends of plant oils and diesel fuel show that in short-term trials, straight plant oils give satisfactory engine performance and power output often equal to or even slightly better than conventional diesel fuel. In long term trials, however, straight plant oils cause various engine problems such as coking of injector nozzles, sticking piston rings, crankcase oil dilution, lubricating oil contamination, and other operational problems. Many of these problems are due to the polymerization of triglycerides via their double bonds which leads to formation of engine deposits as well as the low volatility and high viscosity with resulting poor atomization patterns. Accordingly, the general trend has been directed towards the use of chemically-modified plant oils through a transesterification process to produce the mono alkyl esters of long chain fatty acids derived from plant oils – more commonly known as biodiesel. In a limited scale, the use of twin tank or dual fuel system has been found to yield satisfactory results. Similarly, the use of the microemulsification technology to address the problem of poor fuel atomization and improve the quality of the fuel mist upon injection has also been found to yield acceptable engine performance in limited field trials.

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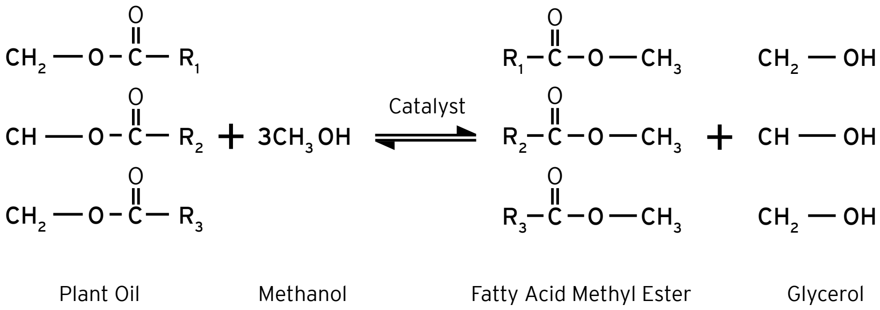
Chapter 5:

Production and Use of Methyl Ester

Biodiesel is technically defined as the fatty acid methyl ester or mono-alkyl esters derived from vegetable (plant) oils or animal fats and other biomass-derived oils that meet certain quality specifications[1]. The chemical conversion of plant oils to mono-alkyl esters is achieved through a process called transesterification. There are several methods available: acid-catalyzed, alkaline-catalyzed, enzyme-catalyzed, or non-catalyzed[2]. However, the use of alkaline catalyst is the most widely used method due to its short reaction time. An excess of methanol is normally required to complete the reaction above the stoichiometric ratio of 3 parts methanol to one part plant oil.

Production of Methyl Ester

During the process of transesterification, an alcohol (such as methanol) reacts with the triglyceride oils contained in plant oils, animal fats or recycled greases to form fatty acid alkyl esters (biodiesel) and glycerin. The reaction requires heat and a strong base catalyst such as sodium hydroxide or potassium hydroxide. The simplified chemical reaction is shown below.



Some types of feedstocks require pretreatment before they can go through the transesterification process. Feedstocks with less than 4% free fatty acids such as most plant oils and some food-grade animal fats do not require pretreatment. However, feedstocks with more than 4% fatty acids require pretreatment using an acid esterification process. These include inedible animal fats and recycled greases. In this pretreatment step, the feedstock is reacted with an alcohol (like methanol) in the presence of a strong acid catalyst (like sulfuric acid) to convert the free fatty acids into biodiesel. The remaining triglycerides are then converted to biodiesel through the usual transesterification reaction.

Triglycerides + Free Fatty Acids + Alcohol = Alkyl Esters + Triglycerides

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[1] Implementing rules and regulations of Republic Act No. 9367 (Biofuels Act of 2006), Philippines.

[2] Paweetida, S., Hiroi, J., Yoshikawa, K., Namioka, T., Basic Chemical Reaction Study on Biodiesel Fuel Production from Plant Oil, Tokyo Institute of Technology, paper presented at 2nd AUN SEEDNet Regional Conference on New and Renewable Energy, Thailand, January 2010.

The complete process for the production of methyl ester from plant oil and other feedstocks therefore involves basically five steps: acid esterification, transesterification, methanol recovery, biodiesel refining, and glycerin refining. The simplified process flow diagram is shown in Figure 5.1.

Acid Esterification. The oil feedstock containing more than 4% free fatty acids is usually pretreated using an acid esterification process to increase the yield of biodiesel. The feedstock is first filtered and then pre-processed to remove water and other contaminants such as unwanted solids. The pretreated oil is then fed to the acid esterification process. The catalyst, sulfuric acid, is dissolved in methanol and then mixed with the pretreated oil. The mixture is heated and stirred, and the free fatty acids are converted to biodiesel. Once the reaction is complete, it is dewatered and then fed to the transesterification process.

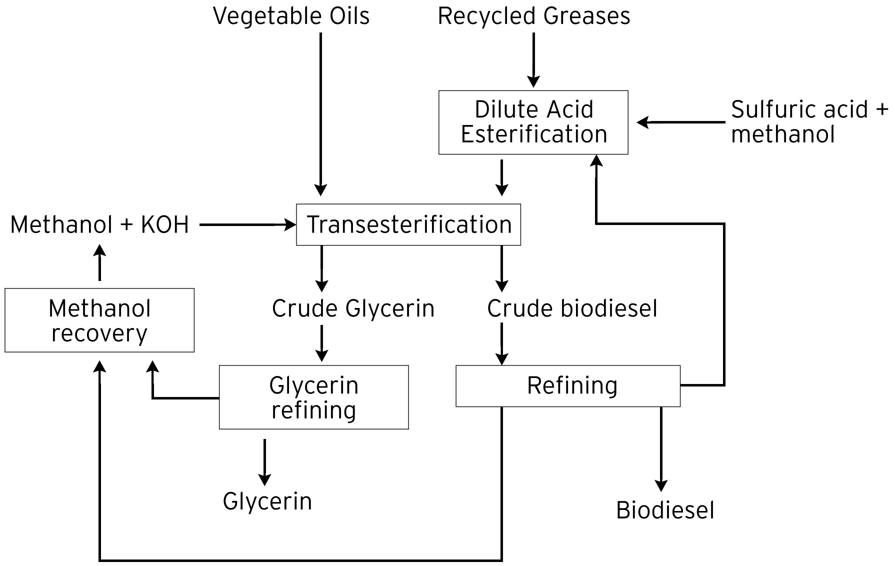
Transesterification. The plant oil, which contains less than 4% free fatty acids, is first filtered and then pre-processed to remove water and other contaminants. The pretreated oil is then fed directly to the transesterification process along with any products of the acid esterification process. The catalyst, potassium hydroxide, is dissolved in methanol and then mixed with the pretreated oil. If an acid esterification process is used, then additional alkaline catalyst must be added to neutralize any excess acid remaining from that step. Once the reaction is complete, the major co-products, biodiesel and glycerin, are separated into two layers.

Methanol recovery. The methanol is usually removed immediately after the biodiesel and glycerine have been separated. This is done to prevent the reaction from reversing itself. The recovered methanol is cleaned and recycled back to the beginning of the process.

Biodiesel refining. Once separated from the glycerin, the biodiesel goes through a series of cleaning-up or purification steps to remove excess alcohol, residual catalyst and soaps. These consist of multistage washings with clean water. The product biodiesel is then dried and sent to storage. If required, the product biodiesel can be further refined through an additional distillation step to produce a colorless, odorless, zero-sulfur, and premium quality biodiesel.

Glycerin refining. The crude glycerin from the transesterification process may be recovered or used in a fuel blend for steam production. The crude glycerin contains unreacted catalyst and soaps that must be neutralized with an acid. The water and alcohol are also removed to produce 50%-80% crude glycerin. The remaining contaminants include unreacted fats and oils. In large biodiesel plants, the glycerin can be further purified through a series of unit operations to produce a product of 99% or higher purity. This purified product is suitable for use in the pharmaceutical and cosmetic industries.

Figure 5.1 – Simplified process flow diagram for biodiesel production



A detailed process flow diagram for the production of biodiesel from mixed waste cooking oil is presented in Figure 5.2 while a detailed glycerin recovery process flow diagram is presented in Figure 5.3. The description of the various unit processes and unit operations involved is presented in Box 5.1. The process flow diagram and description are based on an existing commercially operating biodiesel plant in Japan that collects waste oils from restaurants and other food outlets to produce high quality biodiesel as transport fuel.[3]

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[3] Tanimoto, S., Production Process of Vegetable Diesel Oil, Kanazawa Institute of Technology, Japan, 2004.

Figure 5.2 – Production of biodiesel from mixed waste plant oils

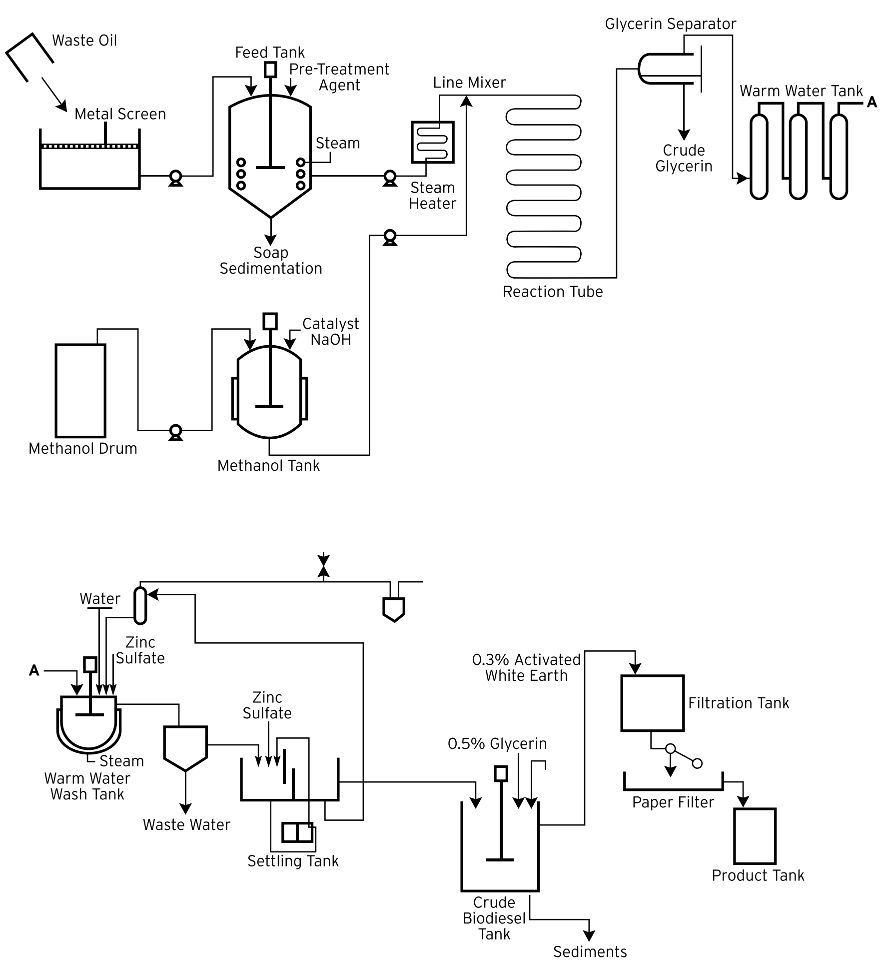
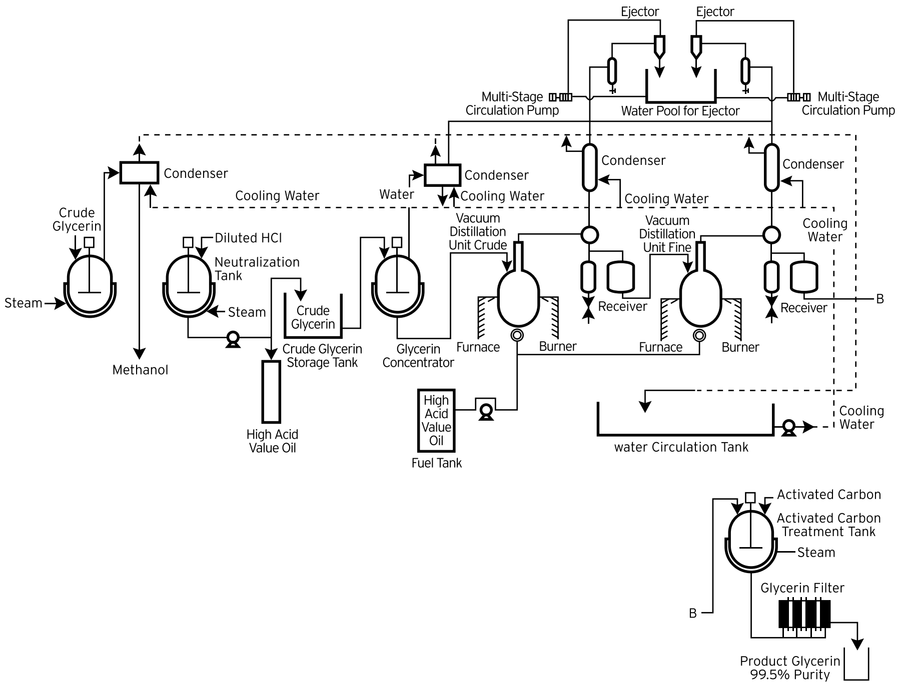


Figure 5.3 - Glycerin processing and recovery



Box 5.1 – Description of a biodiesel manufacturing process from waste oils

Pretreatment of waste mixed oils

The feedstock comprising a mixture of various waste plant oils recovered from restaurants and other sources is fed into a vessel with metal filter to remove undesirable materials. The filtered oil accumulates at the bottom of the vessel and is transferred by a gear pump to the Feed Tank up to the level of about 80% of the tank. The Feed Tank is then heated to 50^0-60^0C. A pre-treatment agent and 5-10% crude glycerin are added to prevent solidification of the oil and hasten the precipitation and sedimentation of soap particles. The mixture is agitated for about 20 minutes and then settled for about one hour. The soap sediment is removed from the bottom of the tank and the pre-treated oil fed into the esterification reactor.

Esterification process

Methanol and caustic soda, as catalyst, are mixed together in the Methanol Tank. Caution is necessary to ensure that not too much catalyst is added since the reaction is exothermic. Normally, the amount of caustic soda is about 4.7% of that of methanol, which is sufficient to raise the temperature of the mixture in the Methanol Tank to 50°C, still below the boiling temperature of methanol of 65°C. This mixture is pumped to the continuous esterification reactor to mix and react with the pre-treated feed oil.

Feed oil is first preheated to 70°C by passing it through a tube coil heater before it enters the esterification reactor. The preheated feed oil and the solution from the Methanol Tank are mixed through a line mixer and then reacted inside the continuous tube esterification reactor where the retention time is around 30 minutes and the temperature is kept under 60°C. The reaction products are sent to the Glycerin Separator where crude glycerin, which contains residual soap and methanol, is separated. The crude biodiesel is sent to the Warm Water Tanks and the Warm Water Wash Tank for further treatment and refining.

The Warm Water Wash Tank is heated by a steam jacket and equipped with an agitator. Zinc sulfate is added to the crude biodiesel in the Warm Water Wash Tank to destroy the emulsion and precipitate residual soap. The mixture then goes to the Warm Water Separator where the impurities are separated from the supernatant crude biodiesel. At this point the crude biodiesel still looks whitish and muddy due to residual water contaminants in emulsion. This crude product is sent to the Settling Tank to remove the contaminants. The recovered water from the Settling Tank is treated under vacuum to remove contaminants and then recycled back into the Warm Water Wash Tank.

The crude biodiesel is further treated in the Crude Biodiesel Tank by the addition of 0.5% glycerin as de-watering agent and 0.3% activated white earth as sedimentation agent. The solution is agitated for 15 minutes and settled overnight. The sediments are removed from the bottom and the treated supernatant is further refined through filtration in the Filtration Tank. Further cleaning is attained by a second stage filtration in a Paper Filter equipped with a float type level regulator. The refined biodiesel product is then placed in regular drums ready for delivery and use.

Glycerin processing and recovery

The crude glycerin from the Glycerin Separator is stored in the Neutralization Tank, which is glass-lined and equipped with a closed-type agitator. The crude glycerin is heated under normal pressure to distill out the methanol, which is recovered from the condenser located at the top of the Neutralization Tank. The remaining crude glycerin is neutralized by the addition of hydrochloric acid and the residual soap is converted into oil, which is removed from the upper layer. Crude glycerin is taken from the bottom of the Neutralization Tank and pumped first to the Crude Glycerin Tank and then to the Crude Glycerin Concentrator for further treatment. The crude oil that is skimmed off from the Neutralization Tank is burned as fuel for heating the Vacuum Distillation Unit. The Crude Glycerin Concentrator is equipped with steam-heated jacket and vacuum ejector to remove water from crude glycerin.

The crude glycerin is then sent to a two-stage Vacuum Distillation Unit where dissolved solids such as sodium chloride are removed (first stage) and 99.5% glycerin with a light yellow color is produced. This product is further refined in the Activated Carbon Treatment Tank to remove residual color. The amount of activated carbon needed to produce a product of acceptable quality is 2-3% of the amount of glycerin. The activated carbon is mixed with glycerin for 15 minutes at a temperature of 90°-100°C. The mixture is then passed through the Glycerin Filter to produce the final product of clear 99.5% glycerin.

Wastewater treatment

The wastewater effluents from the Warm Water Separator and Warm Water Wash Tank, which contain soap, sodium soap, and residual biodiesel, are accumulated in the Waste Water Storage Tank. Once the level in the tank reaches a certain point, the wastewater is automatically pumped to the Acid Treatment Tank where dilute hydrochloric acid is added to keep the pH at 2-3. After mixing for about 10 minutes, the mixture is allowed to stand to separate the oily phase (upper layer) from the aqueous phase (bottom layer). The treated water is withdrawn from the bottom of the tank and sent to the pH Control Tank where the pH is automatically adjusted to around pH 9 with the addition of dilute caustic soda before being discharged to the public sewerage system. The oily materials from the Acid Treatment Tank and the pH Control Tank are recovered and used as heating fuel for the production of process steam.

Source: Tanimoto, S., Production Process of Vegetable Diesel Oil, Kanazawa Institute of Technology, Japan, 2004.

Transesterification Process Developments

The conversion of triglycerides to simple alkyl esters with various alcohols reduces the high viscosity of oils and fats. As a result, they improve the injection process and ensure better atomization of the fuel in the combustion chamber. It has been shown that base catalysis of the transesterification with reagents such as sodium hydroxide is faster than acid catalysis[4]. Transesterification is a reversible reaction. For example, the transesterification of soybean oil with methanol or 1-butanol proceeded with pseudo-first order or second order kinetics, depending on the molar ratio of alcohol to soybean oil (30:1 pseudo-first order, 6:1 second order; NaOBu catalyst) while the reverse reaction was second order[5].

