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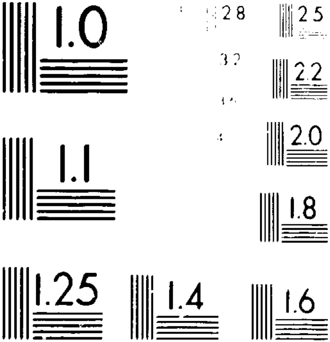
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STUDY ON THE

ALTERNATIVE SUBSTITUTES FOR

DIESEL ENGINE FUEL

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for

Special Advisory Group on Energy

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

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SUMMARY AND CONCLUSIONS

In many rural areas of developing countries the generators for electricity production are driven by diesel engines. The cost of the diesel fuel in those areas is usually very high, mainly due to the costs of transportation and distribution. This has become a matter of concern to UNIDO, which, at present, is exploring the possibilities of finding alternatives to diesel fuel, for total or partial substitution. UNIDO also intends to take necessary actions to assist developing countries in the development and utilization of such substitutes.

In view of the foregoing, in Part 1 of this study all the potential sources for diesel fuel substitution have been assessed, and from among the eight broad categories of these sources, three have been selected as the most promising options. These three are: a) vegetable oils and their esters, b) producer gas, and c) biomass-derived alcohols (ethanol and to a lesser extent methanol).

Part 2 of the study consits of recommendations to UNIDO for action in order to promote the development and utilization of the diesel fuel substitutes. It is recommended that UNIDO should at first bring to the attention of policy makers in developing member states the idea that diesel fuel substitution is possible in many cases and can be very beneficial to the country. Those developing countries that show positive response should be asked to formally commit themselves and sign a co-operation agreement with UNIDO and designate a national project leader as the liaison as well as an institute with overall initial responsibility for the project. It is also recommended that UNIDO have a team of specialized personnel of its own in this sector and at the same time have access to outside consulting firms and experts in order to help the relevant member states.

It is further recommended that UNIDO give technical assistance in the areas of planning, conducting studies, and carrying out projects with regard to the related programs of diesel fuel substitution. UNIDO should publish a series of documents on the subject matter, organize study tours, possibly set up regional demonstration projects and build up an effective monitoring system for follow-up action.

INTRODUCTION

This study deals with the most promising substitutes for diesel engine fuel. The question arises from the fact that in rural areas of many energy-deficient developing countries the cost of diesel fuel is excessively high. In some parts of Latin America, for example, the cost is two dollar per liter of diesel fuel.

The purposes of this study are:

a) to review potential substitutes for diesel fuel, which is used in stationary engines in rural areas of developing countries;

b) to identify the most promising options among these potential substitutes; and

c) to recommend to UNIDO the actions which should be taken in order to promote the development, production, and utilization of such substitutes by energy-deficient developing countries.

In carrying out this study, the consultant had access to a great deal of literature and publications which were made available to him by the UNIDO Special Advisory Group on Energy. The consultant also gathered information from libraries at the Vienna International Center and elsewhere and from discussions with UNIDO staff. Most of the publications, however, deal with vehicular diesel engines and to a lesser extent farm machinery. Relatively few publications cover diesel engines for electricity generation in rural, remote areas. Nevertheless, it is possible to draw parallels between diesel engines in general and those under consideration in this study. For example, increases in size and weight of a diesel engine to accommodate a substitute fuel is a source of major concern for vehicular application, but is of minor importance for a stationary unit.

PART 1

1.1. DIESEL ENGINES

The diesel engine, developed towards the end of the nineteenth century, offers a higher thermal efficiency than that of other internal combustion engines. The necessary air for the combustion is compressed to such an extent that its temperature reaches 500° - 550° C. An injection system atomizes the fuel, and combustion is initiated by the high temperature of the compressed air.

As compared to spark-ignition gasoline engines, diesel engines:

- are heavier and sturdier
- have a longer life
- operate at a higher temperature
- have a higher compression ratio
- consume less fuel
- operate on a fuel which is nonvolatile and much safer to handle than gasoline
- are characterized by fuel injection system and compression ignition.

Diesel engines have wide applications in heavy vehicles, such as trucks and buses, rail transport, ships, etc. They are also commonly used for stationary electricity generation. Until recently their popularity for passenger cars has been limited, due to their weight, cost and noise.

Diesel engines can be divided into two basic types as explained below. Diesel fuel substitutes yield different results when tested in these two engine types:

a) direct injection diesel engines

This type of engine is in common usage and most of the slow-speed, large engines have direct injection systems with a single combustion chamber. Some of the problems in these engines arise from the interaction between fuel spray and the air flow.

b) indirect injection diesel engines

Indirect injection diesel engines with a pre-combustion chamber, have been develcped to overcome the problems associated with the direct injection engines. The pre-combustion chamber is rather small, about one fourth of the size of the combustion chamber in which all the fuel vaporization takes place and no droplet of the fuel enters the main combustion chamber. The combustion is smooth, complete, and usually suitable for high speed diesel engines.

1.2. DIESEL FUEL

Diesel fuel is a middle distillate derived from crude oil refining. Its specifications are as follows:

- Specific Gravity	0.750 - 0.935
- Calorific value	18,500 - 19,000 Btu / lb or 145,000 - 150,000 Btu / gallon
- Viscosity at 100° F	1.4 - 5.8 centistokes
- Cetane Number	30 - 60 (45 - 55 is a more common range)
- Sulfur	1 % by weight
- Ash content	0.1 % by weight
- Flash Point	55° C

Each country usually has certain regulations for the specifications of the diesel fuel marketed in that country. The manufacturers of the engines also recommend a type of fuel for the best performance of the engine.

Among the above-mentioned specifications, two are very important. Cetane number (rating) indicates the fuel auto-ignition qualities. In other words, a low-cetane number fuel cannot initiate combustion. There are cetane improver chemicals such as amyl nitrate and hexyl nitrate, but these additives are usually costly and the quantities used are kept to a minimum.

Viscosity is another important factor. High viscosity fuels create problems in diesel engines operations and start-up, particularly in cold regions. On the other hand, very low viscosity fuels lose their lubricating quality which has an adverse effect on engine life.

Stationary diesel engines can use a much heavier fuel (20° API gravity) within the range of diesel fuels, as compared with other diesel engines (40° API gravity).

1.3. CRITERIA FOR SELECTION OF DIESEL FUEL SUBSTITUTES

The qualities and characteristics which determine the suitability of candidate substitutes fall into economic, technical and environmental categories. In reality, the situation is likely to require some compromise or trade-off in attributes, to seek ways of improving certain qualities, or to use the substitute as an extender of the diesel fuel.

1.3.1. Economic Considerations

a) availability and abundance of local resources

If the quantities of the resource is only sufficient to support a limited production level, then the substitute will only partially replace diesel fuel.

b) availability of production technology

The substitute production technology should be either available locally or easily obtained. If the technology is not available at present, it must be within near reach insofar as the necessary time and development are concerned. The technology must also provide efficient conversions of raw material to the new fuel.

c) project economic viability

The entire project of the substitute production should be economically viable. The unit cost of production should be competitive with the cost of delivered diesel fuel as well as with that of other substitutes. Furthermore, if a substitute can be derived from more than one source, naturally the most economic route must be chosen.

d) low capital investment for substitute production

e) storage and distribution suitability

The storage and distribution of the substitute should be suitable for the existing network or require minimum modification.

f) short lead time for substitute production

g) socio-economic aspects

The development of substitutes should be integrated with the national plans of the developing country.

It should be emphasized that in certain cases the substitute production may not be economically competitive, but a country may opt for such a project for reasons of saving foreign exchange, job creation, etc.

The production and utilization of the substitute should be in line with consumer behavior.