Methyl esters are the most commonly used esters as alternative fuel. One reason is the low price of methanol compared to other alcohols. The effect of the possible polymerization reaction is also decreased. Another advantage of the esters is more benign emissions, for example, with the removal of glycerol (which is separated from the esters) the formation of undesirable acrolein may be avoided. These reasons as well as ease and rapidity of the process are responsible for the popularity of the transesterification method for reducing the viscosity-related problems of plant oils. The popularity of methyl esters has contributed to the term "biodiesel" now usually referring to plant oil esters and not neat plant oils.

It was shown that in homogeneous catalysis, alkali catalysis is a much more rapid process than acid catalysis in the transesterification reaction[6, 7]. At 32^{0}C, transesterification was 99% complete in 4 h when using an alkaline catalyst (NaOH or NaOMe). At 60^{0}C and a molar ratio alcohol:oil of at least 6:1 and with fully refined oils, the reaction was complete in 1 h to give methyl, ethyl, or butyl esters. The reaction parameters investigated were molar ratio of alcohol to vegetable oil, type of catalyst (alkaline vs. acidic), temperature, reaction time, degree of refinement of the vegetable oil, and effect of the presence of moisture and free fatty acid. Although the crude oils could be transesterified, ester yields were reduced because of gums and extraneous material present in the crude oils.

Besides sodium hydroxide and sodium methoxide, potassium hydroxide is another common transesterification catalyst. Both NaOH and KOH were used in early work on the transesterification of rapeseed oil[8]. Recent work on producing biodiesel (suitable for waste frying oils) employed KOH. With the reaction conducted at ambient pressure and temperature, conversion rates of 80 to 90% were achieved within 5 minutes, even when stoichiometric amounts of methanol were employed[9]. In two steps, the ester yields are 99%. It was concluded that even a free fatty acid content of up to 3% in the feedstock did not affect the process negatively and phosphatides up to 300 ppm phosphorus were acceptable. In a study similar to previous work on the transesterification of soybean oil, it was concluded that KOH is preferable to NaOH in the transesterification of safflower oil[10, 11]. The optimal conditions were given as 1 wt-% KOH at 69 ± 1^{0}C with a 7:1 alcohol:vegetable oil molar ratio to give 97.7% methyl ester yield in 18 minutes.

Most patents dealing with transesterification emphasize the engineering improvement of the process. Using patented procedures, a transesterification process permitting the recovery of all byproducts, such as glycerol and fatty acids, has been described[12]. The use of alkaline catalysts is also preferred on the technical scale, as is documented by patents using sodium hydroxide, sodium methoxide, and potassium hydroxide[13, 14, 15]. Different esters of C_{9-24} fatty acids were prepared with Al_2O_3 or Fe_2O_3 containing catalysts[16]. A sulfonated ion exchange catalyst was preferred as catalyst in the esterification of free fatty acids[17].

Methyl and ethyl esters of palm and coconut oils were produced by alcoholysis of raw or refined oils using boiler ashes, H_2SO_4 and KOH as catalysts[18]. Fuel yields > 90% were obtained using alcohols with low moisture content and EtOH-H_2O azeotrope. Instead of using the extracted oil as starting material for transesterification, sunflower seed oils were transesterified in situ using macerated seeds with methanol in the presence of H_2SO_4[19]. Higher yields were obtained than from transesterification of the extracted oils. Moisture in the seeds reduced the yield of methyl esters. The cloud points of the *in situ* prepared esters appear slightly lower than those prepared by conventional methods.

Another study reported the synthesis of methyl or ethyl esters with 90% yield by reacting palm and coconut oil from the press cake and oil mill and refinery waste with MeOH or EtOH in the presence of easily available catalysts such as ashes of the waste of these two oilseeds (fibers, shell, husk), lime, zeolites, etc[20]. Similarly, it was reported that the methanolysis of vegetable oils is catalyzed by ashes from the combustion of plant wastes such as coconut shells or fibers of a palm tree that contain K_2CO_3 or Na_2CO_3 as catalyst[21]. Thus the methanolysis of palm oil by refluxing 2 h with MeOH in the presence of coconut shell ash gave 96-98% methyl esters containing only 0.8-1.0% soap. The ethanolysis of vegetable oils over the readily accessible ash catalysts gave lower yields and less pure esters than the methanolysis.

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Several catalysts (CaO, K_2CO_3, Na_2CO_3, Fe_2O_3, MeONa, $NaAlO_2$, Zn, Cu, Sn, Pb, ZnO, and *Dowex 2X8* (anion exchange resin)) were tested (mainly at 60-63°C) for catalytic activity in the transesterification of low-erucic rapeseed oil with MeOH[22]. The best catalyst was CaO or MgO. At 200°C and 68 atm, the anion exchange resin produced substantial amounts of fatty methyl esters and straight-chain hydrocarbons. An enzymatic transesterification method utilizing lipases and methanol, ethanol, 2-propanol, and 2-methyl-1-propanol as alcohols gave alkyl esters of fatty acids[23]. This method eliminates product isolation and waste disposal problems.

Among the recent developments in the transesterification of plant oils is a new process called "advanced dry biodiesel production process"[24 25]. This process has the following advantages over the conventional alkaline transesterification process: (a) oil with high free fatty acid and water content can be used as feedstock; (b) high conversion efficiency of over 99.5% can be achieved in a single-stage reaction (compared to 90-95% conversion efficiency in the conventional process) using nearly theoretical amount of methanol (15% compared to 30% in conventional process) and catalyst (1.5% KOH compared to 3% NaOH in the conventional process); (c) no waste water is produced; and (d) high quality biodiesel can be produced at relatively low temperature (water content <200 ppm). Commercial plants using the advanced dry biodiesel production process of up to 5,000 liters per day of product are now in successful operation in Japan.

Biodiesel Production Commercial Plant (200-liter batch)

Source: Yoshikawa, K., The Industry of Biodiesel, 2nd AUN SEEDNet Regional Conference on New and Renewable Energy, Thailand, January 2010.

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Biodiesel Production Commercial Plant (2,000-5,000 liter/day)

Source: Yoshikawa, K., The Industry of Biodiesel, 2nd AUN SEEDNet Regional Conference on New and Renewable Energy, Thailand, January 2010.

Biodiesel Properties, Standards and Use

Table 5.1 presents the fuel properties (e.g., cetane number, heating value, viscosity, etc.) of methyl and ethyl esters produced from several plant oils (e.g., cottonseed, sunflower, palm, soybean, etc.). Table 5.2 presents a comparison between the national standards for commercial biodiesel in several countries[26]. It shows that France has the most stringent requirement in as far as water content of the biodiesel product is concerned at less than 200 mg/kg. Summarized in Box 5.2 are the relevant provisions accompanying the implementation of the Philippine National Standards (PNS) for the commercial use of biodiesel in the Philippines.

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[26] The Philippine National Standards (PNS) is presented in Chapter 1.

Table 5.1 – Fuel properties of esters

Ester	CN	HV (kJ/kg)	Viscosity (mm^2/s)	CP (°C)	PP (°C)	FP[1] (°C)
			Methyl			
Cottonseed[2]	51.2	-	6.8 (21°C)	-	-4	110
Rapeseed[3]	54.4	40,449	6.7 (40°C)	-2	-9	84
Safflower[4]	49.8	40,060	-	-	-6	180
Soybean[5]	46.2	39,800	4.08 (40°C)	2	-1	171
Sunflower[6]	46.6	39,800	4.22 (40°C)	0	-4	-
Tallow[7]	-	39,949	4.11 (40°C)	12	9	96
			Ethyl			
Palm[8]	56.2	39,070	4.5 (37.8°C)	8	6	19
Soybean[5]	48.2	40,000	4.41 (40°C)	1	-4	174
Tallow[9]	-	-	-	15	12	-

CN = cetane number, CP = cloud point, PP = pour point, FP = flash point.

1. Some flash points are very low. These may be errors in the references or the materials may have contained residual alcohols when tested.
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Source: Biodiesel: The Use of Vegetable Oils and Their Derivatives as Alternative Diesel Fuels, G. Knothe, R.O. Dunn, and M.O. Bagby, in Fuels and Chemicals from Biomass. Washington, D.C.: American Chemical Society.

Table 5.2 – Comparison of national standards for biodiesel

	Europe	Austria	Czech Republic	France	Germany	Italy	Sweden	USA	Australia
Standard/ Specification	EN 14214	ON C1191	CSN 65 6507	Journal Officiel	DIN V 51606	UNI 10635	SS 155436	ASTM D-6751	Fuel Standard (Biodiesel) Determination
Date	2003	Jul 1997	Sep 1998	Sep 1997	Sep 1997	Apr 1997	Nov 1996	Jan 2002	Sep 2003
Application	FAME	FAME	RME	VOME	FAME	VOME	VOME	FAMAE	-
Density (15°C g/cm)	0.86-0.90	0.85 - 0.89	0.87 - 0.89	0.87 - 0.90	0.875 - 0.90	0.86-0.90	0.87 - 0.90	-	860 to 890 kg/m3
Viscosvity at 40°C (mm^2/s)	3.5-5.0	3.5-5.0	3.5-5.0	3.5-5.0	3.5-5.0	3.5-5.0	3.5-5.0	1.9-6.0	3.5-5.0
Distillate. 95% (°C)	-	-	-	<360	-	<360	-	90% @ 360°C	<360
Flashpoint (°C)	>120	>100	>110	>100	>110	>100	>100	>130 (150 av.)	>120
CFPP (°C) cold filter plugging point	*country specific	0/-15	-5	-	0/-10/-20	-	-5	-	-
Pour point (°C)	-	-	-	<-10	-	<0 / <-15	-	-	-
Sulfur (% mass)	<10 mg/kg	<0.02	<0.02	-	<0.01	<0.01	<0.001	<0.05	50 mg/kg (max) 10 mg/kg (max) (from 1 Feb 2006)
CCR 100% (% mass)	-	<0.05	<0.05	-	<0.05	-	-	-	-
10% dist. resid. (% mass)	<0.3	-	-	<0.3	-	<0.5	-	-	-
Sulfated ash (% mass)	<0.02	<0.02	<0.02	-	<0.03	-	-	<0.02	<0.02
(Oxid) Ash (% mass)	-	-	-	-	-	<0.01	<0.01	-	-
Water (mg/kg)	<500	-	<500	<200	<300	<700	<300	<0.05% vol. (water & sediment)	<0.05% vol (water & sediment)
Total contam. (mg/kg)	<24	-	<24	-	<20	-	<20	-	<24
Cu-Corros. 3h/50°C	1	-	1	-	1	-	-	<No.3	<10 mg/kg sulfur Class 1 (max) >10 mg/kg sulfur No. 3 (max)
Oxidation stability at 110°C (hrs)	6 hours min	-	-	-	-	-	-	-	6 hours min
Cetane No.	>51	>49	>48	>49	>49	-	>48	>47	>51
Neutral. No. Acid value (mg KOH/g)	<0.5	<0.8	<0.5	<0.5	<0.5	<0.5	<0.6	<0.8	<0.8

	Europe	**Austria**	**Czech Republic**	**France**	**Germany**	**Italy**	**Sweden**	**USA**	**Australia**
Standard/ Specification	EN 14214	ON C1191	CSN 65 6507	Journal Officiel	DIN V 51606	UNI 10635	SS 155436	ASTM D-6751	Fuel Standard (Biodiesel) Determination
Date	2003	Jul 1997	Sep 1998	Sep 1997	Sep 1997	Apr 1997	Nov 1996	Jan 2002	Sep 2003
Application	FAME	FAME	RME	VOME	FAME	VOME	VOME	FAMAE	-
Methanol (% mass)	<0.20	<0.20	-	<0.1	<0.3	<0.2	<0.2	-	<0.2
Ester content (% mass)	>96.5	-	-	>96.5	-	>98	>98	-	>96.5
Monoglyceride. (% mass)	<0.8	-	-	<0.8	<0.8	<0.8	<0.8	-	-
Diglyceride (% mass)	<0.2	-	-	<0.2	<0.4	<0.2	<0.1	-	-
Triglyceride (% mass)	<0.2	-	-	<0.2	<0.4	<0.1	<0.1	-	-
Free glycerol (% mass)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.05	<0.02	<0.02	<0.02
Total glycerol (% mass)	<0.25	<0.24	<0.24	<0.25	<0.25	-	-	<0.24	<0.25
Iodine No.	<120	<120	-	<115	<115	-	<125	-	-
Linolenic acid ME (%mass)	<12	-	-	-	-	-	-	-	-
C18:3 and high. unsat.acids (% mass)	-	<15	-	-	-	-	-	-	-
C(x:4) & greater unsaturated esters (% mass)	<1	-	-	-	-	-	-	-	-
Phosphor (mg/kg)	<10	<20	<20	<10	<10	<10	<10	<0.001% mass	<10
Ramsbottom carbon residue (% mass)	-	-	-	-	-	-	-	0.10	-
Carbon residue	-	-	-	-	-	-	-	<0.050% by mass	<0.30% mass (10% distillation residue) <0.050% mass (100% distillation sample)
Gp I metals Na,K (mg/kg)	<5	-	-	-	-	-	-	-	<5
Gp II metals Ca,Mg (mg/kg)	<5	-	-	-	-	-	-	-	<5
Alkalinity (mg/kg)	-	-	<10	<5	<5	-	<10	-	-

RME: Rapeseed oil methyl ester
FAME: Fatty acid methyl ester
VOME: Vegetable oil methyl ester
FAMAE: Fatty acid mono alkyl ester

US standard -- D6751-02 Standard Specification for Biodiesel Fuel (B100) Blend Stock for Distillate Fuels.
<http://www.astm.org/cgi-bin/SoftCart.exe/STORE/filtrexx40.cgi?U+mystore+mofc8213+-L+D6751+/usr6/htdocs/astm.org/DATABASE.CART/PAGES/D6751.htm>

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Australian standard: <http://www.deh.gov.au/atmosphere/biodiesel/index.html>

Source: Biodiesel: The Use of Vegetable Oils and Their Derivatives as Alternative Diesel Fuels, G. Knothe, R.O. Dunn, and M.O. Bagby, in Fuels and Chemicals from Biomass. Washington, D.C.: American Chemical Society.

Box 5.2 – Relevant rules to implement Philippine standards for biodiesel

Rule 23. Biofuel Standards (of the Rules and Regulations Implementing Republic Act No. 9367, otherwise known as the Biofuels Act of 2006)

23.1 Quality Standards

All biofuel and the biofuel blend qualified under the Act shall be limited to those compliant with the PNS.

Facilities for the production, handling, distribution and storage shall likewise conform to standards and guidelines set by the DOE.

23.2 Quality Assurance

All biofuel producers shall assure compliance with quality standards in accordance with the following guidelines:

(a) All biofuel deliveries must be accompanied by a Certificate of Quality indicating the level of its properties in compliance with the PNS.

(b) Biofuels packaged in individual containers shall be appropriately labeled and shall contain information such as DOE Accreditation No., batch manufacturing date, and expiry date, in accordance with existing guidelines that will be issued by the DOE.

(c) Establish and implement quality assurance system within a compliance period to be set by the DOE which may cover the following:
  i. Quality Management System of ISO 9000 standards
  ii. Environmental Management System or ISO 14000 standards
  iii. Occupational Safety and Health Compliance standards

DOE – Department of Energy created under Republic Act No. 7638, as amended.

PNS – Philippine National Standards consistent with Section 26 of R.A. No. 8749, otherwise known as the "Philippine Clean Air Act of 1999"

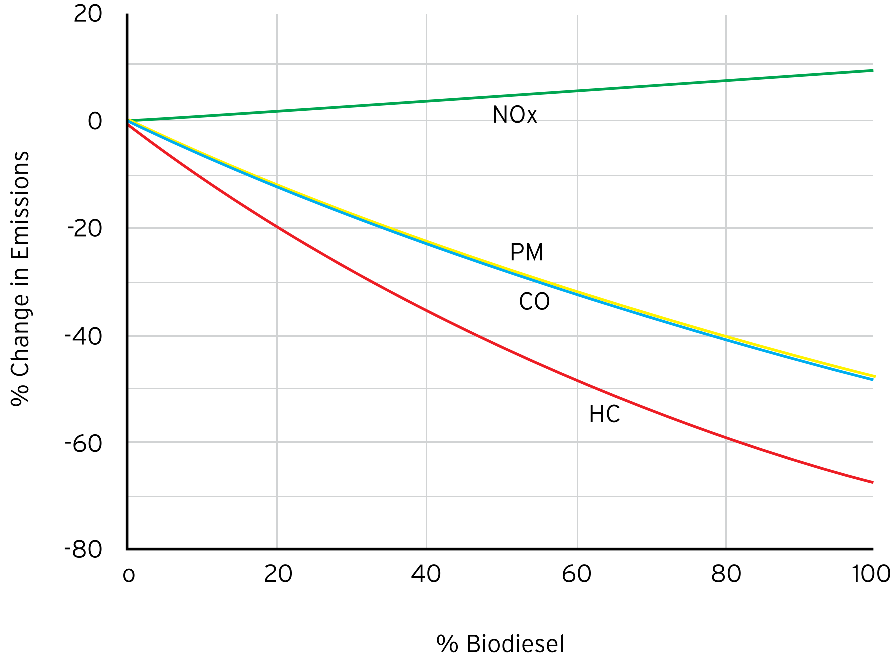
The interest in biodiesel as an alternative transportation fuel stems mainly from its renewable, domestic production, its safe, clean-burning properties, and its compatibility with existing diesel engines. Biodiesel can be blended with petroleum diesel in any percentage. The percentages are designated as B1 for a blend containing 1% biodiesel and 99% petroleum diesel, B20 for a blend containing 20% biodiesel and 80% petroleum diesel, B100 for 100% biodiesel, and so forth. When biodiesel is blended with petroleum diesel, it produces a fuel that is compatible with diesel engines, displaces imported petroleum, and reduces harmful emissions. Even the use of as little as 0.25% biodiesel, which is very low in sulfur, can significantly increase fuel lubricity. Thus blends like B2 and B5 are becoming increasingly popular for this reason. In the Philippines, the use of B1 and B2 is mandated by legislation. The most acceptable biodiesel blends are those in the range of B20 and below. The use of B20 and below provides substantial benefits associated with the use of biodiesel but avoids many of the cold-weather performance and material compatibility concerns associated with B100. B20 and lower-level blends can be used in nearly all diesel equipment, is compatible with most storage and distribution equipment, and generally do not require engine modifications.

Biodiesel contains about 8% less energy per unit volume than petroleum diesel. For B20, this could mean a 1% to 2% difference, but most B20 users report no noticeable difference in performance or fuel economy. However, as biodiesel blend levels increase significantly beyond B20, a number of concerns come into play. Users must be aware of lower energy content per liter and potential issues with impact on engine warranties, low-temperature gelling, solvency/cleaning effect if regular diesel was previously used, and microbial contamination.

Compared with using petroleum diesel, using biodiesel in a conventional diesel engine substantially reduces emissions of unburned hydrocarbons (HC), carbon monoxide (CO), sulfates, polycyclic aromatic hydrocarbons, nitrated polycyclic aromatic hydrocarbons, and particulate matter (PM). The reductions increase as the amount of biodiesel blended into diesel fuel increases. B100 provides the best emission reductions, but lower-level blends also provide benefits. B20 has been shown to reduce PM emissions 10%, CO 11%, and unburned HC 21%, as shown in Figure 5.4. Using biodiesel also reduces greenhouse gas emissions because carbon dioxide released from biodiesel combustion is offset by the carbon dioxide sequestered while growing the soybeans or other feedstock. B100 use reduces carbon dioxide emissions by more than 75% compared with petroleum diesel. Using B20 reduces carbon dioxide emissions by 15%.

Biodiesel is nontoxic, so it causes far less damage than petroleum diesel if spilled or otherwise released to the environment. It is also safer than petroleum diesel because it is less combustible. The flashpoint for biodiesel is higher than 150°C, compared with about 52°C for petroleum diesel. Biodiesel is safe to handle, store, and transport. Biodiesel is a domestically produced, clean-burning, renewable substitute for petroleum diesel. Using biodiesel as a vehicle fuel increases energy security, improves public health and the environment, and provides safety benefits.

Figure 5.4 – Average emission impacts of biodiesel for heavy-duty highway engines



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Chapter 6:

Production and Use of Microemulsified Hybrid Fuel

Many properties of plant oils resemble those of diesel fuel, except that they have high viscosity and low volatility. High viscosity makes direct injection into diesel engines difficult while low volatility causes serious combustion problems. These disadvantages, particularly high viscosity, limit the use of plant oils as a substitute for diesel fuel. But there are three ways to reduce viscosity and make the plant oil more suitable as a diesel substitute, namely, by heating, transesterification, and microemulsification. The viscosity of plant oil can be reduced by heating it to sufficiently high temperatures but this involves many practical and operational difficulties and increases the cost significantly. Accordingly, this method has not received wide acceptance and application although there are examples of successful commercial applications[1]. The transesterification of plant oils to produce alkyl esters, in particular methyl ester or biodiesel, has found the widest commercial application for blending with diesel fuel[2].

Plant oils can be made a more suitable substitute for diesel fuel through microemulsification[3] [4]. This is done by blending plant oil with diesel and/or various types of alcohols in the presence of suitable additives such as surfactants or surface active agents. Plant oil is mixed with alcohols, diesel fuel, petrol, surfactants, cetane improvers, water (often as a component of an aqueous alcohol) and solvents in varying mixes and proportions to form a microemulsion or blend. Short chain alcohols such as 1, 2, or 3-butanol are the most effective agents for reducing viscosity of plant oils, although ethanol and methanol can also be used. The resulting fuel has been found to be more suitable than straight plant oil for operation in diesel engines.

Production of Hybrid Fuels

Fuels produced using microemulsification technology are called "hybrid fuels". They are called ionic or non-ionic depending on the type of surfactant present. For example, those hybrid fuels containing a basic nitrogen compound are termed ionic while those consisting only of plant oil, aqueous ethanol, and another alcohol, such as 1-butanol, are termed non-ionic or detergentless microemulsions, referring to the absence of a surfactant. Mixtures of hexadecane, 1-butanol, and 95% ethanol are examples of detergentless microemulsions. C_1 to C_3 alcohols (methanol, ethanol, propanol) are used as viscosity-lowering additives while longer chain alcohols and alkylamines serve as surfactants. For example, *n*-butanol is claimed to produce microemulsions that are more stable and have lower viscosity than those made with methanol or ethanol[5]. Surfactants are important constituents in the production of microemulsified hybrid fuels. They increase the solubility of diesel-plant oil-water blends producing single phase, homogeneous mixtures.

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[1] The dual fuel tank system such as the Greasecar Vegetable Oil Conversion System presented in Chapter 4 is one example.

[2] The production and use of methyl ester is discussed in Chapter 5.

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Various formulations of hybrid fuels have been tested in engines using the 200-hr Engine Manufacturers Association (EMA) test. A microemulsion fuel containing soybean oil, methanol, 2-octanol, and a cetane enhancer was the cheapest vegetable oil fuel ever to pass the EMA test[6]. Goering found that eight parts of soybean oil, when emulsified with two parts ethanol and five parts of 1-butanol as stabilizer, performed as well as diesel fuel and was able to start a cold engine[7]. Two studies of palm oil, diesel fuel and 5-10% water microemulsions revealed performance comparable to diesel fuel with less engine wear[8] [9]. Sapaun et al reported that studies in Malaysia with palm oil as diesel fuel substitutes exhibited encouraging results. Performance tests indicated that power outputs were nearly the same for 100% palm oil, blends of palm oil and diesel fuel, and 100% diesel fuel. Short-term tests using palm oil fuels showed no signs of adverse combustion chamber wear, increase in carbon deposits, or lubricating oil contamination[10].

Using the same EMA 200-hour engine screening test, several fuels showed technical promise with performance comparable to that of diesel fuel[11]. These include the following blends: (a) diesel:soybean oil:butanol:cetane improver (33:33:33:1); (b) diesel:soybean oil:190 proof ethanol:butanol, (50:25:5:20); and (c) soybean oil:methanol:2-octanol:cetane improver, (53:13:33:1). The fuel injection characteristics were also studied and recorded using a pressure vessel, fuel injection system, and high speed motion picture camera, in a quiescent nitrogen atmosphere at 480^{0}C and a pressure of 4.1MPa. It was observed that the injection and atomization characteristics were markedly different from those of diesel fuel. Heating the vegetable oils to lower their viscosities increased spray penetration rate, reduced spray cone angles, and resulted in spray characteristics that more closely resembled those of diesel fuel. Significant chemical changes occurred following injection such that appreciable amounts of C_4-C_{16} hydrocarbons and free carboxyl groups were detected at about 400 microseconds after injection.

Unsaturated fatty acids are used to produce microemulsions of alcohols with diesel fuel since saturated fatty acids produce unsatisfactory results because of the formation of crystalline phases upon refrigeration[12]. The addition of n,n-dimethylamino ethanol (DMAE) produces microemulsions with satisfactory viscosity. Two types of fuels were tested, one ionic and another non-ionic: (a) 66.7% diesel fuel, 16.7% ethanol (95%), 12.5% soybean acids, and 4.1% DMAE (ionic); and (b) 66.7% diesel fuel, 11.1% ethanol (95%), and 22.2% 1-butanol (non-ionic)[13]. Both hybrid fuels gave acceptable performance with improved brake thermal efficiency and lower exhaust temperatures. Smoke and CO levels were lower but the unburned hydrocarbon levels were higher compared to pure diesel fuel. The non-ionic microemulsion was superior to the ionic one in those properties relevant to good engine performance but the ionic hybrid fuel showed better water tolerance. A hybrid fuel consisting of 50% diesel fuel, 25% degummed, alkali-refined soybean oil, 5% aqueous ethanol (95%) and 20% 1-butanol was studied by the same group of researchers using the 200-hr EMA (Engine Manufacturers Association) test. The engine running on this hybrid fuel completed the EMA test without difficulty, causing less engine wear than diesel fuel but producing greater amounts of carbon and lacquer on the injector tips, intake valves and tops of the cylinder liners. The engine performance declined by 5% at the end of the test.

Microemulsified hybrid fuels using plant oils but without diesel fuel have also been widely studied. A hybrid fuel comprising a plant oil, a lower (C_1-C_3) alcohol, water, and a surfactant system consisting of a trialkylamine or the reaction product of a trialkylamine with a long-chain fatty compound was reported[14]. In another patent, a hybrid fuel was produced using a plant oil, a C_1-C_3 alcohol, water, and 1-butanol as nonionic surfactant[15]. This formulation produced a hybrid fuel with acceptable viscosity and compared favorably to diesel fuel in terms of engine performance. Another hybrid fuel formulation consisted of a plant oil, methanol or ethanol, a straight-chain isomer of octanol, and water, which again exhibited high water tolerance, acceptable viscosity and performance comparable to diesel fuel[16]. Another patent reported the formulation of a hybrid fuel from degummed rapeseed oil, water, and a surfactant such as an alkaline soap or a potassium salt of fatty acids[17]. Another reported hybrid fuel formulation consisted of fatty esters, aqueous alcohol, and small amount of alkali metal soap[18]. All these microemulsified hybrid fuels showed acceptable performance comparable to that of diesel fuel.

Two other hybrid fuels were tested[19]. One was non-ionic consisting of 53.3% soybean oil, 13.3% aqueous ethanol (95%) and 33.4% 1-butanol and the other was ionic composed of 52.3% soybean oil, 17.4% aqueous ethanol (95%), 20.5% 1-butanol, 6.54% linoleic acid and 3.27% triethylamine. The two hybrid fuels performed nearly as well as diesel fuel despite their lower cetane numbers and less energy content. The non-ionic hybrid fuel produced nearly as much engine power as pure diesel fuel. The higher viscosity of the hybrid fuels produced a 16% increase in the mass of each fuel injection at maximum power, but the injections contained 6% less energy than those of diesel fuel. However, there was a 6% gain in thermal efficiency. In contrast, in a separate study, a non-ionic

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microemulsified hybrid fuel comprising of alkali-refined, winterized sunflower oil (53.3%), 95% aqueous ethanol (13.3%) and 1-butanol (33.4%) encountered major problems of incomplete combustion at low-load engine operation[20]. In addition, carbon residues were deposited on the piston ring grooves and in the intake ports, and premature injection nozzle deterioration was experienced.

Box 6.1 – Microemulsions from vegetable oil and lower alcohol with octanol surfactant as alternative fuel for diesel engines

We claim:

1. A hybrid fuel composition comprising: (a) a vegetable oil; (b) a lower alcohol selected from methanol and ethanol; (c) optionally, water; and (d) a surfactant comprising a straight-chain isomer of octanol; wherein said octanol surfactant is present in the fuel composition in an amount effective for said composition to exist as a thermodynamically stable microemulsion and the combined amounts of lower alcohol, water, and surfactant relative to said vegetable oil are sufficient to impart to said composition a kinematic viscosity in the range of 2-9 centistokes at 37.8° C.

2. A hybrid fuel composition as described in claim 1 wherein said vegetable oil is selected from the group consisting of soybean, corn, rapeseed, sesame, cottonseed, crambe, sunflower seed, peanut, linseed, safflower, high oleic safflower, and triolein.

3. A hybrid fuel composition as described in claim 1 wherein said lower alcohol is methanol or ethanol.

4. A hybrid fuel composition as described in claim 1 wherein the ratio of lower alcohol:water is about 19:1.

5. A hybrid fuel composition as described in claim 1 wherein said surfactant is 1-octanol or 2-octanol.

SUMMARY OF THE INVENTION

We have now developed a vegetable oil-based hybrid fuel for diesel engines characterized by a critical solution temperature as low as -10° C in the presence of more than 1% water. The fuel is a detergentless microemulsion in which either an anhydrous or aqueous lower alcohol is dispersed in the oil by means of a straight-chain octanol serving as a single-component nonionic surfactant. Despite the absence of an ionic emulsifier, these microemulsions display all the desirable physical and chemical properties exhibited by those hybrid fuels heretofore formulated with multicomponent detergent systems.

In accordance with this discovery, it is an object of the invention to convert crude vegetable oil into a fuel suitable for diesel engines without alteration of its chemical structure. It is also an object of the invention to prepare an economically attractive vegetable oil-based fuel which lends itself to on-the-farm blending. Another object of the invention is to prepare a nonpetroleum alternative diesel fuel which is tolerant to relatively high levels of water even at temperatures below 0°C. A further object of the invention is to produce a totally nonionic microemulsion fuel free of corrosive emulsifiers.

DETAILED DESCRIPTION OF THE INVENTION

The base vegetable oils for use in the fuels of the invention are the commonly available vegetable triglycerides. In terms of high cetane rating, long induction period, low viscosity, low cloud point, and low pour point, the preferred oils are soybean, corn, rapeseed, sesame, and cottonseed. However, others including crambe, sunflower, peanut, linseed, safflower, and high oleic safflower would be operative. While it is contemplated that these oils be employed in the crude state as originally expressed from the seed material, there are advantages to subjecting them to certain preliminary processing steps. For example, winterization to remove the saturated fatty acid triglycerides extends the lower end of the operable temperature range. Alkali refining removes the free fatty acids thereby reducing corrosivity and the tendency to pick up metal ions that promote oxidative instability. Degumming is desirable for reduced tendency to deposit gummy residues, enhanced atomization, and inhibition of injector fouling. Viscosities of the aforementioned oils when degummed and alkali-refined typically range from about 27 centistokes (cSt, mm^2/s) at 37.8°C for linseed oil to about 54 cSt for crambe oil. Other properties related to the performance of these oils as engine fuels have been summarized by Goering, supra. Synthetic counterparts of the natural oils such as triolein are also considered to be within the scope of the term "vegetable oils" for purposes of the invention.

The lower alcohols contemplated for hybridizing with the vegetable oil include methanol and ethanol. The alcohol may be anhydrous or aqueous. In its aqueous form the alcohol is a convenient source of water.

The surfactant contemplated herein may be any of the straight-chain isomers of octanol to include 1-octanol, 2-octanol, 3-octanol, and 4-octanol.

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Its function is to convert the mixture of vegetable oil, lower alcohol, and any water, either associated with the alcohol or otherwise introduced into the fuel formulation, to a microemulsion without the need for an ionic detergent. The relative proportions of these components, as well as the particular selection of vegetable oil and octanol isomer, will determine the properties of the final fuel composition. In formulating the hybrid fuels of the invention, primary consideration is given to microemulsion stability and viscosity. Acceptable viscosities would typically be in the range of about 2-9 cSt at 37.8°C. The microemulsion stability is a function of the water tolerance. While 1-octanol and 4-octanol are the best in terms of critical solution temperature, 2-octanol is currently preferred in terms of availability and economics. 2-octanol has a cetane number of approximately 30. Other pertinent properties to consider in formulating the instant fuels relate to engine performance, including cetane number, power output, brake thermal efficiency, and the like.

In regard to the proportion of the oil in the hybrid fuel formulations, the upper limit will be set by the maximum tolerable viscosity (about 9 cSt at 37.8°C), and the lower limit by engine performance. For most of the aforementioned vegetable oils, the level of addition will typically be within the range of about 40-70% by volume. The remainder of the composition comprises the lower alcohol, the octanol, and water in any combination yielding a microemulsion which is stable at or above a predetermined temperature and which is characterized by an acceptable viscosity. If water is intentionally added for the purpose of enhancing the fuel's combustion properties, it should be incorporated in an amount of at least about 0.1%. This level can be achieved by direct addition or by means of the addition of 2% of 95% aqueous alcohol or 0.5% of 80% aqueous alcohol. Within the confines of these parameters, the properties of the hybrid fuels can be tailored to satisfy a multitude of conditions. For example, as the proportion of vegetable oil to water and/or lower alcohol is increased, the cetane number increases. As the relative amount of water to lower alcohol decreases, particularly at the higher ratios of vegetable oil to lower alcohol, or as the octanol level increases, the viscosity decreases. Also, reduction of the water:lower alcohol ratio enhances the tolerance of the system to phase separation, thereby either permitting the use of less surfactant, or allowing the ratio of lower alcohol to vegetable oil to be increased.

The order of adding the fuel constituents to one another is not particularly critical. Though the microemulsions will form spontaneously without mixing, any conventional means of simple agitation such as gentle stirring or shaking will expedite the process.

The actual physical structure of a detergentless microemulsion is unknown. However, in the context of the present system, it can be thought of as the presence of an interphase separating submicroscopic droplets of the lower alcohol and/or water in the discontinuous phase from the vegetable oil in the continuous phase. The presence of a microemulsion is readily ascertained by standard methods of rheology, light scattering, ultracentrifugation, conductivity, refractivity, and density.

The cetane value of the hybrid fuels of the invention varies with the amount of vegetable oil. Typically these fuels will have cetane numbers lower than the minimum ASTM specification of 40 for No. 2 diesel oil without adverse effect on engine performance. This is presumably attributable to the presence of the water. However, it is envisioned that cetane improvers such as primary alkyl nitrates and other fuel additives may be included in the instant formulations in minor amounts without significant adverse effect on the microemulsion's stability. The critical solution temperatures of the present fuels are dependent upon the specific formulation, but may be as low or even lower than -14°C.

ENGINE TESTING

The fuel was tested in a 4-cylinder "John Deere" model 4219D, 3.589-L turbocharged diesel engine rated at 41.8 kW continuous at 2,200 rev/min and having a compression ratio of 16.3:1.

An AW model 400 portable, cradled dynamometer was used to provide engine loads. Fuel consumption was measured through use of an automated weighing system. Temperatures at critical points including the exhaust gas, coolant, return fuel, lubricating oil in the pan, and air in the intake manifold were monitored with chromel-alumel thermocouples and with a digital indicator.

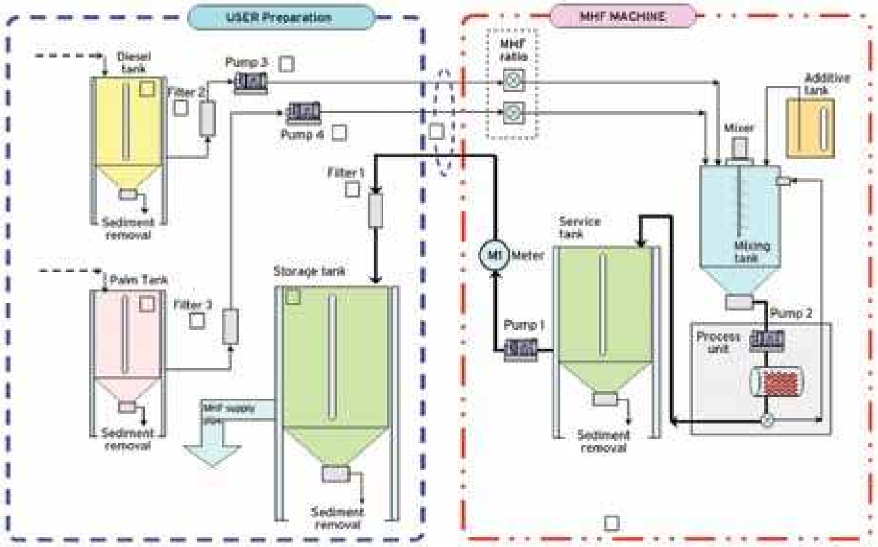
Commercial grade No. 2 diesel fuel was used as a reference fuel. Following a break-in period, the engine was subjected to an initial performance test with each fuel over a wide range of speeds. Torque, speed, fuel consumption, critical temperatures, atmospheric conditions, and blowby were observed at each engine load. The fuels were thereafter evaluated in accord with the Engine Manufacturer's Association (EMA) test sequence.