1.3.2. Technical Considerations

The desired attributes of the substitute include:

a) a relatively high calorific value

b) lubricating qualities

c) auto-ignition qualities (a high cetane rating)

d) a viscosity suitable for diesel engines

e) no damaging corrosive effects

f) satisfactory tests as a fuel for diesel engines

g) quick start-up and turn-down of diesel engines

h) low engine maintenance

i) suitability for the present engine population

Ideally the engines could alternatively run on the new feul and diesel fuel. If engine modification is necessary, it should be minor.

j) simple facilities for storage and handling

1.3.3. Environmental and Safety Considerations

a) production of substitutes should not be damaging to the environment. The substitute should not be toxic and its handling should not endanger the safety of the people.

b) the polluting emissions of engines which run on the substitute should not exceed the permissible levels

These emissions are:

- NO_x emissions (nitrogen oxides)
- hydrocarbon emissions
- carbon monoxide emissions
- aldehyde emissions
- particulate (shoot) emissions
- noise

1.4. ASSESSMENT OF POTENTIAL SUBSTITUTES

1.4.1. Vegetable Oils

Vegetable oils are produced from many varieties of sources; these sources include:

- Soya beans
- Oil palm
- Rape seeds
- Coconut palm
- Cotton seeds
- Castor seeds
- Safflower seeds
- Linseeds
- Peanuts
- Sunflower seeds
- Sesame seeds

The total world vegetable oils production at present is estimated to be sixty million tons per year. The most important sources for production quantities are:

a) Soya beans: The world oil production in the year 1985 is projected at 16.9 million tons. Of this figure, the USA will produce 10, Brazil 3, and China 1,6 million tons.

b) Oil palm: The entire oil production in the year 1985 is projected to be 6 million tons. Of this figure, Malaysia will produce 3.4 million tons

c) Coconut palm: The total oil production for the year 1985 is projected to be 3.2 million tons, of which the Philippines will produce 1.5 million tons. The entire production of coconut oil is in the developing countries.

In many developing countries, oil extraction from oilseeds is for subsistance and is normally carried out at a village level scale. On a commercial basis, mechanical and/or chemical means can be employed for oil extraction. Mechanical methods require the utilization of expellers; chemical methods are based on solvent extraction.

After the oil has been extracted from the oilseeds, it is filtered to remove impurities, and is refined to remove unpleasant odors and colors.

The number of developing countries which produce the bulk of the seed oil in the developing world is less then twenty. Therefore, many developing countries are dependent on seed oil imports. Seed oils as such, in developing countries, are produced or imported mainly for edible purposes, and this market is far from being saturated. On the contrary, in industrialized countries, per capita consumption of seed oils seems to have reached the saturation level.[30] Seed oils can also be used as raw materials for making soaps, detergents, and paints.

Vegetable oils as fuel have the advantages of being renewable resources, liquid form, and a high calorific value. As an example, rape seed oil has a calorific value which is about that of diesel fuel. Vegetable oils have a range of viscosities, usually between eight and twenty-five times greater than that of conventional diesel fuel. When vegetable oils are used as diesel fuel, their high viscosities cause a series of problems, including carbon deposition in cylinders and around injection nozzles, and also the fouling of crank-case oil. High viscosity is more problematic in cold climates. However, transesterification is a fairly simple chemical process, by which ethanol and methanol can convert vegetable oils to ethyl-ester and methyl-ester respectively.

In this manner the high viscosity of the vegetable oil decreases substantially when the oil is converted to ester. In fact esters' viscosities are quite similar to those of diesel fuels. In addition, the cetane number of the produced esters is much more suitable than that of vegetable oils for use in diesel engines.

Vegetable oils also enjoy the advantage of a possible diesel fuel extender since the two fuels are miscible.

Tests and Trials of Vegetable Oils

The Swedish Institute for Testing Machinery has carried out tests on Volvo-made diesel tractors operating on rape seed oil. The tests were made on pure rape seed oil and also on various admixtures with different proportions of rape seed oil and diesel fuel. The results indicated that the engine did not usually perform well after long durations or with high proportions of rape seed oil in the fuel admixture.[29]

Pure sunflower seed oil has caused carbon build up on injection nozzles when tested on direct injection diesel engines. However, a blend of 20 % sunflower seed oil and 80 % diesel fuel has not shown any unsatisfactory results.[8]

A diesel engine Passat in Brazil was tested running on sunflower seed oil, and it also showed the problem of carbon build up on the injection nozzle. By pre-heating the oil and using an admixture of sunflower seed oil and diesel fuel the problem was overcome in later tests.[8]

In early May 1982, a symposium on Vegetable Oils As Diesel Fuels was held in Toronto, Canada, at which many papers were presented revealing the results of various tests of diesel engines using vegetable oils as fuel.[16] The oils that were used were from sunflower seeds, soya beans, and rape seeds. The high viscosities of these oils were reported to have caused carbon deposition on injection nozzles and fouling the lubricating oil. Short-duration tests of less than ten hours showed positive engine performance results; however, long-duration tests were not satisfactory. A general disadvantage of vegetable oils, identified at the symposium, is that they are more suitable for indirect injection diesel engines. Direct injection diesel engines tests usually indicated unsatisfactory results. The tests also showed that the smaller the proportion of vegetable oil in a blended fuel, the better the performance of the diesel engine.

1.4.2. Producer Gas

Producer gas is a low Btu gas which has, on the average, a calorific value of 100 Btu/ft^3, and is generated by passing air over a hot, glowing surface of solid fuels. It is also called generator gas. The fuels include wood, charcoal, different varieties of coal, coke, briquettes, and agricultural wastes, it is evident that fuelwood, and consequently charcoal, can greatly contribute to the production of producer gas. Therefore, the question of planting the right species of trees for fuelwood production and reforestation are of paramount importance.

The primary fuel should then be prepared in a suitable way for burning in the gasifier. Charcoal would be produced from wood, coke and briquettes from coal, and pellets and briquettes from agricultural wastes. However, wood may also be used directly; it has to be air-dried of course. It was reported in 1952 that in the USSR, green-branch wood was directly used in gasifiers.[20] Acquisition of this technique would help other users to save time, money, and effort directly with the utilization of green-branch wood.

A further point for consideration is that the wood has to be chipped or cut into small pieces. If stickwood could be used, the process of fuel preparation would be much easier, since stickwood could be produced very simply. For solving this problem, certainly, further research would be required.

Gasifier/Generator* of Producer Gas

The gasifier is a piece of equipment in which the solid fuel burns and produces the producer gas. Basically there are three categories of gasifiers: a) downdraft, b) updraft, and c) crossdraft. In downdraft gasifiers the air inlet is at the top, above the fire zone, and the produced gas emerges from the lower part of the gasifier. In this type of gasifier, more ash and less tar are produced and wood is preferable as a fuel, since the tar is degraded, i.e., cracked to methane. This type is suitable for vehicle use. Updraft gasifiers function in the exact opposite manner. The air inlet is at the bottom and the gas outlet is at the top. The small quantities of ash and the large quantities of tar which are produced in this manner make the updraft gasifiers suitable for only direct-heat applications. Crossdraft gasifiers have their air inlet and gas outlet on two different sides of the gasifier. These gasifiers operate quite well on selected clean charcoal and are suitable for running engines of village scale.

In gasifiers, carbon (C) in the presence of air will produce carbon monoxide (CO), which is the main combustible component of the producer gas. Other components are nitrogen (N), hydrogen (H), carbon dioxide (CO_2), water vapor (H_2O), methane (CH_4), and negligible quantities of heavy hydrocarbons.