Source: United States Patent No. 4557734. Inventors: Schwab, Arthur W. and Pryde, Everett H. Publication Date: 12/10/1985

The NES Microemulsification Technology[21]

MHF is produced by physically blending and microemulsifying various ratios of plant oil with diesel fuel in the presence of an additive, which could be composed of cetane enhancers, viscosity reducers and/or emulsifiers. A blend of 30% plant oil and 70% diesel fuel is called MHF30 while a blend of 50% plant oil and 50% diesel fuel is called MHF50 and so forth. Different types of plant oils can be used such as palm oil, jatropha oil, coconut oil and others as well as recycled mixed waste cooking oil. Figure 6.1 shows a schematic process flow diagram for the production of microemulsified hybrid fuel. Plant oil and diesel in the desired ratio are pumped from their respective storage tanks through micro-filters (around 10 microns) into the MHF machine where they are mixed together with a small amount of proprietary additive (less than 1%). The mixture is then recirculated through a proprietary reactor for about two hours before it is discharged into a service tank where it remains quiescent to allow the removal of any residual sediment. The supernatant liquid is then again pumped through micro-filters (around 5 microns) before being sent into the final storage tank ready for delivery and use.

Figure 6.1 – Process flow chart of MHF processing plant



Source: Technical bulletin, Nippon Ecosolutions, Inc.

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[21] Sakamoto, A. and Uriarte, F. A. Jr., Production of Microemulsified Hybrid Fuel, Nippon Ecosolutions, Ltd., Japan, and LAUDS Technologies, Inc., Philippines, 2007.

External view of the NES MHF Machine capable of producing 1,000 liters per hour of product.
(Photo by Nippon Ecosolutions, Ltd.)

View inside the NES MHF Machine showing its various parts and components.
(Photo by Nippon Ecosolutions, Ltd.)

Samples of palm olein (left) and MHF100 (right)
(Photo by LAUDS Technologies, Inc.)

The core of the technology is the ability to produce particles in the range of 1-2 microns in size compared to the conventional technology that produces particles in the range of 10-20 microns. By producing much smaller and more uniform dispersion, the combustion efficiency is greatly enhanced resulting in much improved engine performance. This is illustrated in Figure 6.2. When the particles of the fuel spray are large, the combustion is less efficient, and when the particles are of varying sizes, the power delivered is lower since the fuel particles do not burn at exactly the same time. Actual fuel injection spray tests show that the spray produced using palm oil MHF50 have very fine droplets or particles.

Figure 6.2 – Spray pattern inside an engine cylinder

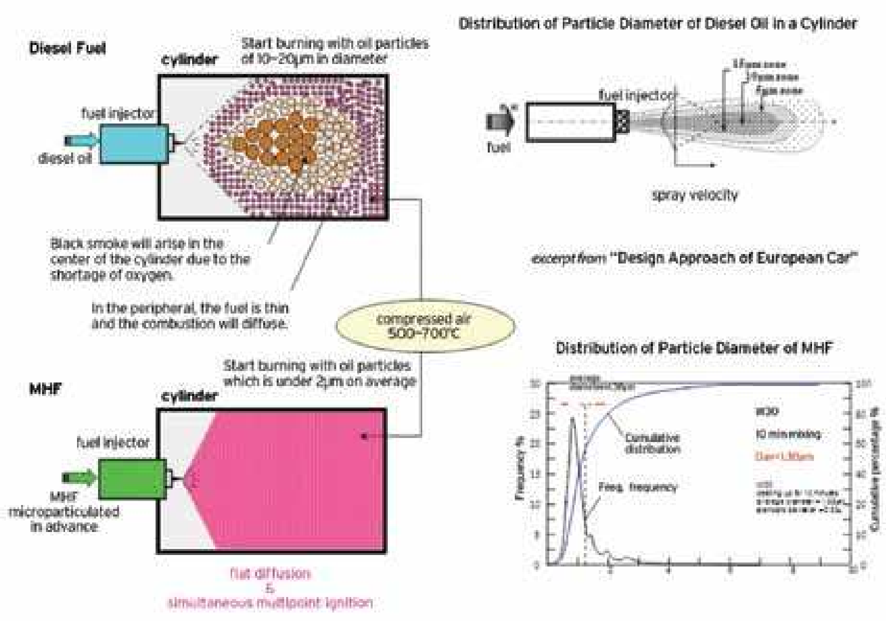

Figure 6.3 – Fuel injection spray test using MHF50 from palm oil

Very fine mist particles are produced in an actual fuel injection spray test using MHF50 produced from palm olein. (Photo by Nippon Ecosolutions, Ltd. and LAUDS Technologies, Inc.)

Palm oil is the preferred blending material because of its ready availability and price advantage. However, once jatropha oil becomes available in sufficient quantities, it will be the preferred blending material. Depending on the actual prices of plant oil and diesel fuel in a given locality, the price of MHF can be competitive with diesel fuel. Since the technology does not involve chemical processing, the total processing cost is generally much lower compared to transesterification. In addition, since glycerin is not removed from the plant oil, the heating value of the resulting product is generally higher compared to the equivalent methyl ester produced through transesterification.

MHF Field Studies and Tests

Field tests conducted in a Philippine trucking company using MHF50 in one of its trucks used for hauling coal and gypsum from Manila to Bulacan showed improved acceleration, better pulling power, and cleaner emissions, as well as a 5% improvement in fuel consumption[22]. The actual results are presented in Table 6.1.

Sampling of the exhaust gases from the test truck running on MHF25.

Trained technician preparing the various sampling and test equipment.

Air compressor (above) and smoke meter (below)
(Photos by LAUDS Technologies, Inc.)

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[22] Field tests were conducted in 2006 using MHF 25 in a fully loaded 40-ton truck from Manila to Bulacan and back (four round trips). The driver wrote the following remarks in his report: "*Naging pino ang takbo*" (the drive became smoother), "*ang usok ay hindi na itim*" (the emission was no longer black). The test results showed good starting quality, good engine acceleration, and good climbing ability.

Table 6.1 – Results of the analysis of exhaust gases from the test truck

Parameter	Pure Diesel (MHF0)	MHF25
Black Smoke (%)	5.9	1.3
HC (ppm)	19.7	19
CO (ppm)	0.02	0.02
CO_2 (ppm)	1.45	1.45

A similar test using MHF50 conducted at a Philippine bus company in one of its buses running from Quezon City to Lucena City and back showed considerable improvement in emission (disappearance of dark smoke), better pulling power and acceleration and a 5% improvement in fuel consumption[23]. Varying blends of microemulsified hybrid fuels ranging from MHF5 to MHF30 were also used in actual field tests using a cargo truck over a period of several months and a total distance travelled of 8,000 kilometers with similar results – disappearance of the usual black smoke, better pulling power and acceleration, and a 2%-5% improvement in fuel consumption[24]. The engine was opened before the field test was conducted and again after 8,000 kilometers revealing no significant change in the appearance or condition inside the engine.

View of open truck engine cylinder.
(Photo by Nippon Ecosolutions, Ltd. and LAUDS Technologies, Inc.)

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[23] The field test was conducted in November 2006 using a passenger bus Quezon City-Lucena City-Quezon City (one round trip).

[24] The field test was conducted by LAUDS Technologies, Inc. and Nippon Ecosolutions, Ltd. using an old cargo truck operating its usual hauling routes between Manila and surrounding provinces.

Close up view inside the engine.
(Photo by NES/LAUDS)

Injection nozzles removed from the engine for inspection.
(Photo by NES/LAUDS)

Advantages of Microemulsified Hybrid Fuel

The first and most important advantage of MHF is that it is generally cheaper than biodiesel and has the potential to be cheaper than diesel fuel. Two factors have significant impact on the price of biodiesel: first, the price of the raw material, which is plant oil; and second, the prices of the chemicals used in the processing such as methanol and caustic soda. For example, the price of coconut oil, which is the raw material used to produce coconut methyl ester (CME), is generally higher than the price of diesel fuel. If the cost of chemicals and processing is added, then the price of the biodiesel product becomes even higher than diesel. For this reason, only a small percentage of biodiesel (1%-2%) can be blended with diesel without significantly increasing the price of the blended biodiesel, B1 or B2. It is expected, however, that jatropha oil – once more areas are planted to the crop – will become available at a price lower than or comparable to that of diesel fuel. Since no significant amounts of other chemicals such as methanol and caustic soda are needed in the production of MHF from jatropha oil, it is expected that jatropha MHF would be lower in price compared to biodiesel such as CME.

The second advantage of MHF is its higher heating value compared to the equivalent methyl ester. The transesterification of plant oil to produce its methyl ester basically involves the removal of glycerin from the chemical structure of the oil. While this results in a significant reduction in viscosity, it also reduces the heating value of the resulting methyl ester compared to the original plant oil (basically due to the removal of glycerin). On the other hand, no chemical reaction takes place in the production of MHF and the heating value of the product MHF is the same as the heating value of the raw material plant oil.

The third advantage of MHF is that its production requires a much simpler processing. The production of MHF involves the simple physical process of microemulsification. On the other hand, transesterification involves complex chemical processing with the use of chemicals such as methanol and catalysts such as sodium hydroxide. In many cases, these chemicals have to be imported, thus somewhat negating one of the very purposes of using alternative fuels, which is conservation of foreign exchange. In particular, the amount of methanol needed in the transesterification of plant oils is quite considerable amounting to one liter of methanol for every 4-5 liters of plant oil.

The fourth advantage of MHF is that there is no residual waste product to be disposed of or treated. The transesterification of plant oil produces crude glycerin, waste oil and crude recovered sodium hydroxide. If the crude glycerin cannot be sold to other users (which is generally the case), then it must be properly disposed of or treated prior to disposal. Otherwise, it will cause serious water pollution problem. In most cases, crude glycerin is further processed to produce chemical-grade glycerin. This increases the initial investment required for the processing equipment and facilities.

The fifth advantage of MHF is that it is a generally cleaner fuel. For example, if 50% palm oil or jatropha oil is microemulsified and blended with diesel fuel (MHF50), then 50% of the fuel is carbon neutral and does not add up to the problem of carbon dioxide and climate change. On the other hand, a mere 1% or 2% biodiesel has a very small contribution to reducing carbon dioxide emission and preventing climate change since 98% to 99% of biodiesel is still comprised of fossil fuel. In addition, the emission of sulfur oxides is greatly minimized with the use of MHF since plant oil does not contain any sulfur, unlike fossil fuels.

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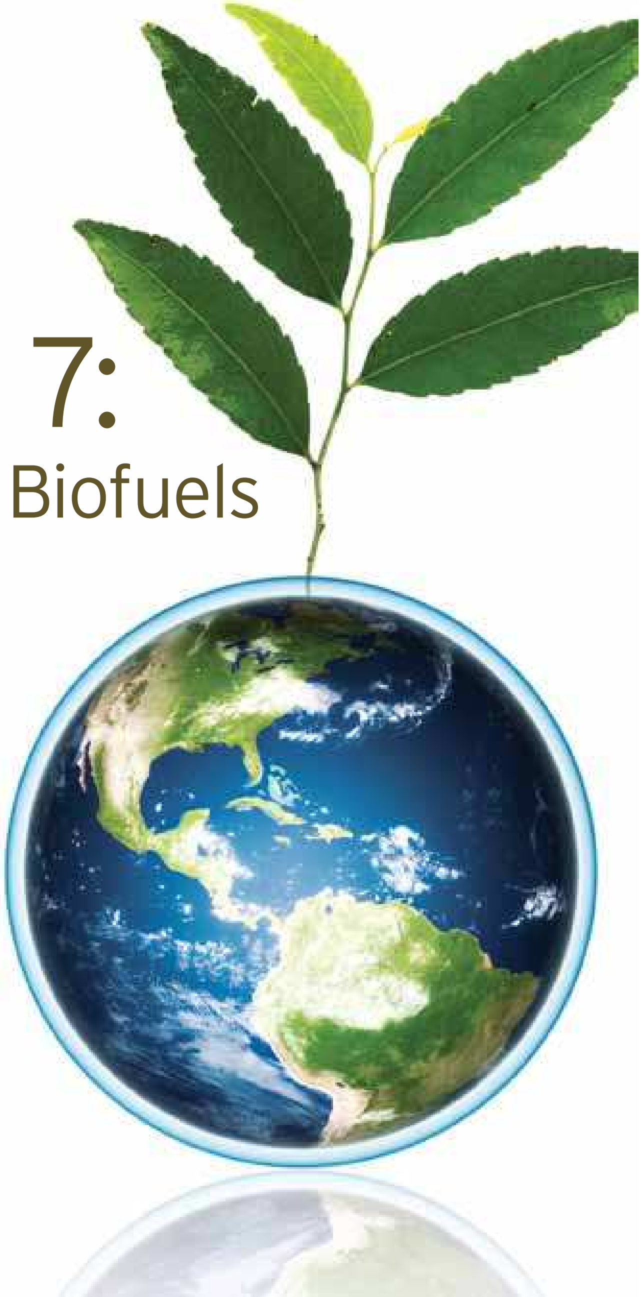
Chapter 7:

The Future of Biofuels



There is an enormous potential to produce energy from biomass. It is estimated that about 100,000 terawatts of solar energy reach the earth's surface. The existing crop lands cover approximately 1.5 billion hectares of the earth's surface. Accordingly, about 4,000 terawatts of solar energy can be captured by crop lands. Even assuming that modern biomass technologies can attain only one percent energy conversion efficiency, still these existing crop lands could theoretically produce 40 terawatts of usable energy flow. This figure is more than 3 times the current global primary energy supply flow of 14 terawatts[1]. What this simple and approximate calculation shows is that, at least theoretically, there is scope for significant expansion of modern biomass energy contribution, given that this contribution was estimated at only 0.17 gigawatts in 2003[2].

The first and most crucial element of an effective energy strategy, particularly for developing countries, is finding energy solutions that can be adapted or deployed with only modest capital requirements. The second and equally important element is managing the competing demands for food production, ecological preservation, and energy use. In most of the developing countries of the world, there is still scope for substituting the current foraging of indigenous plants with the planting and harvesting of improved biofuel feedstocks. In areas where the resource base is still abundant to support both food and energy crops, the efficient use of biomass feedstocks for the local co-production of heat, electricity and transportation fuel will have significant positive impact on the rural economy. It will, for example, enable rural populations to have access to modern, cleaner forms of energy with the consequent improvements in the quality of life. However, in areas where the production of crops for energy will significantly reduce the areas available for food production, there will be need to search for win-win solutions such as the use of higher yielding food crops and the cultivation of new or marginal areas without adversely affecting the need for ecological conservation. This concern becomes even more important when the food being produced is consumed locally while the most of the energy is used elsewhere or exported to other countries.

The recent scientific advances and technological developments in agriculture, biology and chemistry provide win-win possible solutions to the food-versus-energy dilemma. These include the development of genetically-improved crops for energy and food production, the production of affordable specialized enzymes, and the ability to artificially simulate natural biological processes such as photosynthesis. Nevertheless, a lot of work still needs to be done to reduce costs, mitigate environmental impacts and biodiversity losses, and minimize the pressure on scarce land resources, particularly on existing productive, arable lands.

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[1] Somerville, C., Energy from Biomass, Workshop presentation for the InterAcademy Council study report, *Lighting the Way: Toward a Sustainable Energy Future*, IAC, Amsterdam, 2005.

[2] Macedo, I.C., Biomass as a Source of Energy, Unpublished paper commissioned for the InterAcademy Council study report, *Lighting the Way:Toward a Sustainable Energy Future*, IAC, Amsterdam, 2005.

The production of biofuels from lignocellulose rather than sugars and starches appears to be one of the possible long-term solutions. Research and development efforts are currently focused on efficiently recovering sugars through improved hydrolysis of cellulose and hemicellulose fractions of biomass followed by much better fermentation of sugars into alcohol. Success in this field will result in minimizing the potential conflicts between food and energy production and in maximizing environmental benefits (including greenhouse gas reductions) relative to fossil-fuel use. But such advances in production and conversion technologies must be combined with appropriate policies that will integrate biomass energy development with sustainable agricultural and forestry practices and improve crop productivity with regard to land, water and nutrient use in order to be sustainable.

First and Second Generation Biofuels

The first generation biofuels are those that are characterized by mature commercial markets and well understood technologies[3]. Some examples are sugarcane ethanol in Brazil, corn ethanol in the United States, oilseed rape biodiesel in Germany, and palm oil biodiesel in Malaysia. The development and use of first generation biofuels are encouraged by the desire to attain energy security by reducing oil and coal imports, support the rural economy and agricultural industries, and mitigate the accumulation of greenhouse gases. Bioethanol from sugar cane has a positive net energy balance and provides an effective means of reducing greenhouse gas emissions. However, the commercial production of ethanol and biodiesel in some of the developed countries has zero or negative energy balance if upstream energy and chemical inputs are accounted for. For example, fertilizers used to grow biomass feedstocks for fuel can produce nitrous oxide, which is an extremely potent greenhouse gas. This therefore offsets some of the climate benefits associated with avoided fossil fuel use. The use of fossil fuels during the production and processing of some biofuels can also significantly reduce the performance of such fuels from a climate mitigation perspective.

Most of the evaluation studies and life cycle analyses done on first generation biofuels show that there is still a net benefit in terms of greenhouse gas emissions and energy balance. Nevertheless, first generation biofuels continue to draw a number of concerns, whether completely valid or not, as follows: (a) they contribute to higher food prices due to competition with food crops; (b) since biofuels production normally receive government grants and subsidies, it is an expensive option for attaining energy security; (c) with the exception of sugar cane ethanol, most biofuels provide only limited greenhouse gas reduction benefits; (d) since the production of biomass feedstock may not always be done in a sustainable manner, biofuels do not meet the claimed environmental benefits; (e) they have potentially negative impact on biodiversity, for example, through mono-culture cultivation of large tracts of land; and (f) they compete for already scarce water resources in some areas.

The second generation biofuels address many of the problems and concerns associated with first generation biofuels. Table 7.1 presents a classification of second generation biofuels. Since most second generation biofuels are still relatively immature technologically, there is therefore great potential for cost reductions and increased efficiency levels as the technologies develop and experience in using them accumulate. The current biofuels industry is primarily based on the production of ethanol via the fermentation of sugars or starches and on the production of biodiesel derived from plant oils. To develop second generation biofuels, research and development work has been directed towards advanced technologies such as ethanol hydrolysis and fermentation, biodiesel enzymes, higher carbon fixation in roots, and improved oil recovery. Through advances in genetic engineering, it has become possible to develop crops that: (a) are disease-resistant, (b) viable even in degraded lands previously considered not suitable for cultivation, and (c) require much lower inputs of chemicals and water. New cutting-edge technologies are also being developed for the processing of lignocellulosic materials for the production of both industrial chemicals and biofuels, with overall conversion efficiencies of up to 70-90 percent. For this purpose, low-cost crops and forest residues, wood process wastes, and municipal solid wastes can all be used as feedstocks.

The other examples of second generation biofuel technologies that show a great deal of promise for eventual commercialization include gasification processes that incorporate the co-production of multiple valuable outputs, including electricity, industrial chemicals and liquid transportation fuels. These processes are capable of handling multiple feedstocks such as energy crops, animal wastes, and a wide range of organic materials. In general, gasification processes involve two-steps: firstly, the production of a synthesis gas, comprising primarily of carbon monoxide and hydrogen, from any carbon-containing and/or hydrogen-containing material; and secondly, the use of this synthesis gas to drive highly efficient turbines for power production and as a feedstock for the production of a variety of synthetic chemicals or fuels.