Generally, as a local industry, gasifiers can be made in workshops equipped for welding, sheet metal work and steel pipe work. However, it is advisable to build certain standardized key parts in a central location.[20]

The major operational hazards of gasifiers include the presence of carbon monxide (CO), the prolonged exposure to carcinogenic tar, and the utilization of certain types of gasifiers in the fire zones.

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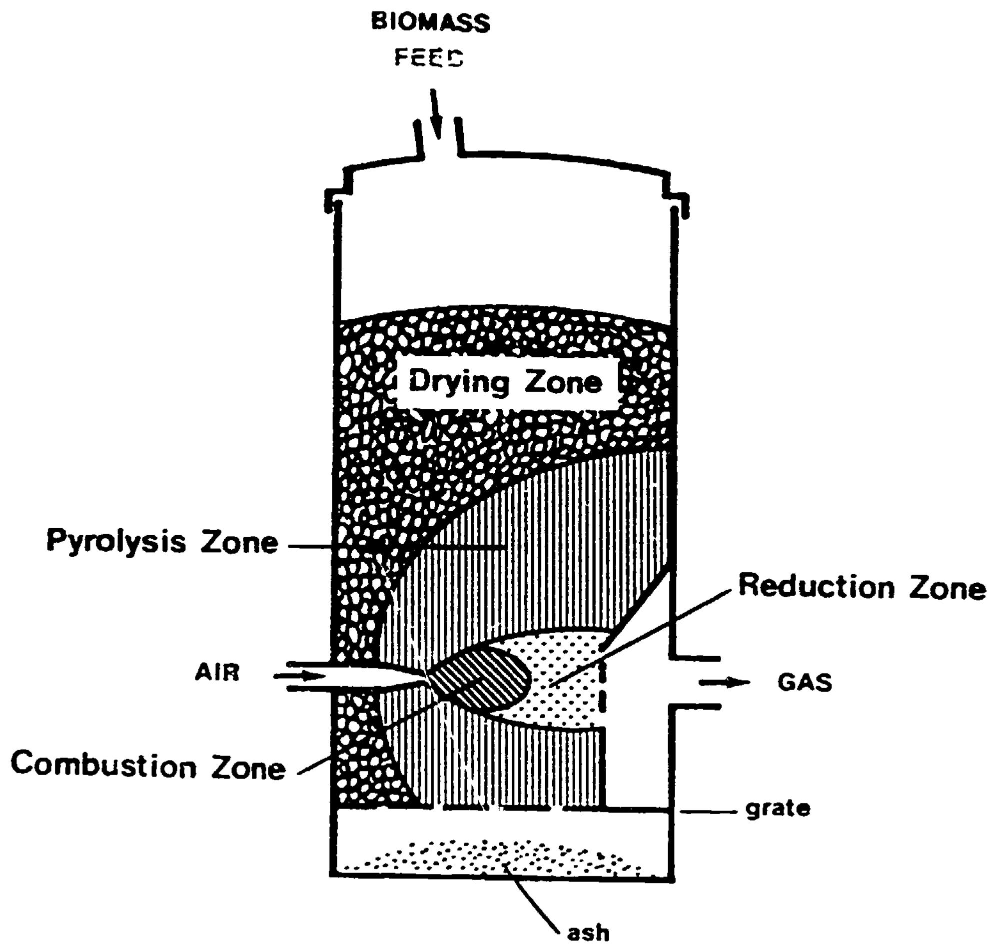
* Generator and gasifier are used interchangeably.



Schematic Diagram of a Cross-draught Gasifier

"The main advantages of the cross-draught gasifier are its rapid response to changes in load, its simplicity of construction, and its reduced weight. It is best suited for running engines with an output of up to 50 kW. However, it is very sensitive to changes in the fuel composition and moisture content. For practical purposes, specially selected clean charcoal is almost always required."

Source: "Biomass Gasification in Developing Countries", Energy Information Programme, Technical Report No. 1, Earthscan, 1983, By: Gerald Foley and Geoffrey Barnard

Producer Gas Utilization / Tests and Trials on Engines

During World War II, many countries used producer gas to cope with a lack or shortage of petroleum. European countries, Japan, India, Australia, and New Zealand have had good experience in using producer gas mainly in the field of transportation. Owing to the availability of cheap oil in the 1950's and 1960's, the utilization of producer gas was almost abandoned. At present, only a few countries have active producer gas projects. However, the new technologies and innovations which have been made since World War II, when applied, could result in numerous improvements in the various stages of producer gas utilization.

It has been reported that under the sponsorship of the Swedish Institute for Testing Machinery, from 1961 up to the present, the tests and trials include:

- Twelve tractors. The utilization of producer gas has been successfully tried on twelve diesel engine tractors, which altogether operated for at least 15,000 hours.(29)

- Six trucks. These diesel engine trucks worked on producer gas and ran for a total distance of at least 680,000 kilometers.(29)

- One bus. One diesel engine bus has also been successfully tested.(29)

The engines are usually modified and have natural aspiration (no turbocharger), with direct injection (no pre-combustion chamber). For ignition, a pilot (diesel) fuel is necessary. It was reported that one truck, over a distance of ten kilometers used 0,55 liters of pilot (diesel) fuel in addition to 12 kilograms of chipped wood. Without producer gas, normally this truck under similar conditions would have consumed three liters of diesel fuel. It is noteworthy to mention that in the case of natural aspiration only 20 % - 25 % of the calorific value of the producer gas can be utilized.

In 1981, in Australia, a Toyota diesel land cruiser was successfully tested with a dual firebox gas producer.[20] The Philippines has had recent experience with various prototypes of irrigation pumps and fishing boats as well as electricity generation, all based on producer gas.[20] Much of this experience has been presumably with diesel engines. A jeepney was also field tested and calculations have shown that the additional cost of the producer gas system could be repaid in five to six months. Other countries with successful trials include: Belgium and Finland.

It is reported that in at least four countries a great deal of progress has been made in the generation of electricity in remote locations and rural areas presumably through diesel engines running on producer gas. In the Federal Republic of Germany (by the Gesellschaft für Zusammenarbeit), in the U.K. (by the Tropical Development and Research Institute), in Switzerland, and in France the experiments have been concentrated on the manufacturing of small gasifiers for electricity generation in rural areas.

In utilization of producer gas, certain research work has to be carried out in the following areas:

- Minimization of the hazards of carbon monoxide poisoning
- Removal of ash and tar / cleaning of filters, coolers, traps and scrubbers in gasifiers
- Utilization of stickwood instead of chipped wood
- Recovery and returning the heat of exhaust to the gasifier
- Possible selection of more appropriate catalysts for dissociation of the water injected into the gasifiers for hydrogen production and gas quality improvement. At present the catalysts are potassium and sodium carbonates.

1.4.3. Ethanol and Methanol (Alcohols)

Ethanol or ethylic alcohol can be derived from a biomass contraining sugar, starch or cellulose. If the biomass contains sugar, then it can go through the process of fermentation as follows:

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

glucose ethanol carbon dioxide

If the biomass contains mainly starch or cellulose, these substances must first be converted to sugar and then the sugar has to be fermented. The processes of converting sugar to ethanol, and also of converting starch to sugar and then to ethanol are being implemented and practiced on industrial scales. Ethanol produced in this manner must afterwards be extracted through distillation of the fermentation results. The results are composed of liquids and some solid materials. Depending on sources such as sugarcane, grain, cassavo (manioc), etc. and other relevant conditions, each hectare of land can produce from several hundred to several thousand liters of ethanol annually. In ethanol production, the cost of raw materials usually constitutes between 60 and 70 percent of the total production cost.

It is natural that a great deal of energy has to be expended on agricultural and industrial needs in order to obtain energy in the form of ethanol. The energy consumed and the energy gained in this manner largely depend on the type of the biomass. It has been reported that sugarcane and sweet sorghum are excellent for energy net gains.(2) Due to its oxygen content, ethanol has a lower calorific value (29.9 MJ/kg) as compared to diesel fuel and therefore the production of the same amount of work or energy, takes 60 % more of this alcohol than it would of diesel fuel.

Ethanol can be produced also in a synthetic manner, i.e., through catalytic hydrolysis of ethylene which itself is derived from petroleum.

$$CH_2 = CH_2 + H_2O \text{ -------}\rightarrow CH_3CH_2OH$$

ethylene

Methanol or methylic alcohol, like ethanol, can be produced from biomass, say from the pyrolysis of wood. Methanol is also known as wood alcohol; as ethanol is sometimes called grain alcohol. Methanol is highly toxic. The wood-to-methanol production is inefficient and very expensive. Most of the methanol production today is through synthetic processes.

Natural gas is a good source of carbon monoxide and hydrogen and therefore suitable for methanol production. Extensive research work is also being carried out on the coal-to-methanol and wood-to-methanol production as well as obtaining methanol from municipal wastes. Brazil, Canada, Australia, New Zealand and the U.S. are active in these research projects.

Methanol from natural gas which is mostly methane (CH_4) is produced as follows:

$$3\ CH_4 + 2\ H_2O + CO_2 \text{ -----}\rightarrow 8\ H_2 + 4\ CO$$

$$8\ H_2 + 4\ CO \text{ -----}\rightarrow 4\ CH_3OH \text{ (methanol)}$$

Actually the gas mixture has to be compressed and liquefied.

Methanol production from wood is less efficient than production from natural gas. Four liters of methanol can be obtained from 2 1/4 kilogram of natural gas or nine kilograms of wood.

Methanol has a calorific value of 8600 Btu/lb or 20 MJ/kg; in other words, on a volumetric basis a little less than half the energy contained in gasoline.

In general, ethanol has gained wide application in subsitution of fuel (gasoline, mainly in Brazil). Nevertheless, the extent of methanol production (especially from biomass) and its utilization is not at all comparable to that of ethanol.

With respect to the economic impacts of alcohol production, a Brazilian report gives the following statistics on a typical ethanol project and orders of magnitude.

a) 7000 hectares of land are needed for the entire project

b) distillary capacity 120,000 liters per day (standard size)

c) total annual production of alcohol equals to 24 million liters

d) if the industry is sugarcane-based, such a project creates 600 jobs

e) in addition to the figure above, the creation of each direct job results in the creation of 0.3 indirect job in services, government, commerce, etc.(18)

Brazil's ethanol production was 4.9 billion liters in 1980, the equivalent of 1.3 billion gallons or 4.3 million tons.

Alcohols have low cetane number, i. e., 0 - 5 for methanol and o - 8 for ethanol. As a canditate substitute for diesel fuel, this factor creates a disadavantage for alcohols. In addition they are poor lubricants. Therefore many experts immediately conclude that alcohols do not have much potential as a substitute for diesel fuel. This also stems from the fact that alcohols are more suitable as a replacement for gasoline and therefore their suitability as diesel fuel is of secondary importance. However, partial substitution of diesel fuel by alcohols is being considered and several countries are interested in such projects.

There are numerous ways to overcome the poor auto-ignition quality (low cetane number) of alcohols and make them suitable to replace diesel fuel or act as its extender. These solutions, though not yet fully practical from the technical and the economic viewpoints, are as follows:

Addition of Cetane Improvers to Alcohols

Cetane improvers are nitrated substances such as amyl nitrate and hexyl nitrate. Considering the fact that the volume of methanol to be used as fuel has to be two to three times greater than that of diesel fuel due to different calorific values, and also the fact that around 10 % of the methanol volume, a costly cetane improver is needed, the utilization of methanol as diesel fuel becomes uneconomical. In the case of ethanol the situation is better since its calorific value is higher and thus requires a smaller volume, as compared to methanol. This, in turn requires a smaller quantity of the costly cetane improver. On the whole, experience has shown that for the same energy production, the quantity of ethanol should be 60 - 80 percent more than that of diesel fuel.

Another point is that diesel engines, in the case of unmodified injection systems, show reductions of 45 % and 25 % in their maximum powers when operating on methanol and ethanol, respectively.

Brazil has tested ethanol on trial runs of a bus. The fuel had 12 % cetane improver and 1 % lubricating ricin oil as additives. Usually in such a case, power and efficiency of the engine do not decrease as compared with diesel fuel use.

SAAB Scania of Sweden has been working on ethanol fuel since

1973. The tests have shown satisfactory results as far as the engine wear, efficiency, and emissions are concerned.[29]

On the contrary, Volvo's diesel engine tests on methanol, with cetane improver, showed increased wear of the piston ring and cylinder bore.[29]

Daimler Benz has made some tests in Brazil on diesel engines with ethanol as fuel. The results showed adverse effects on fuel filters, valve seats, and high pressure parts of the injection system.[29]

A great deal of research and development is being carried out in Brazil for a cetane improver which is more effective. The aim is for reduced requirement for quantities which could be produced locally from renewable resources at reduced costs.

Diesel Fuel Injection for Ignition when Alcohol is the Main Fuel

Another solution is to supply alcohol through the air inlet of the diesel engine. In this manner, the diesel fuel continues to be supplied through the injection system. The partial substitution of diesel fuel by alcohol is below thirty percent. The mixture of vaporized alcohol and air becomes flammable, but combustion is initiated by the diesel fuel. Various tests of this method, which is called fumigation, have shown that as the percentage of alcohol in relation to the total quantities of the two fuels increases, the engine efficiency decreases, the NO_x (nitrate oxides) emissions decrease, the hydrocarbon emissions increase, smoke levels decrease, and the (CO) carbon monoxide emissions remain unchanged.[29]

SAAB Scania of Sweden has run some fumigation tests with ethanol for diesel engines in the Brazilian market.

Emulsification (Alcohol and Diesel Fuel)

Methanol is almost completely insoluble in diesel fuel and ethanol is soluble only under limited and difficult conditions. Moreover, alcohols solubility in diesel fuel decreases rapidly with minute quantities of water. Therefore the blending of alcohols with diesel fuel does not present a solution for partial subsitution of diesel fuel.

However, alcohols and diesel fuel can form emulsions, which are characterized by droplets of one liquid in a continuous phase of another liquid. Emulsification is done through mechanical or chemical means; the first one being rather unstable. Mechanical means include rotating systems, jets, ultrasonic devices mounted on the engine. Volvo has tested engines on emulsions of methanol and diesel fuel, changing the proportion of the two fuels to suit different working conditions of the engine. Emulsification can be carried out chemically through the adding of surfactants, which results in a rather stable emulsion.

Dual Fuel Mode (Alcohol and Diesel Fuel)

In the Federal Republic of Germany, Kloeckner - Humboldt - Deutz AG has tested diesel engines with both direct injection and indirect injection systems, which run on a two-fuel principle. In the first case (direct injection) the results were satisfactory, as far as energy consumption, cold starting, and emissions were concerned. In the second case (indirect injection), the tests showed that nitrogen oxides (NO_x) and smoke emissions are less on a two fuel basis than when only diesel fuel is used, and the other emissions remain unchanged.[29]

As for the proportions of the two fuels, methanol can contribute up to 85 % at the engine full load.

The engines which run on two fuels are expected to cost about twenty percent more than conventional engines because of two fuel injection systems, a second fuel pump, etc.