The use of lignocellulosic biomass materials (as second generation biofuels technology) – as opposed to starches or sugars (as first generation biofuels technology) – offers the greatest potential for maximizing the efficient conversion of sunlight, water and nutrients into biofuels. The currently available methods of producing ethanol from cellulosic feedstock involve three steps: first, the thermochemical pretreatment of raw biomass to make complex cellulose and hemicellulose polymers more accessible to enzymatic breakdown; second, the use of a mixture of special enzymes that can hydrolyze plant cell-wall polysaccharides into a mixture of simple sugars; and third, the fermentation of sugars into ethanol in the presence of bacteria or yeast. These unit operations and processes are complex and energy-intensive and special enzymes are expensive. For this reason, there is need for further research and development work to make these technologies commercially viable.

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[3] International Energy Agency, From 1st to 2nd Generation Biofuel Technologies: An Overview of Current Industry and RD&D Activities, IEA Bioenergy, OECD/IEA, November 2008.

Table 7.1 – Classification of second generation biofuels

Biofuel group	Specific biofuel	Biomass feedstock	Production process
Bioethanol	Cellulosic ethanol	Lignocellulosic materials	Advanced enzymatic hydrolysis and fermentation**
Synthetic biofuels	Biomass-to-liquids (BTL) Fischer-Tropsch diesel (FT) Synthetic diesel Biomethanol Synthetic diesel Biomethanol Heavier alcohols (butanol and mixed) Dimethyl ether (DME) P-series* (ethanol+MTHF etc)	Lignocellulosic materials	Gasification and synthesis***
Biodiesel (hybrid of 1st and 2nd)	NExBTL H-Bio Green pyrolysis diesel* Algal oil*	Vegetable oils and animal fats Lignocellulosic materials Algae	Hydrogenation (refining) Pyrolysis*** Cultivation
Methane	Bio synthetic natural gas* (SNG)	Lignocellulosic materials	Gasification and synthesis***
Bio hydrogen	Hydrogen	Lignocellulosic materials	Gasification and synthesis*** or biological processes**

* Some fuels listed can be classified as "advanced" biofuels.

** *Bio-chemical route*: After comminution of the biomass feedstock and pre-treatment, ethanol can be produced by the hydrolysis of lignocellulosic raw materials, the fermentation of the extracted sugars followed by distillation and formulation to give the final fuel product. Fermentation of glucose sugars is mature commercial technology, but the hydrolysis of agricultural residues and woody biomass and the fermentation of pentose sugars still need further development.

*** *Thermo-chemical route*: Indirect liquefaction methods require the biomass to be first pyrolyzed to bio-oil, or gasified and the product gas cleaned and processed to form synthesis gas (mainly CO and H_2). This gaseous mixture can then be used in a commercial chemical process to synthesize a range of liquid biofuels including methanol, Fischer-Tropsch diesel, DME (dimethyl ether) or as gaseous methane or hydrogen fuels.

Source: International Energy Agency, From 1st to 2nd Generation Biofuel Technologies: An Overview of Current Industry and RD&D Activities, IEA Bioenergy, OECD/IEA, November 2008.

The current research and development work on lignocellulosic feedstocks is proceeding through two very different processing routes. They are: (a) biochemical – in which enzymes and other microorganisms are used to convert cellulose and hemicellulose components of the feedstocks to sugars prior to their fermentation to produce ethanol; and (b) thermo-chemical – where pyrolysis or gasification technologies produce a synthesis gas (carbon monoxide and hydrogen) from which a wide range of long chain biofuels, such as synthetic diesel or aviation fuel can be reformed. Both the biochemical enzyme hydrolysis route and the thermo-chemical biomass-to-liquid (BTL) route have now reached the demonstration or pilot plant stage. Both processes can potentially have an overall biomass to biofuel conversion efficiently of around 35%. This means both can convert one dry ton of biomass, which contains about 20 GJ/ton, to around 6.5 GJ/ton of energy carrier in the form of biofuels. The biochemical process can potentially produce up to 300 liters ethanol per dry ton of biomass while the thermo-chemical process can yield up to 200 liters of synthetic diesel per dry ton. The overall yield in energy terms (around 6.5 GJ per ton biofuels) is about the same because synthetic diesel has a higher energy density by volume than ethanol. Table 7.2 shows the indicative biofuel yield ranges per dry ton of feedstock. The relatively low energy efficiency of both processes can be further increased if excess heat utilization and power and co-product generation are incorporated in the total production system.

At their present level of development, there is no clear commercial or technical advantage between the biochemical and thermo-chemical routes. Both pathways still have to overcome significant economic, technical and environmental hurdles before they can become commercially viable. But one key difference between the biochemical and thermo-chemical processes is that in the biochemical process the lignin component becomes a by-product of the enzymatic hydrolysis step and can be used for heat and power generation; whereas in the thermo-chemical process the lignin component is converted into synthesis gas along with the cellulose and hemicelluloses. In the case of the biochemical process, there is still need to improve the overall process integration, reduce the cost of pretreatment, improve the efficiency of the enzymes and lower their production costs, and improve feedstock characteristics. Despite all these current technical and economic drawbacks, most experts believe that the biochemical route offers the greater potential to provide affordable biofuels in the future compared to the thermo-chemical route.

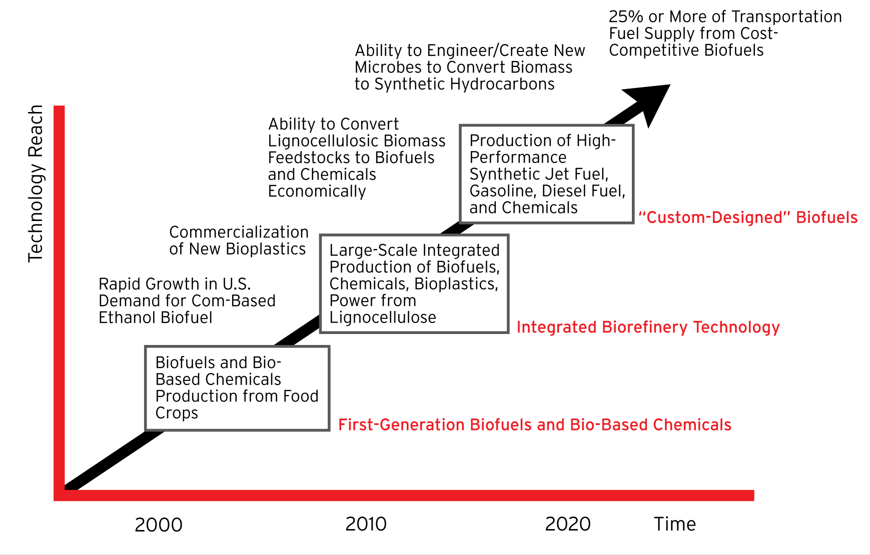
Compared to the biochemical process, there are fewer technical hurdles to the thermo-chemical process since many of the technologies are already proven. But the biggest single problem confronting the commercial viability of the thermo-chemical process is that of securing a large enough quantity of feedstock for a reasonable delivered cost at the plant site. Unfortunately, the thermo-chemical process requires an integrated, large-scale operation at a single site in order for it to become economically feasible. At the technical level, there is also need to improve the reliability of the gasification of biomass and to do this at reasonable cost. But the greatest long-term drawback of this process is that since most of the technologies involved are already mature, there is less opportunity for further cost reductions.

Table 7.2 – Indicative biofuel yield ranges per dry ton of feedstock

	Biofuel yield (liters/dry t)		Energy content (MJ/l)	Energy yields (GJ/t)	
Process	**Low**	**High**	**Low heat value**	**Low**	**High**
Biochemical Enzymatic hydrolysis ethanol	110	300	21.1	2.3	6.3
Thermo-chemical Syngas-to-Fischer Tropsch diesel	75	200	34.4	2.6	6.9
Syngas-to-ethanol	120	160	21.1	2.5	3.4

Source: International Energy Agency, From 1st to 2nd Generation Biofuel Technologies: An Overview of Current Industry and RD&D Activities, IEA Bioenergy, OECD/IEA, November 2008.

Box 7.1 – Biofuels technology roadmap



First generation biofuels technologies comprise mainly of fuel ethanol from crops such as corn and sugarcane and biodiesel from crops such as rapeseed and soy. Second generation processes are those that produce energy-efficient biofuels that do not compete with the food chain for feedstocks. Second-generation processes convert lignocellulosic materials, including agricultural and forest residues such as corn stover, rice straw, wheat straw, and bagasse and possible nonfood bioenergy crops such as switchgrass, poplar, and Miscanthus grass (elephant grass). Cellulosic ethanol technology is still a few years away from economic viability. There are two alternative types of technology platforms: (a) a biochemical or sugar platform depending on acid or enzymatic hydrolysis of lignocellulose to sugars with subsequent fermentation to ethanol; and (b) a thermochemical platform using gasification of biomass to syngas with subsequent fermentation or catalytic conversion to alcohols.

Biodiesel is another biofuel seeing rapid growth worldwide. Feedstocks include plant-derived oils such as rapeseed, soy, and palm oil, as well as waste oils. Jatropha, a weed that grows in arid climates, is also gaining support in India and some other locations. Conventional biodiesel processing often converts less than 10% of the mass of dried plants, so a clear need exists for more efficient biodiesel technologies. Choren Industries GmbH (Freiberg, Germany) is developing a new biomass-to-liquids (BTL) technology that involves high-temperature gasification of biomass followed by a catalytic Fischer Tropsch process to make a high-cetane synthetic biodiesel. Algae are a potentially rich source of biofuels and an area of intense interest today. Significant potential exists for cultivating high-oil-content, high-growth microalgae containing more than 50% oil for conversion to biodiesel. Algae can grow on marginal land or in water so as not to compete with food crops.

New biofuels are also under development. Biobutanol is attracting the attention of a number of companies because it has some key advantages over ethanol, including higher energy content and better transport characteristics. BP Biofuels is progressing a near-term effort with DuPont to develop and commercialize biobutanol. The biobutanol-fermentation process initially will use DuPont's biocatalyst and bioprocess technology using locally grown sugar beets. BP and DuPont are working on the development of a second-generation process using a more-targeted biocatalyst and the ability to process lignocellulosic feedstocks.

Future breakthroughs in cellulosic-ethanol production and entirely new biofuels may come from the field of synthetic biology. Several start-up companies are using synthetic biology techniques to make renewable hydrocarbon fuels that are very similar to today's petroleum fuels and are thus completely compatible with existing fuel infrastructures. Researchers are engineering microbes by incorporating genetic pathways from other microbes, plants, and animals. Synthetic Genomics (Rockville, Maryland), founded by biotechnology pioneer Craig Venter, is trying to produce a highly engineered "synthetic organism" that can perform multiple tasks well: efficiently break down cellulose like a bacterium, ferment sugar like a yeast, and tolerate high levels of ethanol. Hoping to improve on the attributes of ethanol fuel, start-up companies Amyris Biotechnologies, Inc. (Emeryville, California), and LS9, Inc. (San Carlos, California), are both targeting the custom-designed fuels arena. Amyris is focusing on advanced diesel and jet-fuel formulations; LS9's focus is on jet fuel, low-sulfur gasoline biofuels, and specialty biochemicals. Although still early stage, the companies hope to bring these products to market within four or five years. Technology challenges include the massive scale-up necessary to produce the new biofuels in large volumes.

A growing number of bio-based chemicals, such as the biodegradable bioplastic PLA (polylactic acid) that derives from corn, are already in commercial production, and several additional products will reach commercialization in the next few years. The longer-term plan is to use lower-cost lignocellulosic feedstocks in stand-alone plants or future integrated biorefineries. Production of high-value chemical building blocks and biopolymers is key to the success of biorefineries.

For biochemical-conversion technologies, a major R&D focus is on improving pretreatment technology for breaking hemicellulose down to component sugars and developing more cost-effective cellulase enzymes (biocatalysts) for breaking cellulose down to its component sugar. Another key enabling technology is the engineering of microorganisms and enzymes that can efficiently convert the complex cellulosic wastes to simple sugars and then to ethanol or chemical building blocks. Lignocellulosic feedstocks contain both five-carbon pentose sugars (D-xylose and L-arabinose) and six-carbon sugars (glucose, mannose, and galactose). Cost-effective processes need to ferment all five sugars rapidly, but the pentoses in particular are not easily metabolized by common yeasts in use for ethanol production today. For thermochemical-conversion technologies, much of the current R&D is on syngas production and use to make fuels and other valuable products. Technology developers are also working to demonstrate their integrated conversion processes in real-world applications in rural areas.

Rising prices for crops such as corn, sugar, wheat, and oilseeds and inadequate infrastructure are serious impediments to the wholesale adoption of first-generation biofuels. The development and implementation of new lignocellulose conversion and biorefinery technologies could enable a range of new biofuel and bio-based chemical products that are fully cost competitive (without government subsidies) with conventional petroleum-based fuels and products beginning in the 2010 to 2015 timeframe. Future biofuels and bioproducts may also offer improved performance and environmental attributes, including biodegradability.

A large-scale bioenergy economy will rely on technologies such as genetic engineering and agricultural practices to help increase biomass yields and lower cultivation costs. Harvesting crops, collecting biomass residues, and storing and transporting biomass resources are critical aspects of the biomass-resource supply chain. Biomass handling systems are also important—they can represent a significant portion of the capital and operating costs of a biomass conversion facility. For example, rice straw is very fibrous and can be difficult to process. New integrated biorefinery technology requires new bioprocessing techniques and lower-cost separation methods in addition to improved biocatalysts. The design of bioreactors is another important area of research to allow maximum process efficiency.

Integrated biorefineries based on waste agricultural and other lignocellulosic biomass feedstocks will use locally available resources to produce biofuels and other bio-based products. The six biorefinery demonstration plants that the Department of Energy is co-funding illustrate a range of locations and approaches:

> Abengoa Bioenergy (Chesterfield, Missouri) will operate a facility in Kansas to process 700 tons per day (tpd) of corn stover, wheat straw, switchgrass, and other feedstocks to produce 11.4 million gallons per year of cellulosic ethanol and syngas for energy.
>
> Alico Inc. (LaBelle, Florida) will turn 770 tpd of yard, wood, and vegetative wastes such as citrus peel into 13.9 million gallons per year of cellulosic ethanol, 6,255 kW power, 50 tpd ammonia, and 8.8 tpd hydrogen.
>
> BlueFire Ethanol, Inc. (Irvine, California), will convert 700 tpd of sorted green waste and wood waste from an urban landfill in Southern California to produce 24 million gallons per year of cellulosic ethanol.
>
> Poet Design & Construction (Sioux Falls, South Dakota) will convert an existing ethanol facility in Iowa to a biorefinery processing 842 tpd of corn fiber and stover to produce 26.4 million gallons per year of cellulosic ethanol.
>
> Iogen Biorefinery Partners, LLC (Arlington, Virginia), will operate a biorefinery in Idaho to convert 700 tpd of wheat straw, barley straw, corn stover, switchgrass, and rice straw to produce 18 million gallons per year of cellulosic ethanol.
>
> Range Fuels Inc. (Broomfield, Colorado) will operate a plant in Georgia to convert 1,200 tpd of woody residues and energy crops to produce some 40 million gallons per year of ethanol and 9 million gallons per year of methanol.

Source: Biofuels and Bio-Based Chemicals, Global Trends 2025, SRI Consulting Business Intelligence, 2008.

Biofuels from Micro-algae

The development of photosynthetic microbes that produce lipids or hydrocarbons also has great potential for biofuels production. While plant production of useable biomass is unlikely to exceed an overall solar conversion efficiency of 1-2 percent, algae can convert solar power at efficiencies in excess of 10 percent. A combination of anaerobic and aerobic microbial processes can be separately optimized so that a fuel precursor can be produced in an anaerobic environment and the final product in an aerobic setting. Efficient algae cultivation that would take full advantage of the high quantum efficiency of these micro-organisms would, however, require capital intensive infrastructure.

Algae are the fastest growers of the plant kingdom. When photosynthesizing, certain species can produce and store inside the cell large amounts of carbohydrates and up to 50% by weight of oil as triglycerides. The conversion of algae oil into biodiesel is a similar process as for plant oils based on esterification of the triglycerides after extraction, but the cost of producing algae oil is relatively high at present.

Algae can be produced continuously in closed photo-reactors but oil concentration is relatively low and capital costs are high. To collect the biodiesel feedstock more cheaply would need high volumes of algae to be cultivated in large facilities at low cost, hence the interest in growing the algae in open ponds, including sewage ponds where nutrients are in abundance and the sewage is partly treated as a result. In practice a problem is contamination of the desired culture by other organisms that limit algal growth. A combination of closed and open systems is a possible option. The algae are initially grown in closed reactors under controlled conditions that favor continuous cell division and prevent contamination. A portion of the culture is transferred daily to an open pond where it is subjected to stress and nutrient deprivation. This stimulates cell concentration and oil production within a short residence time before contamination can occur.

Catabran and Auresenia (2010) studied five algal strains found in the Philippines to determine their potential for the production of biofuels[4]. The following algae species were used: *Hapalosiphon welwitschii, Nostoc commune Anabaena laxa, Anabaena variabilis,* and *Chlorella sorokiniana*. The optimal conditions for growing the algae strains were determined. It was found that their relative rate constants are: 0.2567 (*N. commune*), 0.1845 (*H. welwitschii*), 0.4359 (*A. variabilis*), 0.3372 (*A. laxa*), and 0.4359 (*C. sorokiniana*). Their mean doubling times were measured as follows: 2.7 days (*N. commune*), 3.76 days (*H. welwitschii*), 1.59 days (*A. variabilis*), 2.056 days (*A. laxa*) and 1.59 days (*C. sorokiniana*). The results showed that the fastest growing algae were A. variabilis and C. sorokiniana. Their cetane numbers were predicted from their fatty acid methyl ester profile: 48.74 (*N. commune*), 53.06 (*H. welwitschii*), 59.21 (*A. variabilis*), 49.09 (*A. laxa*) and 46.40 (*C. sorokiniana*). The algae strain with the highest predicted cetane number was A. variabilis. The optimum operation conditions to yield the highest biomass productivity rate were determined to be 24 light hours in the photoperiod, 30 watts of light intensity and 1.0 L/min of air flow rate. The fatty acids contained in the algae strains were found to be suitable for use as biodiesel feedstock based on the predicted cetane number.

Macaraig, L.C. et al (2010) examined the optimization of a light emitting diode-based photobioreactor system for the production of the eicosapentanoic acid-producing algae species *Nannochloropsis oculata sp*[5]. The parameters examined were lighting, plant nutrients, carbon dioxide feed and growing conditions that could maximize total algal biomass yield. The experiments showed that certain wavelengths of light affected different stages of algal growth. Algae cell size was found to increase when algae was exposed to light at 680 nm, whereas algae cell production was found to increase under light at 470 nm. The marine *Nannochloropsis* species was also found to survive in fresh water media at temperatures lower than 35ºC and was generally stable at brackish salinities of 15-23%. Photoperiods with longer light exposure was found to favor the growth of *N. oculata*. Work on carbon dioxide feed done through the bicarbonate pathway was found to be more efficient than bubbling pure carbon dioxide and was as effective as bubbling compressed air.