The Greater Stockholm Transport Authority, in co-operation with Volvo and SAAB, has tested two buses with methanol as a second fuel.[29] Fuel consumption in energy terms remained unchanged as compared to diesel fuel consumption, and the methanol contribution to the total fuel quantity was seventy-eight percent. Moreover, when a second pump was fitted for the pilot (diesel) fuel and the first pump was retained for the main (alcohol) fuel, the engine's maximum power was reduced by 35 % using methanol and 15 % using ethanol.

Spark-Plug Ignition when Alcohol is the Fuel

Ignition can be initiated through a spark plug. Then one characteristic of diesel engine, namely compression ignition, is abolished. However, the fuel (alcohol) is still injected into the engine after combustion has already taken place (unlike gasoline engine). MAN of the Federal Republic of Germany is reported in this way to have obtained higher engine efficiencies and therefore lower energy consumption on trial runs of a bus. Engine emissions are less than those when the engine runs on the diesel fuel. Kloeckner-Humboldt-Deutz of the Federal Republic of Germany and Komatsu of Japan are interested in research on the development of the spark-plug diesel engine which also runs on alcohol.

Glow Plug Ignition When Alcohol is the Fuel

Glow-plug or hot wire can in this case help combustion initiation of methanol. Research in this direction has been carried out in Brazil.

x x x

In October 1982 it was announced that in the U.S.A. the California Energy Commission awarded two million dollars to Acurex Corporation for the testing of buses which would run on pure methanol.(9) These passenger buses were planned to operate between San Francisco and neighboring counties. The Acurex Corporation decided to purchase two identical buses from each manufacturer; one with a diesel engine and the other with a special engine for pure methanol. The information and data on the engines's performance were to be collected and analysed for a period of thirty months.

1.4.4. Liquefied Petroleum Gas

Liquefied Petroleum Gas (LPG) is composed primarily of butane and propane and can be derived basically from hydrocarbons as follows:

a) LPG can be extracted in natural gas processing plants and the quantities obtained depend on the composition of the natural gas of particular producing field.

b) On account of refining and cracking operations, approximately two percent of crude oil will result in the production of LPG.

In the U.S., about 2/3 of LPG is derived from natural gas processing and 1/3 is derived from crude oil refining and cracking processes.

LPG can be used as diesel fuel extender, the situation being very similar to that of compressed natural gas (CNG). In this manner LPG replaces approximately 35 % of the diesel fuel. TNO of the Netherlands offers engine conversion kits for this purpose. Moreover, some manufacturers offer converted engines which can run on LPG, on the basis of spark-plug ignition or dual-fuel mode. The Swiss AG Adolf Saurer has developed an engine with spark-plugs and a reduced compression ratio of 10.3 : 1.[29] Two similiar engines were tested to run on diesel fuel and LPG. The results showed that the energy consumption for the LPG engine is a little higher than that of the diesel engine. Scania of Sweden has manufactured a bus which has a combined diesel / LPG engine and operates on the basis of fumigation.

1.4.5. Natural Gas / Methane

Natural gas is produced either from gas fields or as associated gas together with oil, from oil fields. Methane (CH_4) is the main-component of natural gas. Since it may be "wet" and also may contain sulfur, it usually has to be treated at the production site. Then it may be piped to the consumption point in the form of gas. However, for long distance overseas transportation or for storage reasons, natural gas may be liquefied under pressure and cold temperatures to form LNG, which has to be regasified at the point of consumption. LNG's volume is about 600 times less than that of the equivalent quantity of natural gas.

Natural gas has been widely used in the compressor stations of its own pipelines. Usually, natural gas is the main fuel and is aspirated through the engine air inlet and a much smaller quantity of diesel fuel is used as pilot fuel for combustion initiation.

Natural gas may be compressed to form CNG. CNG has a better energy input/output efficiency as compared to that of LNG. It has been reported that in Italy there are diesel engines which run on 90 % CNG and 10 % diesel fuel as pilot fuel. However, in order to avoid the overheating of the injection nozzle and its clogging with carbon, 75 % CNG and 25 % diesel fuel would be a much more desirable ratio. Most of the diesel engines modified in recent years in Italy to run on dual fuels or on CNG alone, have been of the stationary type.

In the U.S.A., as well as in the Netherlands, some limited tests have been made for the development of modified diesel engines which run on CNG and diesel fuel or on CNG alone (spark-ignition). CNG Fuels Systems, Ltd. of Canada reported its intention for the manufacturing and marketing of an engine to operate on a dual-fuel system (CNG and diesel fuel).[45]

All in all, natural gas application is much more suitable for stationary and marine rather than other types of diesel engines.

If natural gas is going to substitute diesel fuel, certain problems should be overcome, namely:

a) practical modifications of diesel engines
b) engine efficiency
c) engine emissions
d) corrosion caused by impurities in CNG
e) safety aspects

Methane can also be derived from such sources as coal, biomass, waste products, etc.

When organic materials are collected in a container* and their molecules break down into simpler molecules through anaerobic bacterial fermentation, a gas will be produced which is usually called biogas. These organic materials include crop residues, domestic wastes, animal wastes, night soil, etc. Biogas is composed of about 60 % methane (CH_4) and about 40 % carbon dioxide (CO_2) as well as quantities of nitrogen (N), hydrogen (H), and hydrogen sulfudie (H_2S). Methane has a slight, but not unpleasant odor.

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* In this case it is called a digester.

The unpleasant odor of biogas is due to its hydrogen sulfide (H_2S) content. The calorific value of biogas is around 500 Btu/ft^3 or 18676 kj/m^3.

When the process of fermentation is finished, some residues will be left in the digester which are valuable fertilizers and contain practically all the necessary materials. This is a positive point for biogas production, as the fertilizers produced in this manner help the economic viability of the entire biogas project, as well as the fact that from an environmental viewpoint the practice is very sound.

Each kilogram of volatile solids of highly biodegradable material normally produces 0.5 - 0.6 cubic meter of biogas (or 8 - 9 cubic feet per pound of volatile solid), within a period of 10 - 20 days.

In turn, one cubic foot of biogas can produce sufficient energy to light a 25 watt bulb for aroung six hours. Biogas has many applications in the areas of heating, cooking, and lighting and is especially favorable in rural areas.

If internal combustion engines can be modified in a simple manner to run on biogas, then the biogas utilization extends well beyond its present primary use for cooking and lighting.

Many countries are involved in biogas production. These countries include: India, China, and some other Far Eastern Countries as well as Bangladesh, Tanzania, Uganda, Mexico, and a few of the South Pacific islands.

As previously stated, methane may also be produced through coal gasification. The gas obtained in this manner is called synthetic or substitute natural gas (SNG).

The processes for synthetic gas production through coal gasification are known as:

a) Winkler, b) Lurgi, and c) Koppers-Totzek.

Approximately two years ago, it was reported in the U.S. that the price of CNG and LNG derived from coal was 11 - 17 percent higher than when the source was natural gas.

Most of the world's known coal resources (90 %) are located in four countries:

a) U.S.S.R. 42 %
b) U.S.A. 26 %
c) China 13 %
d) Australia 6 %

These countries also have seventy percent of the economically proven recoverable reserves of coal in the world.

1.4.6. Solid Fuels

In the summer of 1983, General Motors of the U.S.A. announced its testing of two cars which ran on coal. These cars have gas turbines instead of internal combustion engines. Usually gas turbines run on hot gases which may be produced from practically any fuel. This was not the first time that coal was fuel for a car, as many experiments have been carried out with coal-fired, gas turbine driven cars in recent decades. The operational problems were always due to coal sulfur and coal ash and also due to the fact that coal could not be pulverized to sizes smaller than fifty microns. Perhaps these were not the only reasons, but the main reason for the lack of succes of coal-fired cars was the availability of cheap oil. New technological developments in the meantime have made it possible to prepare low-ash, low-sulfur coal which can be properly pulverized into sizes of few microns. Theoretically this coal can compete with diesel fuel which is produced from crude oil costing twenty-one dollars per barrel at the refinery entrance gate.

As for diesel engines, solid fuels such as coal can be pulverized and mixed with diesel fuel so that the whole fuel mixture would not contain more than thirty-two percent coal by weight. Various tests have shown that there is a loss in engine efficiency equivalent to less than ten percent.[29] There is a great deal of research and dvelopment which has to be carried out before conclusive results become available.

1.4.7. Hydrogen

Hydrogen can also be used in diesel engines, and the combustion has to be initiated through pilot (diesel) fuel or through spark-plugs. Among the various gases, however, hydrogen is the most unsuitable one for diesel engines because of its pre-ignition characteristics.

1.4.8. Petroleum Products Heavier Than Diesel Fuel

Certain fuel oils can also be used in large diesel engines. This situation creates some problems due to the fact that fuel oils have high:

- ash content
- sulfur content
- vanadium content
- viscosity

The last difficulty may be alleviated by the pre-heating of the fuel.

Generally all the problems may be overcome; however, the solutions may cause increased engine size and weight, and increased costs.

1.5. GENERAL REMARKS AND SELECTION OF SUBSTITUTES

Activities by UNIDO to replace diesel fuel by its substitutes in rural areas of developing countries would be quite different from UNIDO's other promotional activities. UNIDO usually assists developing countries in acquisition of various industries and technologies from industrialized countries. However, in the case of the sector under consideration, the technology has, as yet, to be developed. It is also evident that the problem has two important inter-related aspects, i. e., to find a new fuel for diesel engines and to manufacture a new engine (or modify the old ones) to run on the new fuel. The ideal situation would be for the new fuel not to require any engine modification thus avoiding extra costs.

The substitutes selected in this study as the most promising options show only the consultant's opinion. However, other experts or readers may have different views. Moreover, the advantages of a potential substitute may change with future technological innovations.

It is noteworthy to mention that many experts, mostly in the oil industry, are of the opinion that economical engines and economical fuels such as diesel fuel will be in great demand. They believe that fuel oil rather than diesel fuel should be replaced by coal, nuclear energy, or natural gas, and the extra fuel oil saved in this manner could be converted to diesel fuel and lighter distillates in refineries.

The examination of the question of total substitution of diesel fuel indicates that global solutions are likelier to appear on the medium term and long term horizons. As for the short term, the solution for a number of developing countries will be almost total substitution and for some others it will be sporadic and localized.

Partial substitution is also another solution. In other words, substitutes will be used as diesel fuel extenders or will be used only whenever the conditions justify, either due to their insufficient qualities or due to their insufficient quantities. There are usually occasions when diesel fuel is in short supply and, in fact, substitution will take place only at such occasions.

Any effort to find substitutes for diesel fuel should not be made in isolation of national plans and should be integrated with other development programs. For example, development of substitutes in certain cases may require a great deal of farming activities. If a country has a food shortage and the land-to-man ratio is low, then this country cannot opt for crops which are suitable for energy production. Otherwise, energy will be produced at the expense of food, which naturally would create an undesirable socio-economic imbalance. A further example for the necessity of integrated programs is that diesel fuel replacement and replacement of other oil products should somehow take place concurrently and in a balanced manner. If this is not the case and the country imports petroleum and refines it inside the country, which is on the whole more economical than importing petroleum products, there will be either a surplus of diesel fuel since it is already replaced or a shortage of gasoline, kerosine and fuel oil.

There are certainly many advantages if substitution of diesel fuel occurs on a large scale and in as many countries as possible. More quantities of substitutes mean more engines which run on these substitutes, and more modified and new engines mean that more substitutes will be developed and produced. Therefore, on a global basis, the cost of substitutes production and the cost of engine manufacturing will decrease.

The selection of diesel fuel substitutes is a rather difficult task since none of the potential substitutes fully meets the requirements expected from a substitute. Thus expectations have to be lowered and measures introduced to increase the degree of "substitutability" of the substitute through chemical and mechanical means as well as engine modifications. Or alternatively, partial substitution may be a solution. Moreover, an energy source which would probably provide one developing country with a diesel fuel substitute, does not necessarily exist in another country. Therefore, the choice must be qualitative rather than a precise quantitative assessment.

The following diesel fuel substitutes can be eliminated for the indicated reasons:

	Reason for Elimination
- Petroleum products heavier than diesel fuel	This requires hydrocarbon resources and the developing country is assumed to be petroleum deficient.
- Liquefied petroleum gas	This requires hydrocarbon resources and the developing country is assumed to be petroleum deficient.
- Natural gas	This requires hydrocarbon resources and the developing country is assumed to be petroleum deficient.
- Methanol from hydrocarbons and from coal	This requires hydrocarbon resources and the developing country is assumed to be petroleum deficient. Conversion of coal to methanol requires a rather high degree of industrialization. Moreover, coal is a good substitute of fuel oil.
- Methane from hydrocarbons and from coal	This requires hydrocarbon resources and the developing country is assumed to be petroleum deficient. Conversion of coal to methanol requires a rather high degree of industrialization. Moreover, coal is a good substitute of fuel oil.
- Methane from biomass	Needs conclusive tests and trials on engines.
- Hydrogen	Unsuitability owing to pre-ignition tendencies.
- Solid fuels	Needs conclusive tests and trials on engines.

The most promising options for diesel fuel substitution in energy-importing developing countries are vegetable oils and their esters, producer gas, and biomass-derived alcohols (ethanol and to a lesser extent methanol).

a) vegetable oils

The advantages of vegetable oils and the relation of their attributes to the previously mentioned criteria are as follows:

- renewable resources
- high calorific value (on the average, 88 % of that of diesel fuel)
- liquid form
- miscibility with diesel fuel
- extensive tests and trials / present practice

Examples of the present practice mention that coconut oil had wide applications in Fiji and in the Philippines, and is generally an economical fuel in many areas of the Pacific.

Coconut palms of one hectare of land produce approximately two tons of oil annually, making them the second largest oil yielding palms. Oil palms have the largest yields and the corresponding figure is about four tons of oil per year.[21]. There are also other species such as Guayale, Jojoba, and Tallow Tree which have high yields of non-edible oils, and can grow on arid, non-fertile lands wich are not normally used for food production.

As for the capital cost of the oil production sector, it is reported that a factory which produces about 32 liters of coconut oil per hour, from 50 kilograms of copra, costs about $ 20,000.[21] It has also been reported that a plant with annual capacity of ten million gallons of coconut methyl-ester costs about $ 12,000,000.

System and Logistics In Brief / Option of Vegetable Oils and Their Esters

	Considerations and Requirements
- Cultivation of Oil Seeds	- allocation of land - farm machinery - water - manpower - capital - fertilizers and pesticides - other agricultural inputs - identification and cultivation of suitable species with high yields of light oil
- Oil Extraction - mechanical - chemical	- efficient operations - expansion of capacity
- Oil Refining	- efficient operations - expansion of capacity
- Transesterification	- applicability of technology at village level
- Network	- little is known; preferably should be used locally
- Applications - Vegetable oil and diesel fuel blends* can be used in indirect injection engines for short durations - Vegetable oil and diesel fuel blends* can be used in direct injection engines for emergency and occasional use - Vegetable oil esters in their pure form can be used in diesel engines for short durations	- extensive research has been carried out; however, more techno-economic R and D activities are still required

* Blended fuels usually contain 1/4 to 1/3 vegetable oil.

b) producer gas

Producer gas has been selected as a most promising option to replace diesel fuel for the following reasons and qualities:

- renewable resources when derived from biomass
- simple fuel production
- large extent replacement, except for the pilot (diesel) fuel
- extensive tests and trials/present practice

The combination of charcoal as the fuel and a cross-draft gasifier provides a rural community with the most suitable manner of the producer gas utilization for electricity generation.