Perez and Josol (2010) studied the effect of light intensity and nitrogen concentration on the growth and lipid production of *Chlorella vulgaris*[6]. The results of his experiments showed that different levels of light intensity significantly affected growth and lipid production ($p<0.05$). The highest optical density, highest proliferous rate (0.08 per day), and shortest generation time (3.79 days) were observed at 2,700 lux while the highest lipid yield was observed at 800 lux. Although nitrate concentration did not significantly affect growth and lipid production, nevertheless the highest lipid yields occurred at concentrations of 1.5 g/l and 0.15 g/l of nitrate. The results also showed that it was in the stationary phase that the most amounts of biomass and lipids were harvested. The experiments showed that the optimum conditions for growth and lipid production of *C. vulgaris* were at 800 and 2,700 lux in the presence of 1.5 g/l and 0.15 g/l of nitrate.

Numerous other studies are currently being undertaken worldwide in universities and research centers to determine optimum conditions for the production of oil from micro-algae. The results are promising since these studies

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[4] Catabran, I.A.Y., Auresenia, J., "Characterization of Fatty Acids from Locally Available Algae Strains for Use as Biodiesel Feedstock", De La Salle University, 2nd Regional Conference on Biotechnology, AUN SEEDNet, Cambodia, February 2010.

[5] Macaraig, L.C., et. al., "Optimization of a Light-Emitting Diode-Based Photobioreactor System for Oil-Producing Algae Species *Nannochloropsis oculata sp.*", Ateneo de Manila University, 2nd AUN SEEDNet Regional Conference on New and Renewable Energy, Thailand, January 2010.

[6] Perez, T., Josol, J.C., "Effect of Light Intensity and Nitrogen Concentration on Growth and Lipid Production of *Chlorella Vulgaris*", Ateneo de Manila University, 2nd AUN SEEDNet Regional Conference on New and Renewable Energy, Thailand, January 2010.

show that the projected micro-algae oil yield per hectare can be 16 times higher than palm oil and up to 100 times higher than for traditional plant oil crops grown in soil. In addition, algae also consume 99% less water. Nevertheless, there are still great technical and economic challenges that will need to be overcome before micro-algae become a viable commercial source of fuel oil. For example, to produce large oil volumes, it will be necessary to have large surface areas of ponds. This requires very high capital investment. However, one specific application that is rapidly being developed is the use of algae to clean flue gases from coal-fired power plants. Since algae absorb carbon dioxide, the injection of carbon dioxide from fossil-fueled thermal power plants could be used to enhance growth. The application of this system could make coal-fired power plants more environmentally friendly while addressing the need to produce carbon neutral biofuels.

Conversion of Municipal Solid Wastes to Fuels[7]

A special type of biomass that can also be converted into various forms of biofuels are municipal solid wastes commonly referred to as garbage. There are many processes at various levels of technological and commercial development to convert municipal solid wastes into various types of fuels. These technologies can also be applied to agricultural wastes and residues and other cellulosic feedstocks. These include physical-chemical processes to convert solid wastes into some form of coarse or fine powdered solid fuel, commonly referred to as refuse-derived fuel. Other technologies involve the thermal-chemical conversion of solid wastes into gasoline or fuel oil through selective pyrolysis of wastes, converting them to gases rich in olefins, followed by purification of these gases and polymerization of the gaseous olefins to selectively form the desired hydrocarbon liquid fuel.

A variety of processes involving pyrolysis have also been developed to convert municipal solid wastes and agricultural wastes to various types of solid, liquid and gaseous fuels. The relative amounts of char, bitumen-like liquid and gas produced depend on the time and temperature sequence used during pyrolysis. At lower heating rates and temperatures, more char is produced. Higher temperatures produce more liquid fuels.

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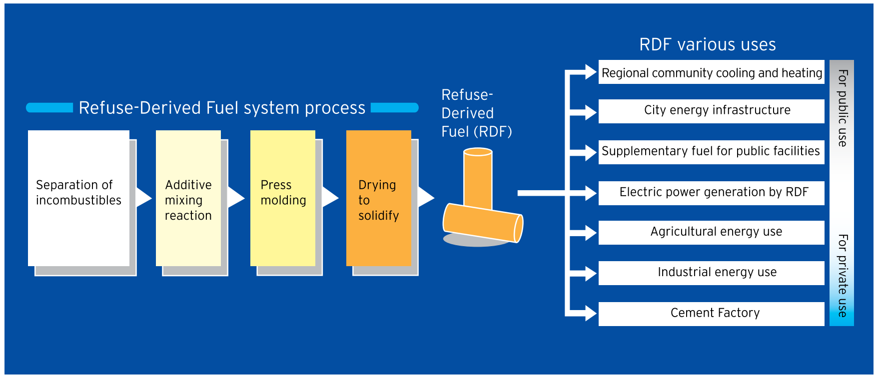
[7] This section is taken fully from an earlier book of the author – Uriarte, F. A. Jr., Solid Waste Management: Principles and Practices, University of the Philippines Press, Quezon City, Philippines, 2008 – and reproduced here since municipal solid waste (MSW) represents a special type of biomass that is produced daily in ever increasing quantities, requiring proper treatment and disposal to prevent adverse environmental and health impacts. With suitable landfill sites becoming more difficult to find and energy costs ever increasing, it is expected that in the future the conversion of MSW into biofuels will be the preferred method of MSW treatment and disposal. Therefore, in the future, MSW will be a significant source of feedstock for biofuels. The specific references for the various technologies are found in this earlier book.

Refuse-derived fuel

Among the most advanced, as far as technological development is concerned, is the production of refuse-derived fuel (RDF). Presently, two types of refuse-derived fuels are being developed: coarse solid fuel and fine powdered supplementary fuel. There are many developers of the coarse solid fuel systems and a number of power plants run on RDF or mixed RDF and coal. The process of preparing coarse solid fuel includes a combination of shredding, magnetic separation, and air classification to remove the non-combustible fraction. Some systems pass the material through trommel screens for additional contaminant removal. The coarse products are then briquetted, with or without a suitable binder, for easier handling.

A simplified process flow diagram for the production of RDF, as shown in Figure 7.1, includes the separation of the non-combustible components through size reduction followed by screening, mixing with an additive, press molding and drying.

Figure 7.1 – Simplified process flow diagram for the production of refuse-derived fuel



A variety of innovative refuse-derived fuel systems are being developed that recycle difficult-to-process municipal solid wastes into readily transportable solid fuel, which can be stored for long periods of time without secondary pollution or unwanted odors. It is possible to produce RDF that is odorless, 80-90% less bulky and 70-80% lighter than municipal solid waste. A typical product has a diameter of 15-30 mm, length of 30-150 mm, specific gravity of 0.45-0.6, and heating value of 3,000-4,000 kcal/kg (Figure 7.2).

Figure 7.2 – Refuse-derived fuel produced in a modern RDF plant

Combustion Equipment Associates of the United States has also developed a process of preparing a powdered supplementary fuel from refuse, which has handling and combustion properties analogous to pulverized coal. Called Eco-Fuel II, it has a reasonably high density (560 kg/cu m) and low moisture content (less than 2 percent). The Powdered Eco-Fuel II is produced by shredding, magnetic separation, screening, reshredding of screen oversize, air classification, screening and hot ball milling in the presence of proprietary embrittling agent.

Thermal conversion processes

A variety of pyrolysis processes have been developed to convert municipal solid wastes and agricultural and wood residues to solid, liquid and gaseous fuels. The thermal process can be designed to maximize the desired end products since the quantity of char, bitumen-like liquid and gas produced varies as a function of the time and temperature sequence used during pyrolysis. Lower heating rates and lower temperature produce higher amounts of solid fuel or char.

Various processes for producing gas from refuse are also in various stages of technological development. Basically, gas is produced either by pyrolysis or biological conversion. Among the more successful pyrolysis systems is the Purox process developed by Union Carbide while the Dynatech Process biologically converts domestic refuse into high-grade methane gas.

Other technologies that are undergoing rapid development include the conversion of garbage and other organic solid wastes into gasoline (trash-to-gasoline process). A series of non-catalytic petrochemical processes can convert organic wastes to a synthetic hydrocarbon crude oil containing about 90 percent high-octane gasoline and 10 percent fuel and lubricating oils. The process involves pyrolysis, gas purification, and polymerization.

Wood wastes and other agricultural residues can also be converted to oil. This can be achieved by biomass liquefaction or by reductive formylation. The oils obtained are basically heavy fuel oils comparable to no. 6 fuel oil. They are largely aliphatic, have a low sulfur content and a heat value of about 35,000 J/g (15,000 Btu/lb).

Organic municipal waste and other biomass wastes, such as sawdust and animal manure, can be liquefied to produce an oil-like product. In one process, 30 parts of dry wood flour is blended with 70 parts of vehicle oil, and 7.5 parts of 20 percent aqueous solution of sodium carbonate. The mixture is heated to over 370°C under carbon monoxide or synthesis gas pressure to a final total pressure of about 17,000 kPa (2,500 psi) and for a total residence time ranging from 45 to 60 minutes. If completely converted, 30 parts of wood would yield about 17.4 parts oil having a heating value of about 31,300 J/g (13,500 Btu/lb).

The production of fuel oil through reductive formylation involves heating the solid waste slurry to 300-350°C range at pressures ranging from 1,300 to 3,000 psig for 5 to 10 minutes in the presence of a source of formate, usually formic acid or its compounds. The oils produced have heat of combustion of 35,000 J/g (15,000 Btu/lb) compared to about 40,000 J/g (17,500 Btu/lb) for no. 6 fuel oil.

Another approach to the conversion of cellulosic wastes to liquid fuels uses indirect liquefaction, that is, thermal gasification followed by liquid fuel synthesis. The use of catalysts is incorporated in the reaction steps and the process is capable of using a variety of feedstocks from urban, agricultural forest and industrial sources. Quality products can be produced with anticipated yields of 200 to 400 liters of liquid fuel per ton (dry, ash-free) of feedstock.

The scope for research and development in the field of solid waste conversion to liquid fuels is broad and offers a lot of opportunities. However, many of the technologies are in the early experimental stage and have not reached full pilot scale trials.

Waste gasification and ash-melting system

A fluidized bed waste gasification and ash-melting system has been developed that converts solid wastes into fuel gas and ash into slag. The system involves a revolving-type fluidized-bed gasifier that converts various wastes into synthetic gas at temperatures of 500-600°C. This synthetic fuel gas is then fed into an ash-melting furnace that burns the gas at temperatures of at least 1,350°C, making it possible to convert ash into slag. The fluidized-bed system uses a bed of sand grains 0.5 to 1.0 mm in diameter into which air and gas are blown causing the sand to flow like water, making its surface bubble and swirl like boiling water (hence the term fluidized bed). The large heating surface provided by the billions of sand particles makes heat transfer highly efficient, resulting in very high temperatures.

Figure 7.3 – Schematic process flow diagram of the gasification and ash-melting process

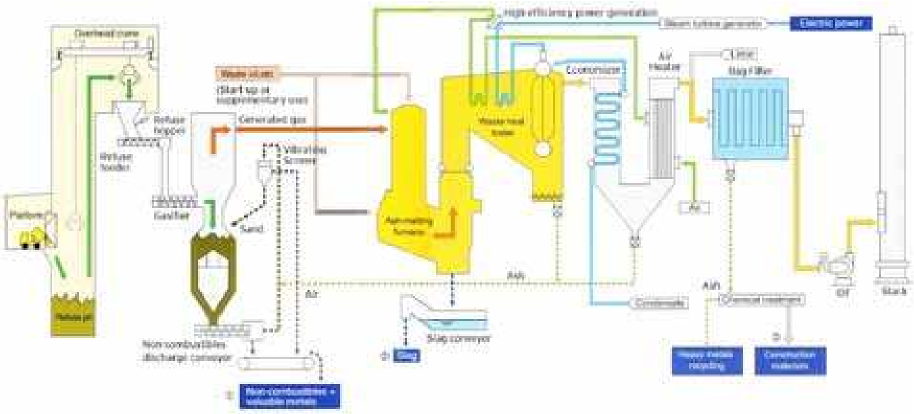


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Figure 7.4 – System configuration of the fluidized-bed gasifier and the ash-melting furnace

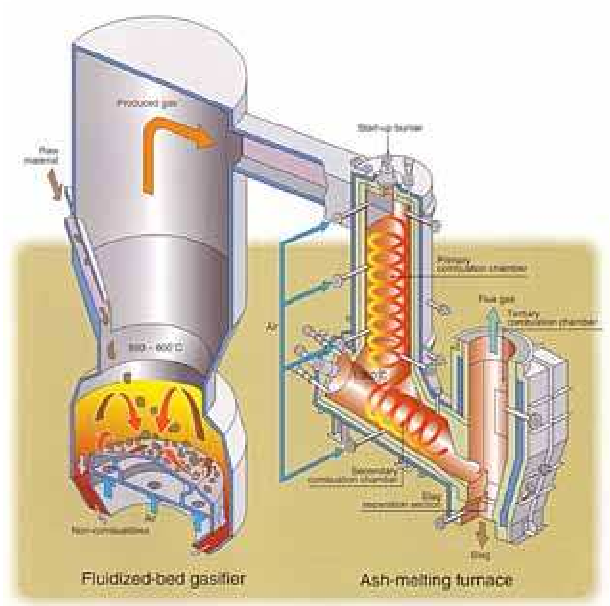

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Figure 7.5 – Products and their possible uses

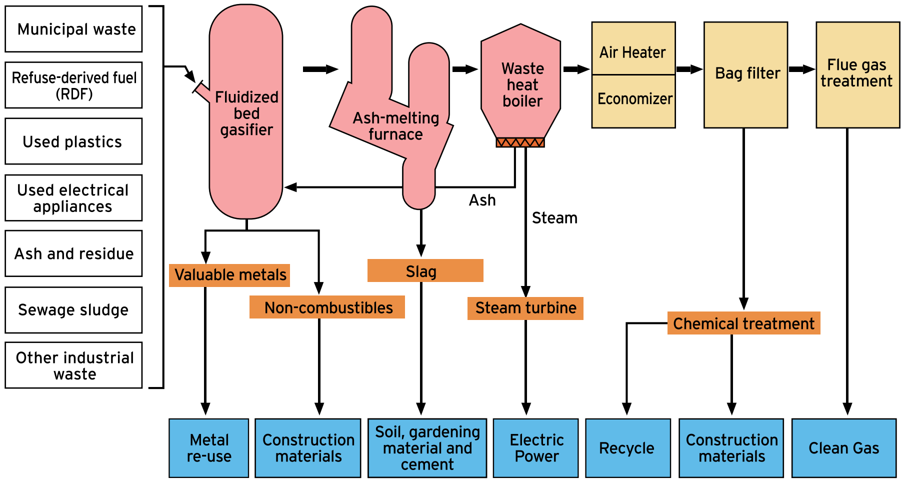

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Figure 7.6 – Materials from the fluidized-bed gasification and ash-melting system

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Figure 7.7 – Slag from the ash-melting system and gasification and ash-melting facility

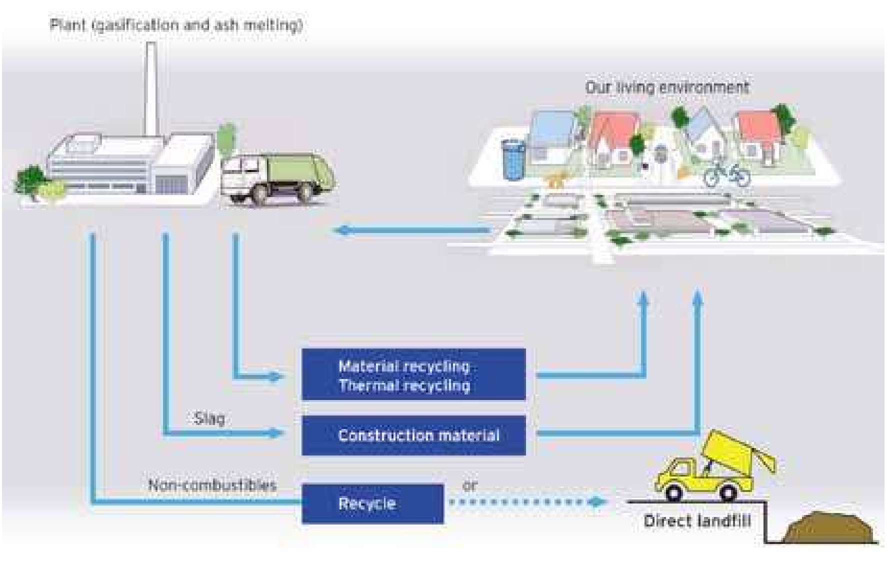
Molten Slag

External view of facility

EBARA Corporation

The fluidized bed gasification and ash-melting process offers the possibility of attaining a near zero-residual solid waste management system. The process converts the solid wastes into useful construction materials, produces heat that can be used to generate energy, recovers recyclable metals and other non-combustible materials from the waste stream, and reduces the amount of wastes to be disposed of to the barest minimum level. The dark-brown slag produced by the process has a specific gravity of 2.9 and ranges in size from 3 to 12 millimeters. When mixed with cement, it produces a construction material of good quality. By enhancing the efficiency of material, thermal and chemical recycling and reuse, the system can be applied in a comprehensive resource recovery facility to attain a near-zero waste community. In such a system the solid wastes produced by the community are sent to a gasification and ash-melting plant, the materials and energy recovered are used by the community, the slag is used as construction materials, and the other non-combustible components that are separated are either recycled or sent to a landfill (Figure 7.8).

Figure 7.8 – Overall solid waste treatment and recycling scheme for a community using the gasification and ash-melting process



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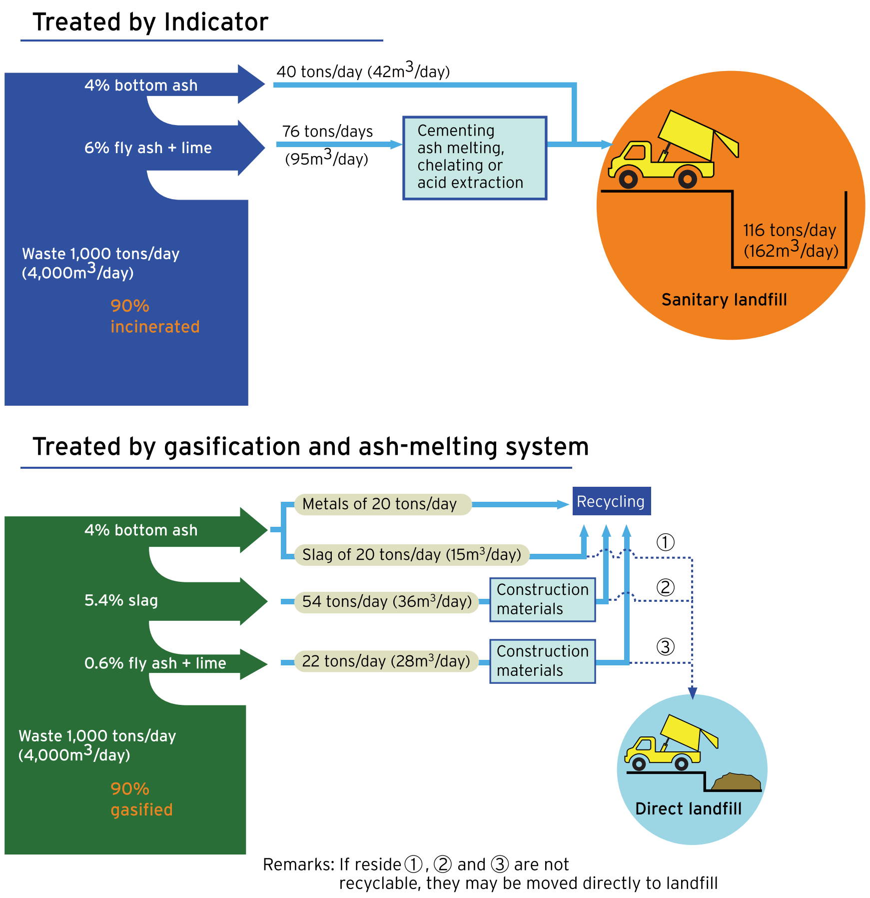
A comparison between a solid waste management system based on incineration and one based on fluidized bed gasification and ash-melting system shows a drastic reduction in the amount of residuals to be disposed of in the case of the latter (Figure 7.9).

Figure 7.9 - Comparison between wastes treated by incineration and by gasification and ash-melting system



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Box 7.2 - Resource recycling system: solid fuel production technology

The pre-treatment of wastes requires a number of different processes such as crushing, drying and deodorizing. An innovative hydrothermal pre-treatment system called Resource Recycling System (RRS) had been developed that can perform these three pre-treatment functions in one step using high pressure saturated steam. This technology is characterized by low energy requirements for drying. Figure 1 shows a schematic process flow diagram of the RRS hydrothermal treatment process. Figure 2 shows a photograph of a commercial hospital waste treatment facility using the RRS technology in Japan. The inner volume of the reactor is 3 cubic meters and this facility can treat 50-60 hospital waste boxes per batch. The average weight of one box is about 7 kg and one batch requires about 4 hours. The facility has been commercially operating for two years. Figures 3 and 4 show the photographs of raw material and products.

Solid wastes are fed into the reactor and then saturated steam at a temperature of 200^{o}C and pressure of 2 MPa is supplied into the reactor for about 30 minutes. The blades installed inside the reactor rotate to mix the wastes for about 10 minutes. The product is discharged after extracting steam. The product is a powder-like substance with moisture content similar to that of the raw material but dries easily upon exposure to the surroundings or under the sun. By producing a product that dries easily, the process results in low energy consumption. The product has no bad smell and can be used as liquid and solid organic fertilizer (if the feedstock is sewage sludge or food residue) or solid fuel (if the feedstock is mixed municipal solid wastes or cellulosic biomass such as wood) that can be mixed with coal for power generation or cement production. For the treatment of municipal solid wastes, the RRS technology has significant technical and commercial advantages over conventional incineration technologies since it is virtually emission free (no emission of dioxins, NO_x, SO_x, dust). The product can be utilized as a solid fuel for co-firing with coal and the capital and operating costs are just half of conventional incinerators. By increasing the pressure of the saturated steam to 2.5MPa, PVC can be converted into a harmless inorganic salt by reaction with the alkaline contents in the waste. Thus there is no chlorine emission or dioxin formation as in the case of conventional incineration.

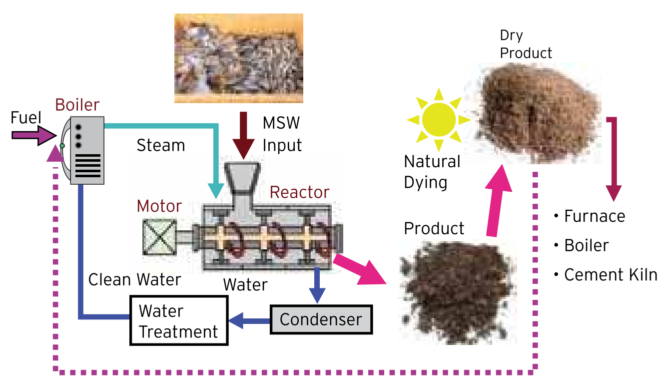

Figure 1 – RRS Hydrothermal treatment process

Figure 2 – RRS Hydrothermal commercial treatment facility

Figure 3 – Municipal solid wastes before and after hydrothermal treatment

Figure 4 – Wood feedstock before and after hydrothermal treatment

Source: Yoshikawa, K., Production of Useful Fuels and Electricity from Biomass and Waste Resources, Frontier Research Center, Tokyo Institute of Technology, Japan, 2010.

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ANNEX

One of the major projects funded by the Government of Japan and the ASEAN Foundation through the Japan-ASEAN Solidarity Fund (JASF) is the "ASEAN University Network – Southeast Asia Engineering Education Development Network" or the AUN/SEEDNet. Involving a partnership of 19 universities in ASEAN countries and 11 supporting universities in Japan, the project covers the period March 2008 to March 2010 with a total funding from the JASF of US$ 778,734. Nine engineering fields are included: chemical engineering, civil engineering, electrical and electronics engineering, geological engineering, information and communication technology, manufacturing engineering, materials engineering, and mechanical and aeronautical engineering. The specific objectives of the project include the following:

- To collect the most updated technology and research in each field;
- To disseminate the knowledge among experts and researchers in each field;
- To share and exchange experiences and research results among academicians, industry, community and policy makers; and
- To strengthen the collaborative relationship among universities, industry, community and policy makers.

The project is extended for another year covering April 2010 to March 2011 with additional funding from the JASF of US$ 392,863.

Five of the 26 scientific and technical conferences under the project include a number of papers that cover the area of energy, including new and renewable energy and biofuels. These are:

- First AUN SEEDNet Regional Workshop on New and Renewable Energy, Bandung, Indonesia, 12-13 March 2009.
- The 2009 ASEAN Symposium on Power and Energy Systems, Hua Hin, Thailand, 28-29 September 2009.
- Second AUN SEEDNet Regional Conference on New and Renewable Energy, Chonburi, Thailand, 21-22 January 2010.
- Regional Conference on Mechanical Engineering and Aerospace Technology, Bali, Indonesia, 9-10 February 2010.
- Second Regional Conference on Biotechnology, Phnom Penh, Cambodia, 11-12 February 2010.

The abstracts of selected papers that are of relevance to the subject matter covered in this book are presented in this annex for further reading and reference[1].

SELECTION OF THE OIL FEEDSTOCK FOR INDONESIA BIODIESEL PRODUCTION

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Abstract

The surging price of crude oil, together with environmental issue, has been encouraging many countries to seek alternative fuels. Since 2004, Indonesia became a net importer of crude oil. Some alternatives energy sources have been developed, such as Natural Gas and Coal, Hydropower, Geothermal and Biofuel. Two well-known biofuels commercially produced are biodiesel and bioethanol. As a large agricultural country, Indonesia has very big potential to produce biofuel. Currently, most biodiesel is commercially produced from vegetable oils by transesterification and/or esterification reaction. This is the most common process technology of biodiesel that has been proven in the world. The detailed process of biodiesel production varies between one another depending on the licensor. However, the principle of process is similar, which consists of esterification and/or transesterification reaction followed by glycerol separation and then ester (biodiesel) purification. Current world production of biodiesel is 2 million kiloliters per year. Certainly this number will increase. If all automotive diesel oil consumption in Indonesia is in the form of B10 (10% of biodiesel), there will be a demand of more than 3.1 million kiloliters of biodiesel per year in 2010. Oil producing plants can be classified into annual, biannual and perennial plants. In Indonesia, annual and biannual plants such as peanut, corn and soybean are cultivated, not for producing cooking oil, but for other purposes such as food and snack production. Many perennial plants such as oil palm, coconut, jatropha, avocado and rubber seed have higher oil content than those of annual and biannual plants. Palm oil, jatropha curcas oil and coconut oil have been identified as potential feedstock for producing biodiesel in Indonesia. The current potential production of Crude Palm Oil (CPO) and jatropha seed are 14 and 0.9 million tons, respectively. The expected potential production of CPO and jatropha seed in year 2010 is 24.9 and 17.7, respectively, in year 2010. It is concluded that to meet the Indonesia biodiesel demand in 2010 (in the form of B10), CPO will be the most possible choice for Indonesia biodiesel feedstock.

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[1] Since these abstracts have already been published in the proceedings of the various conferences, no further language or technical editing has been done. The abstracts are presented as they appear in the proceedings.

COST-EFFECTIVENESS OF BIOMASS POWER GENERATION IN CAMBODIAN RURAL ELECTRIFICATION AND CO2 MITIGATION

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Abstract

The current research analyzes the cost-effectiveness of biomass power generation in rural electrification in Cambodia. Biomass gasification technology is very important for increasing the rural electrification in the country. In 2007, only 21.3% of the households in Cambodia have access to the electricity grid (80% of the households in urban and 9.5% of the households in rural areas). The electricity production in the country is still high depending on the fuel oil combustion machine for a past decade. It is accounted for 90% of total electricity supply in the whole country. In the rural areas diesel is used completely to generate electricity. Due to the high fuel oil used in electricity sector and lack of grid connection, Cambodia has the highest electricity price in the region, approximately 0.5$/kWh. To achieve the government's target of 70% in rural electrification by the year 2030, this study found that around 2 million households are expected to access with the mini-grid which is supplied mainly by biomass power. At the same time, biomass gasification has a significant potential to mitigate CO_2 emission by about 1,050 thousand metric-tons and reduce the high diesel consumption by around 400 million liters for the rural electricity by 2030. However, the technology and capital investment in the biomass power generation remain concerning for achievement in the government's target. This study considers the possibility of cost-effectiveness of biomass power generation by comparing the levelized generation cost with the conventional supply in two cases: (1) incentive carbon credit in era of Kyoto protocol, and (2) no-incentive carbon credit from Kyoto protocol.

OPTIMIZATION OF MICROWAVE-ASSISTED SOLVENT EXTRACTION OF OIL FROM KENAF SEED

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Abstract

Factorial design and response surface methodology (RSM) with Central Composite Design (CCD) were used to optimize the microwave-assisted solvent extraction (MASE) of oil from kenaf (*Hibiscus Cannabinus L.*) seeds. The optimum operation conditions were finally obtained using ANOVA. A 23 factorial design was initially employed and it was found that solid/solvent ratio, temperature, time and interaction between time and temperature had an effect on extraction yield of kenaf seed oil. Results show that the maximum oil (16.5288%) obtained was at the conditions: ratio 1:10, 59°C and 19 minutes. The physicochemical properties of the kenaf seed oil obtained was determined to test its potential for biodiesel production.

STUDY ON SEVERAL PARAMETERS AFFECTING STIMULATION SACCHARIFICATION AND FERMENTATION PROCESS IN ETHANOL PRODUCTION FROM FRESH CASSAVA

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Abstract

The problem of environment was alerted with abuse of using fossil fuels. Bioethanol used as combined with gasoline to reduce consumption of petroleum fuels and in attempts to reduce air pollution was interested in many countries. Ethanol was nowadays mostly deprived from high starch sources, among them; cassava is one of popular feedstock in Vietnam. With the aim to develop technology of ethanol production, including of reducing resident time and improving ethanol efficiency, stimulation saccharification and fermentation process (SSF) was applied and investigated. As a result, the optimum conditions of SSF process are enzyme concentration of 0.2%; temperature for enzyme addition at 40°C, temperature for stimulation saccharification and fermentation at 30°C, pH 4.2-4.5, initial yeast of 0.2 g/l, urea supplement of 0.5 g/l, and time in 72h.

KINETICS OF PALM AND COCONUT OIL TRANSESTERIFICATION TO PRODUCE BIODIESEL

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Abstract

Biodiesel has proved as a viable substitute for petroleum diesel. The fuel can be made easily from either original or waste vegetable oil. A common means of production is base-catalyzed transesterification. The design of a reactor for the production of biodiesel requires the information about kinetics of oil transesterification to receive methyl esters. In this work, palm and coconut oil transesterifications were case studies. Methyl esters were produced by transesterification of palm and coconut oil with methanol in the presence of a catalyst (NaOH). The rates of transesterification at various temperatures in a batch reactor were investigated. Reaction rate equations were modeled. The resulting model was compared with results obtained from experiments to extract kinetic parameters. Finally, the kinetics of palm and coconut oil transesterification were established.

ALCOHOLYSIS OF SUNFLOWER OIL TO PRODUCE BIODIESEL

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Abstract

Biodiesel has been used as an alternative diesel oil due to limited resources of fossil oil, environmental concern and more over increasing oil price. Transesterification of sunflower oil with alcohol was catalyzed by 1% KOH with 6:1 of alcohol to oil molar ratio, 75 minutes reaction time. Alcohols used were methanol and ethanol. Experiments were investigated under various temperatures, i.e., 303 to 343K with interval 10K. The free glycerol formed was analyzed by using periodic acid and the concentration of alkyl ester was evaluated by mass balance of free glycerol. The optimum condition was attained at 333K for methanol and 343K for ethanol. The highest conversions were 99.19% (at 333K) and 98.14 % (at 343K) for methanol and ethanol, respectively. The properties of ester including flash point, carbon residue, cloud point, viscosity and density were analyzed and found to comply with standard values of diesel oil and fuel oil.

INVESTIGATION ON THE COMBUSTION CHARACTERISTICS AND EMISSIONS OF A DIESEL ENGINE USING PREHEATED BIODIESEL OIL

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Abstract

The experimental investigation of this work was to reveal the effects of fuel temperature on the combustion characteristics and emissions of a diesel engine. A single cylinder direct-injection diesel engine, which is modified from four cylinders engine, was used in this work and tested using preheated biodiesel oil as fuel. Preheated fuel was preheated prior to injecting it into the combustion chamber. The testing was conducted at constant speed of 2,000 rpm and 80 % of maximum load. In the study, analysis of in-cylinder pressure data for energy release pattern and emission data was performed. Results show that when the fuel is preheated from 47^{0}C to 90^{0}C, the spray pattern and combustion characteristics are changed moderately. In addition, preheated biodiesel oil leads to slightly retard injection timing and reduces the combustion duration. Then, analysis of the energy release period revealed that fraction of premixed combustion phase increases while that of mixing-controlled combustion phase decreases. This causes the rising of nitrogen oxides and exhaust gas temperature but the reducing of black smoke in the exhaust gas.

EFFECTIVENESS OF COMBINED ADDITIVES ON LONG-TERM STORAGE STABILITYAND FUEL PROPERTIES OF PALM-BIODIESEL

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Abstract

The use of biodiesel is expanding rapidly around the world, making it imperative to fully understand the impacts of biodiesel on diesel engine as they have slightly different properties compared with conventional diesel. This has led to the establishment of biodiesel standards in many countries that focused on several key fuel properties where producers must conformed with. As with other natural substances, if left untreated, biodiesel is susceptible to oxidative degradation that may be caused by long period of storage. The degradation of biodiesel leads to the formation of lower molecular weight acids, peroxides and gums that, in turn, could cause unwanted changes in both the properties and performance of the biodiesel. These deposits and gums can cause damage to the engine and also to the fuel injection systems. This paper aims to investigate the changes on several key properties of palm-biodiesel after a storage period of 1, 2 and 6 months. The fuel samples were divided into two groups – samples with combined additives and samples without any additives. The fuel was stored in transparent High Density Poly Ethylene (HDPE) box without sunlight exposure at room temperature. Fuel properties were measured after the stipulated storage period and the results from the two groups were compared against the established standards. The results had shown that fuel samples with added additives were better protected against rapid deterioration due to oxidation than those without, particularly during extended storage duration.

BASIC CHEMICAL REACTION STUDY ON BDF (BIODIESEL FUEL) PRODUCTION FROM PLANT OIL

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Abstract

This research has been conducted to clarify the BDF (biodiesel fuel) production reaction to optimize the reaction conditions for maximizing the yield of BDF by using plant oil as raw material. The amount of raw corn oil for each batch is 100g and two methods were utilized for BDF production, the mechanical stirring method and the emulsification method (emulsification mixing of raw oil and methanol dissolving KOH followed by mechanical mixing). The main parameters for the mechanical stirring method are the mole ratio between methanol and raw material, the amount of catalyst (only KOH are utilized) and the reaction temperature. The results on the mechanical stirring method show that the yield increase when methanol is increased but if methanol is added excessively, the weight yield drops because the excess methanol is mixed into the glycerol part. Only a small amount of catalyst can give enough yield while the exceed catalyst also decreases the yield. The higher temperature gives higher yield and completes the reaction faster. However, at high temperature, the yield decreases due to the evaporation of methanol. So it can be summarized that it is possible to optimize the reaction conditions for maximizing the yield of BDF. The results of emulsification method gave higher yield of BDF than the mechanical stirring method, with subsequent decrease of the yield due to the decomposition reaction of BDF. These results suggest that there should be optimum mechanical mixing time following the emulsification in order to obtain higher yield of BDF than that obtainable by conventional mechanical mixing methods.

THE EFFECT OF PME AS THE PILOT INJECTION IN LPG-PME DUAL FUEL IN AN IDI COMPRESSION IGNITION ENGINE

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Abstract

This investigation which aimed to identify the effect of biodiesel as the pilot injection in dual fuelled engine can be divided into 2 parts. Firstly, combustion characteristics of liquefied petroleum gas (LPG) premixed charge-palm biodiesel (PME) dual fuelled engine was studied. Next, the investigation continued with varied injection timing for neat liquid as well as dual fuelling to fulfill a comparison. Test bench experiments (steady state) were conducted with a 4-cylinder indirect injection (IDI) compression ignition (CI) engine, at selected high probability operating points corresponding to the ECE15+EUDC cycle, covering the range [10-70] Nm @ [1250-2750] rev/min. The engine ran at overall lean mixture. The LPG-air premixed mixture was maintained at four fixed values by an electronic controlling system. The acquired data included basic parameters, pressure history of fuel line and combustion chambers. The comparative analysis deal with: energy conversion efficiencies, specific total energy consumption, liquid fuel substitution, net heat release. A new approach to determine the start of injection (SOI) based on fuel line pressure data was also proposed. PME provided smooth, knock-free dual fuel operation, at all planned test points and LPG-air premixed charge, with the energy conversion efficiency deterioration increased at lower speeds and higher LPG ratios. Achieved substitution was about 26%-27% at high speed, load and 60%-65% at low speed, load. Ignition delays which retarded within 1.2OCA with LPG-PME, especially at low speed, increased LPG. The start of combustion which was found to advance in LPG-PME due to their shorter ignition delays and advanced SOI caused by the higher bulk modulus and viscosity of the PME. LPG-PME produced faster combustion compared to the neat liquid fuel, leading to

reduced exhaust gas temperatures and the centers of heat release area's moving of towards top-dead-center (TDC). While the coefficient of variation of indicated mean effective pressure (IMEP) was comparable, the combustion noise of LPG-PME was slightly higher. The original equipment manufacturer (OEM) injection timing setting was suitable for LPG-biodiesel combustion.