On this option, three annexes have been included in this report. Annex I is a summary on the economics of electricity generation by producer gas. Annex II shows, in a graph form, the relationship between the plantation area requirements and the electricity requirements of rural communities. Annex III indicates the relationship, both in metric and British systems, between the quantities of the original fuels, the quantities of the gas, the equivalent volume of diesel fuel, the equivalent amount of electricity energy, etc.

System and Logistics in Brief / Option of Producer Gas

	Considerations and Requirements
- Silviculture of Trees	- allocation of land - machinery - water - manpower - capital - fertilizers and pesticides - other silvicultural inputs - identification and plantation of fast growing, suitable species
- Reforestation	- similar to above
- Fuel Production and Preparation	- research in using green-branch wood - research in using stickwood instead of chipped wood - efficient charcoal making
- Gasifiers Technology, Manufacturing, Operations, and Maintenance	- acquisition and increasing level of technology, manufacturing and operations - local servicing - awareness of hazards
- Storage	- producer gas is not usually stored
- Network	- producer gas is usually generated at the engine side or transported over short distances by pipelines
- Applications - Usually utilized in isolated units for driving a single generator. Ignition is initiated through pilot (diesel) fuel or spark plug. - suitable for least engine load fluctuations	- overall performance evaluation and monitoring - R and D activities are required

c) biomass-derived alcohols (ethanol and to a lesser extent methanol)

Biomass-derived ethanol and methanol have been selected as promising options for diesel fuel extenders for the following reasons and qualities:

- renewable resources
- liquid form
- engine emissions at permissible levels
- proven practicability of replacing another internal combustion engine fuel, namely gasoline
- suitability for the present fuel distribution network
- extensive tests and trials

Ethanol production is by far more widespread than that of methanol, providing the former alcohol with a stronger position than that of methanol as a diesel fuel extender. However, based on commitments in Sweden for research and development activities regarding engines operating on methanol, some technological breakthroughs may take place in the future.

Annex IV indicates the electricity requirements of a rural area, the partial replacement of the required diesel fuel by ethanol, and the sugar cane or sugar beet plantation areas requirements.

System and Logistics in Brief / Option of Biomass-Derived Alcohols

	Considerations and Requirements
- Cultivation of Plants	- allocation of land - machinery - water - manpower - capital - fertilizers and pesticides - other agricultural inputs - identification and plantation of species rich in sugar or starch
- Production of Fuel - Sugar extraction from sugar-containing material - Conversion of starch to sugar and extraction of sugar - Fermentation of sugar to alcohol - Distillation of alcohol	- efficient operations - expansion of capacity
- Network	- similar to the present conventional fuels
- Applications - Due to low cetane number, ignition should be initiated through: - addition to cetane improvers - dual-fuel modality (alcohol/diesel fuel) - emulsification with diesel fuel - utilization of spark or glow plugs - fumigation	- a great deal of research and development activities are required for all the possible solutions

PART 2

2.1. RECOMMENDATIONS TO UNIDO FOR ACTION

UNIDO's initial promotional role would be to bring to the attention of policy makers in developing countries the idea that other fuels can substitute for diesel fuel. This should naturally be combined with a great deal of encouragement. Those developing countries that respond and show interest should, in fact, commit themselves to such a project and sign an agreement of co-operation with UNIDO. Subsequently UNIDO should initiate and assist these relevant developing countries in carrying out the work of diesel fuel substitution throughout the entire duration of the project.

Concurrent with the above activities UNIDO should mobilize its efforts inside the Secretariat and also build up sufficient access to outside expertise. In this manner, UNIDO would be able to assist developing countries in practically every stage of their projects.

The recommendations for UNIDO's actions are elaborated below. However, the sequence of the numbered paragraphs does not necessarily show any sequence of time and many of these actions can be carried out simultaneously, or, in some instances, certain actions depend upon the results obtained from previous actions.

2.1.2. Preparation of Booklet

UNIDO should prepare a booklet for circulation in member states. In this booklet it should be explained that UNIDO is strongly concerned about the plight of energy-deficient developing countries for electricity generation in their rural areas due to the high cost of diesel fuel. It should be further explained that UNIDO has conducted a study and has come to the conclusion that the most promising options for totally or partially replacing diesel fuel are: a) vegetable oils and their esters,

b) producer gas, and c) biomass-derived alcohols.

2.1.2. Response From Member States

Along with the circulation of the above-mentioned booklet, UNIDO should ask individual member states to make tentative selections from among the three options, taking into consideration the resource endowments and other relevant conditions prevailing in the country, and inform UNIDO accordingly.

2.1.3. Co-operation Agreement Between UNIDO and Member States

A Co-operation Agreement between UNDIO and the interested member state should be signed. In this agreement the responsibilities and contributions of UNDIO and the member state with regard to the project of diesel fuel substitution should be clarified and elaborated.

2.1.4. Appointment of National Project Leader and Designation of Institute By Member States

In connection with the above agreement, UNIDO should ask the member state to name a National Project Leader who would act as the Liaison Officer with UNIDO and who would be responsible towards UNIDO in accordance with the terms of the Co-operation Agreement. The National Project Leader should be associated with a scientific or technical institute in his home country which has the overall initial responsibility for carrying out the project.

2.1.5. UNIDO's List of Experts

UNIDO should locate international experts who have experience in the field of diesel fuel substitution with vegetable oils, alcohols, or producer gas. These experts may be called for consultation from time to time and/or may be dispatched to member states whenever needed.

2.1.6. Co-operation with Manufacturing Companies

UNIDO should investigate the willingness of the manufacturing companies in industrialized countries for co-operation with UNIDO. As a result of this co-operation the companies may provide UNDIO, and in turn various member states, with engines, conversion kits, expertise, or financial resources, etc. The co-operation should be genuine and devoid of commercialization to the extent possible.

2.1.7. Co-operation with Institutes and Governmental Agencies

UNIDO should investigate the willingness of the various institutes or governmental agencies active in the field, in industrialized and developing countries for co-operation with UNIDO and eventually with the relevant developing countries. This co-operation could be in the form of invitations extended to study groups, training of personnel, provision of experts, etc.

2.1.8. UNIDO Secretariat's Specialized Personnel

Inside the Secretariat, UNIDO should have a team of specialized personnel that allocate most of their efforts to promotional activities with regard to diesel fuel substitution. The activities of the specialized personnel should be strengthened by outside consultants, consulting firms, or experts.

2.1.9. UNIDO's Assistance

Within the framework of the Co-operation Agreement with the developing countries, UNIDO should offer technical assistance as well as advisory and expert service in the areas of:

- national planning
- policy making
- systems analysis
- feasibility studies
- pre-investment studies
- socio-economic studies
- preparation of draft regulations for provision of incentives to promote the development of diesel fuel substitution

2.1.10. Demonstration Projects

When conditions justify and sufficient interest is shown by a group of countries, UNIDO should set up a regional demonstration project to show the practicality of the matter through pilot production of the new fuel, engine testing, etc.

UNIDO should also consider the merits of a mobile demonstration unit.

The demonstration project may be extended to include a small fair or exhibition in which potential suppliers in the field from industrialized countries and consumers from developing countries can meet with the view to indentifying the areas of mutual co-operation.

2.1.11. UNIDO Documents

As the need arises, UNIDO should publish a series of documents which would provide the interested developing countries with supportive information for carrying their activities forward. These documents may be prepared by outside consultants. The contents of each document should be specific and aim at particular areas of activity or at solving problems. As an example, a mannual could be published which would deal with the design, manufacturing, operations, safety, and maintenance aspects of the gasifiers in the case of the option of producer gas.