IMPACT OF USING ETHANOL FUEL IN CONVENTIONAL MOTORBIKE

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Abstract

The objective is to study the impact of using ethanol fuel in conventional motorbike and modify the conventional motorcycle engine using ethanol fuel. The conventional motorcycles with fuel injector and carburetor system were selected for this study. The fuel supply systems were modified for the ethanol fuel. The fuel injection duration was increased to compensate the lower heating value of ethanol. The engine performance, fuel consumption and emissions were measured after modification. The experimental results show that brake horse power increases 29% when using ethanol fuel. The brake specific fuel consumption increases 38%. CO, HC and NO_x emissions were reduced about 17.6%, 38.3% and 54.7%, respectively. This study shows the possibility of engine modification to use the alternative fuel of ethanol in Thailand.

PRODUCTION OF BIODIESEL BASED CAT-FISH FAT AND ASPECTS OF USE IN CONVENTIONAL ENGINES

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Abstract

The paper presents biodiesel production based on cat-fish fat in Vietnam and summarized experimental results of utilization of biodiesel B5 in engines. Impacts of biodiesel B5 on engine performance, exhaust emissions and durability were investigated and discussed. To target these, two engines were experimented on engine test-bed, one used market diesel and another was fueled with biodiesel B5 fuel. Findings of the comparative experiments and 300 hours durability tests show positive impacts of biodiesel B5 on engines in general, except the increase of NO_x. The engine's power and fuel consumption were improved up to 1.33% and 1.39%, respectively. Exhaust emission components HC, CO and PM were reduced in turn up to 14.46%, 12.94% and 2.57%. While NO_x emission component was increased up to 3.80% due to high temperature, it resulted in better combustion process. In addition, no damage to the engine parts was found during the tests with biodiesel B5. The engine fueled with biodiesel B5 showed smaller changes in all parameters during the durability test compared with the engine fueled with diesel. These findings are very important to ensure the utilization of this alternative fuel in engines in Vietnam.

PERFORMANCE AND EMISSION CHARACTERISTICS OF OZONATED COCONUT OIL AS A BIOFUEL FOR DIESEL ENGINES

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Abstract

This work examines a biofuel for diesel engines produced by two successive ozonation-filtration processes developed and promoted by Frontier Japan Inc., (FJI). Filtered crude coconut oil was utilized as feedstock for biofuel production using process parameters originally set by FJI. Selected fuel properties were measured during the process to determine their variation with the different stages of the ozonation-filtration processes. The resulting biofuel, ozonated coconut oil, was blended with neat diesel fuel at 1, 3, 5, 7.5, 10, and 20 percent by volume and tested on a chassis dynamometer using the Japanese 10-15 Mode driving cycle to determine performance and emissions characteristics. Results of measurements indicated that the first filtration stage yielded the most significant reduction in viscosity and cloud point, during the entire process. Flash point was significantly reduced after the first ozonation stage. These results suggest the importance of the first filtration stage in improving the selected biofuel properties thus warranting a more detailed study in the future. Chassis dynamometer test results showed that emissions of CO_2, NO, NO_2, NO_x and THC for blends up to 10% ozonated coconut oil were not considerably different from those of neat diesel fuel. The 20% blend gave 9.5% less CO_2, 14.6% less NO, 10.5% less NO_x, 19.5% less THC than neat diesel fuel. From the standpoint of emissions and fuel economy, the 20% blend showed the best results among the ozonated coconut oil-diesel blends tested. It is recommended for future studies that the filtration stages in the entire ozonation process be examined in more detail in terms of effects on oil properties. Also, similar studies should be done on other vegetable oils with more polyunsaturated components as feedstock .

METHYL ESTER OF MEDIUM-CHAIN FATTY ACIDS: A POTENTIAL BIOFUEL FOR JET ENGINES

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Abstract

The air transport industry is currently looking for appropriate biofuel for blending into, or substituting, the fossil-based jet fuel. Using the critical specifications of jet fuel and biodiesel as comparison references, examination of the fuel-relevant properties of fatty acid methyl esters (FAMEs) indicates that the medium chain FAME is a potential candidate for use as jet biofuel. A result of medium chain FAME's smoke point test confirm the proposition. Ozonolysis of a non- edible oleic-linoleic fatty oils is suggested as a promising route for producing the medium chain FAMEs.

STUDY ON COMBUSTION AND EXHAUST GAS EMISSION IN A DIRECT INJECTION DIESEL ENGINE WITH COMMON RAIL FUEL SYSTEM USING JATROPHA CURCAS L. BIODIESEL FUEL

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Abstract

Southeast Asian (ASEAN) countries in general have high potential sources to produce biofuels by its own geographical location in tropical areas. Jatropha Curcas L. oil (JO) is a non-edible, non-exploited and a renewable source for diesel engine fuel. There is no study using common rail fuel system for Jatropha Curcas L. Oil Fatty Acid Methyl Ester (JME) or biodiesel fuel. The purpose of this study is to observe combustion and exhaust gas emissions in a direct injection diesel engine with common rail fuel system which already use in developed countries and in the future it will be used in ASEAN country also using JME. The engine brake specific fuel consumption (BSFC), engine thermal efficiency, in-cylinder pressure, exhausted gas emissions are measured and they are being compared to standard gas-oil fuel. This study hopefully provides the basic understanding to use JME in developed and ASEAN countries.

A STUDY OF PERFORMANCE OF ENGINE RUNNING ON BIOETHANOL FUEL AND ITS EFFECT ON A FOUR-STROKE ENGINE COMPONENTS

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Abstract

Indonesia is blessed with relatively abundant potential of renewable energy biomass potential of around 50 GW. However, the utilization of biomass in Indonesia is still very low compared to its huge potential. Another political driver encouraging the use of biomass is that are local to generate energy, employment and economic benefits compared to imported fossil fuel. Bioethanol is an alternative for gasoline engine fuel that is produced from cassava (ubi kayu). Cassava is a kind of agriculture product that grows in tropic and sub tropic areas. Indonesia, as a tropical country, has high potential to produce cassava in large scale and is one of the income sources that cannot be disregarded. Ethanol is produced from raw material cassava, the carbohydrate content is the main composition of cassava to converted into alcohol, alcohol fermentation is a carbohydrate decomposition process become ethanol ($2C_2H_5OH$) and CO_2. The experiment is conducted on a single cylinder naturally aspirated and air cooled, horizontal type, four-stroke, spark ignition engine, type OH195 – EA (Robinson) and has the power engine 4HP/3750 rpm, as an engine test bed. In this experiment will to see the engine running with the fuel mixing between gasoline and bioethanol, performance parameters and emission will be recorded. And also this experiment will to see effect of bioethanol fuel mixing with gasoline on the engine components.

INFLUENCE OF INJECTION TIMING ON PERFORMANCE AND COMBUSTION OF AN IDI ENGINE FUELED WITH DME

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Abstract

The influence of injection timing on performance and combustion of a small indirect injection (IDI) engine fueled with DME has been investigated. The DME characteristics and engine conversion requirements are introduced. The investigating results of changing DME injection timing was revealed that the maximum engine performance and fuel conversion efficiency was improved when employed a modified cam for advance injection timing of 4 degree CA. Some injection delay due to the compressibility effect of DME was found. The results also show that DME will be suddenly burnt after injected into the engine combustion chamber.

OPTIMIZATION OF A LIGHT-EMITTING DIODE (LED)-BASED PHOTOBIOREACTOR SYSTEM FOR OIL PRODUCING ALGAE SPECIES NANNOCHLOROPSIS OCULATA SP.

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Abstract

Algae are efficient converters of solar energy. Algae photosynthesis can sequester carbon dioxide emissions to produce natural products like lipids, carbohydrates and proteins for use as human food components, nutraceuticals, animal feeds, aquaculture nutrients and biofuels. The optimization of the photosynthetic process with respect to lighting, plant nutrients, carbon dioxide feed and growing conditions may lead to the maximization of total algal biomass yield. The present study has focused on finding a working practical set-up of a photobioreactor for oil-producing algae species. Work on the eicosapentanoic acid (EPA)-producing algae species *Nannochloropsis oculata sp*. has proven that certain wavelengths of light affect different stages of algal growth. Algae cell size is found to increase when algae is exposed to light at 680 nm, whereas algae cell production is found to increase under light at 470 nm. The marine *Nannochloropsis* species is also found to survive in fresh water media at temperatures lower than 35ºC and is generally stable at brackish salinities of 15-23%. Photoperiods with longer light exposure was found to favor the growth of *N. oculata*. Work on carbon dioxide feed done through the bicarbonate pathway is found to be more efficient than bubbling pure carbon dioxide (CO_2) and is as effective as bubbling compressed air.

MICROALGAE CULTIVATION USING WASTEWATER FROM A PICKLE FACTORY

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Abstract

Evaluation of growth and chemical composition of *Spirulina platensis* in batch cultures utilizing a complex medium containing wastewater from a pickle factory supplemented with urea or effluent from storage pond was undertaken. Response to light intensity and salinity was reported. Biomass concentration (as dry weight) and protein content of cultivation in complex medium were lower to those observed in the inorganic Zarrouk medium, regardless of the light intensity. Increasing salinity of the medium reduced biomass and protein concentration, but considerably increased low molecular weight carbohydrate concentration. High level of gamma linolenic acid (GLA) as a percentage of total fatty acids was observed in the biomass harvested from the complex medium.

CONVERSION OF MUNICIPAL SOLID WASTE INTO COAL CO-FIRING FUEL BY HYDROTHERMAL TREATMENT

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Abstract

In this paper, experimental results of the hydrothermal treatment developed by Tokyo Institute of Technology will be presented. Raw municipal solid waste (MSW) was treated by utilizing saturated steam at various temperatures ranging from 215 to 235ºC, with varied holding period from 30 to 90 minutes in a stirred reactor. The treatment yielded slump products which were then naturally dried to around 5% moisture content in 72 hours, resulting in a uniform, odorless powder with final heating value of around 20 MJ/kg. Thermogravimetric analysis of product blended with various coals showed that even though the blending initiated early volatile release, ignition behavior did not just depend on the blend composition but also depended on the blended coal rank, raising confidence to coal co-combustion application. It was also observed that by hydrothermal process, the organic chlorine compound in MSW was converted into inorganic chlorine, reducing its content to 2,000 ppm level. The inorganic chlorine was then removable by water washing. The results show that considering the heating value, combustion characteristics and chlorine content of the product, the hydrothermal treatment would be a good alternative for MSW treatment.

UPGRADING OF MUNICIPAL SOLID WASTE AS SOLID FUEL TO SUBBITUMINOUS COAL GRADE BY TORREFACTION PROCESS

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Abstract

National primary energy source is still based on fossil fuels, namely, oil, natural gas and coal. With population and per capita energy consumption is likely increasing, the intensive efforts to seek the alternative energy sources are needed. Municipal solid waste (MSW) has the potential to be processed into alternative energy resources. One of the MSW processing technology that promises to produce higher quality solid fuel compared to its raw material is torrefaction. Torrefaction is a heat treatment process at a given temperature (for biomass is usually between 200-300^{0}C), which performed at atmospheric pressure in the absence of oxygen. The objective of the research is upgrading MSW to high quality solid fuel by torrefaction process. The torrefaction process on MSW is expected to produce the high calorific value solid fuel as well as subbituminous coal grade.

COMBUSTION PROPERTIES, PERFORMANCE AND NET ENERGY BENEFITS OF JATROPHA BIO-COALS BRIQUETTES

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Abstract

Bio-coals are coal-biomass briquettes and are used as seamless substitute for coal in process heating and power generation applications. The high heating values of Jatropha press cake residues provides a very promising pair with coal for such applications. The study investigated the combustion properties, performance and net energy balance of various (100%, 50%, 20%) carbonized Jatrophacoal and plain Jatropha-coal briquette blends. Heating value, proximate analysis and combustion efficiency of each blends were tested. A fuel cycle-based energy accounting to determine the net energy and fossil energy requirement of each was implemented. Results showed that both carbonized and non carbonized jatropha press cakes have heating values far higher than lignite coals. 100% carbonized and non carbonized briquettes and 50% carbonized jatropha and coal blends provided net energy production higher than coal. Despite having greater fuel preparation energy requirements, all of the briquette blends tested provided lower fuel cycle fossil energy consumption. The findings validate the potential of jatropha bio-coals as a possible substitute for coals in industrial applications.

COMBUSTION OF PYROLYZED JATHROPA SEED CAKES, CORN COBS AND CASSAVA PEELS AS A FUNCTION OF AIR SUPPLY

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Abstract

Intensive agricultural, forestry and industrial activities in Indonesia unexpectedly deliver plentiful organic wastes. They can contaminate the environment unless properly treated and reused as fuels. In order to substantially increase the calorific values of raw wastes, they can be carbonized (pyrolyzed) prior to briquetting. Experimental researches are carried out to identify the combustion behaviors of carbonized organic wastes. The investigated residues are jatropha curcas (physics nut) seed cakes, corn cobs, and cassava peels. Those materials are formed as cylindrical briquettes with 16 mm diameter. The combustion characteristics are mass reduction, combustion rate, combustion gas temperature, and CO emission. The burning experiments are conducted with a constant furnace wall temperature of 400^{0}C and various air velocities of 0.1, 0.2 and 0.3 m/s. The amount of air supply is obviously very essential in all combustion processes. As expected, increased air velocities will reduce the burning times and the CO emission levels, but the instantaneous combustion rates and gas temperatures exhibit only slight influence of the air supply change.

The following papers were presented at the First AUN SEEDNet Regional Workshop on New and Renewable Energy held in Bandung, Indonesia, on 12-13 March 2009 with no abstracts. Thus only the titles and authors of the papers are presented here.

Polymeric Membrane Application for Biodiesel Transesterification
Associate Professor S. C. Low, School of Mechanical and Aerospace Engineering
Nanyang Technological University, Singapore

Consistent Sets of Pure FAME Fuel Properties for Biodiesel Raw Materials Blending Calculations
Deuansavanh Phommavongsa[1], Dr. Iman K. Reksowardojo[1], Dr. Tatang H. Soerawidjaja[1],
Prof. Wiranto Aridmunandar[1], Assoc. Prof. Toshio Shudo[2]
[1]Institute of Technology Bandung, [2]Hokkaido University

Reactive Distillation Method for the Production of Biodiesel
Kusmiyati
University Mahammadiyah Surakarta

Ethanol Fuel Impacts on Existing Vehicles in Thailand
Dr. Chinda Charoenphonphanich, Head of Automotive Technology Laboratory
Department of Mechanical Engineering
King Mongkut's Institute of Technology Ladkrabang, Thailand

Experimental Study on the Performance of Yanmar NS70 Using Jatropha Curcas Oil
N. Kollika and R. Sopheak
Institute of Technology of Cambodia

Investigating Effects of Using Gasohol E5 and E10 on Engine Performance,
Fuel Consumption and Exhaust Emissions: A Case Study in Vietnam
Le Anh Tuan, Pham Minh Tuan, Tran Quang Vinh, Nguyen The Luong
Hanoi University of Technology

Evaluation of Combustion, Emissions and Properties of Some Biodiesel Mixtures in a Direct Injection Diesel Engine
An Tuan Pham[1], Dr. Iman K. Reksowardojo[1], Dr. Tirto Prakesono[1],
Associate Prof. Toshio Shudo[3], Associate Prof. Mai Xuan Pham[2]
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Evaluation of Combustion, Emissions and Properties of Some Biodiesel Mixtures in a Direct Injection Diesel Engine
Reksowardojo[1], Dr. Tirto Prakesono[1], Assoc. Prof. Toshio Shudo[3],
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Performance, Smoke Characteristics and Economics of Pre-heated Used Vegetable Oil Utilization in Philippine Public Utility Jeepneys
Dr. Archie B. Maglaya, Chair and Professor, Mechanical Engineering Department,
De La Salle University Manila, Philippines, and
Dr. Jose Bienvenido Manual M. Biona, Professor, Mechanical Engineering Department, Don Bosco Technical College, Mandaluyong City, Philippines

ASEAN FOUNDATION

The ASEAN Foundation

Established by the ASEAN Leaders in December 1997 during ASEAN's 30th Anniversary Commemorative Summit, the ASEAN Foundation primarily aims to bring about shared prosperity and a sustainable future for the peoples of the ten ASEAN member countries, namely, Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand and Viet Nam. The Foundation is mandated to undertake a two-fold mission: (1) to promote greater awareness of ASEAN, and greater interaction among the peoples of ASEAN, as well as their wider participation in ASEAN activities through human resources development; and (2) to contribute to the evolution of a development cooperation strategy that promotes mutual assistance, equitable economic development and the alleviation of poverty.

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The ASEAN Foundation is based in Jakarta, Indonesia.

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In May 1998, H.E. Mr. Keizo Obuchi, Minister for Foreign Affairs of Japan, announced a contribution of US$20 million from the Government of Japan to the ASEAN Foundation to support projects in the areas of education, human resources development, business exchanges and other activities to promote development of the ASEAN region and strengthen Japan-ASEAN cooperation.

To date, almost US$18 million of the Fund has been utilized and allocated to support over 100 projects for building capacity and developing human resources, promoting interaction among various ASEAN stakeholders, enhancing ASEAN awareness and identity and alleviating poverty. Unless otherwise stated, projects of the ASEAN Foundation are funded by the Japan-ASEAN Solidarity Fund.

Dr. Filemon A. Uriarte, Jr.

About the Author

Dr. Filemon A. Uriarte, Jr. is the Executive Director of the ASEAN Foundation. He is formerly Cabinet member of the Philippine Government as Secretary (Minister) of the Department of Science and Technology; Principal Officer, Office of the Executive Secretary, and Director, Information, Communication and Space Technology Division, United Nations ESCAP; Director for Functional Cooperation, ASEAN Secretariat; and Chairman, Department of Chemical Engineering, University of the Philippines. In the private sector, Dr. Uriarte was President and CEO of several companies such as LAUDS Technologies, Inc. and TEST Consultants, Inc. and Vice President of Philippine Vinyl Consortium, Inc.

Dr. Uriarte earned his B.S. and M.S. degrees in Chemical Engineering from the University of the Philippines and Ph.D. in Chemical Engineering from Carnegie-Mellon University in the United States. Over the years, Dr. Uriarte has received numerous awards and citations for his outstanding contributions as an engineer, scientist and manager, including Ten Outstanding Young Men (TOYM) in 1974, Most Distinguished Chemical Engineering Alumnus of the University of the Philippines, and Outstanding Chemical Engineer in the Philippines from the Professional Regulation Commission. He is listed among the Outstanding Leaders of the Philippines (Who's Who in 1980) and a member of the Phi Kappa Phi Honor Society. He is an Academician of the National Academy of Science and Technology and has written two earlier books: *Solid Waste Management: Principles and Practices* published by the University of the Philippines Press (2007) and *Introduction to Knowledge Management* published by the ASEAN Foundation (2008).

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