2.1.12. Study Tours

In order to complement its activities, UNIDO should organize study tours composed of developing countries' experts to the countries which have active on-going diesel fuel substitution projects. Study tours may be extended to include different research institutes and manufacturing companies in industrialized and developing countries.

2.1.13. UNIDO's Monitoring System

UNIDO should build up an effective monitoring system for the various projects of diesel fuel substitution in developing countries. Information and data must be collected and interpreted and the underlying factors of any cost overruns and delays should thoroughly be analyzed in order to avoid similar mistakes in the future.

ANNEX I

Economics of Electricty Generation By Producer Gas*

The discussion deals with the calculations and comparison of the costs of electricity generation in a rural community with a power output requirement of 50 kilowatts, when the generator is driven by a diesel engine running on diesel fuel and when the same system runs on dual fuels, i.e., producer gas and diesel fuel. Three baseline cases have been considered in which the gasifier capital cost is:

- case A $ 75 / kw
- case B $ 200 / kw
- case C $ 800 / kw

Other main assumptions for baseline calculations and a later sensitivity analysis are tabulated below:

	For Baseline Cases A, B, and C	For Sensitivity Analysis	
- annual operating period	2000	500 - 8000	hours
- system lifetime	6	3 - 9	years
- wood cost	20	0 - 40	$/ton of air-dry wood
- wood consumption	1.4	1.0 - 1.80	kg/kwh
- gasifier system annual maintenance cost	10	5 - 20	(percent of the (capital cost
- gasifier system lubricant cost	2	1 - 4	(times higher than (that of diesel (system
- diesel fuel price	40	30 - 60	¢/liter
- diesel fuel substitution by gas	80	50 - 100	percent
- diesel fuel consumption	0.4	0.3 - 0.4	liter/kwh

*Summarized from the "Biomass Gasification in Developing Countries", Energy Information Programme, Technical Report No. 1, Earthscan, By: G. Foley and G. Barnard

Baseline calculations on the basis of the assumption on the left column indicate that electricity will be produced at the following costs:*

- diesel fuel	21	¢ per kilowatt hour
- case A	14.8	" " " "
- case B	16.8	" " " "
- case C	26.7	" " " "

When the gasifier cost is $ 425/kw, there will be a breakeven point between the producer gas system and the diesel fuel system.

In the sensitivity analysis, the ranges on the right column have been used. Moreover, charcoal, with a price of $ 50 - $ 150/ton, has also been introduced as another source for gas production.

The results of the sensitivity analysis indicate that the most important determining factors in the system selection are:

- gasifier capital cost
- diesel fuel price
- annual operating period
- system lifetime
- maintenance cost

The price of wood or charcoal does not play a major role.

In short, when the diesel fuel price is higher than 60 ¢ per liter, the producer gas for electricity generation is economical under almost all likely conditions.

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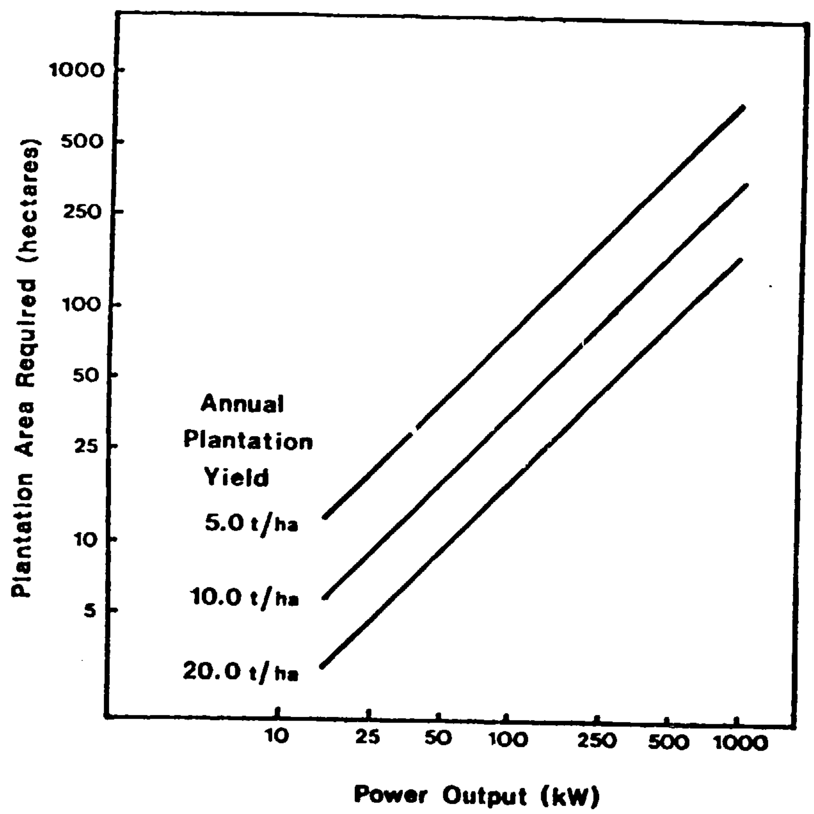
* Electricity from a central grid usually costs below 10 ¢ per kilowatt hour.

ANNEX II

Plantation Area Requirements for Gasifier-Powered Electricity Generation Systems



Source: Biomass Gasification in Developing Countries, Energy Information Programme, Technical Report No. 1, Earthscan, 1983, By: G. Barnard and G. Foley

ANNEX III

Relationships Between Quantities of Original Fuels, Quantities of Gas, Equivalent Volume of Diesel Fuel, and Equivalent Wattage of Electrical Energy

- one	kilogram	of	wood	produces	2 - 3	cubic meters of gas
- "	"	"	lignite	"	4.0	" " " "
- "	"	"	hard-coal coke	"	3.6	" " " "

- one	pound	of	wood	produces	36.8	cubic feet of gas
- "	"	"	lignite	"	64	" " " "
- "	"	"	hard-coal coke	"	57.6	" " " "
- "	"	"	anthracite	"	72	" " " "

- 3.3	kilograms of wood	are equivalent to	1 liter of diesel fuel
- 1-1.3	kilograms of charcoal	" " "	1 kilowatt hour of electricity
- 25-29	pounds of wood	" " "	1 gallon of diesel fuel
- 2-3	pounds of charcoal	" " "	1 kilowatt hour of electricity
- 5.5	pounds of wood	" " "	1 kilowatt hour of electricity

Source: Producer Gas: Another Fuel For Motor Transport
National Research Council,
National Academy Press, 1983

ANNEX IV

Plantation Area Requirements
For Ethanol To Replace Diesel Fuel
For Electricity Generation

Assumptions:[1]

- Rural community power output requirement	75 kilowatts
- Annual operating period	4,350 hours
- Diesel fuel consumption	0,4 liter/kwh
- Extent of diesel fuel replacement (on calorific basis[2])	20 %
- Engine derating	assumed to be negligible

Calculations[1]:

75 x 4,350 x 0.4	= 130,500	liters of diesel fuel required annually before replacement
130,500 x 20 %	= 26,100	liters of diesel fuel to be replaced annually
26,100 x 1.6	= 41,760	liters of ethanol required annually to replace 26,100 liters of diesel fuel

The land and the sugar-containing sources which are required for the production of 41,760 liters of ethanol annually are approximately 8 hectares of sugar cane or about 12 hectares of sugar beet.

[1] Assumptions and calculations have been made by the consultant.

[2] On account of different calorific values, the volume of ethanol will be 60 % more than that of the replaced diesel fuel.

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