GENERAL MANAGEMENT ASSISTANCE CONTRACT (GMAC)

Contract No: 674-C-00-01-00051-00

Farm Scale Ethanol Production Plant – Demonstration Prototype

Grant No. 0047-0402-G-GA15

National Development Initiative for Social Welfare (Ndiswe)

This report was produced for review by the USAID. It was prepared as a performance milestone under Mega-Tech, Inc.'s prime contract.
The contents of this report address activities performed under USAID/South Africa's Strategic Objective No. 6: Increased Access to Shelter and Environmentally Sound Municipal Services

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Activity Summary and achievements:

USAID funded the construction and testing of the Farm Scale Ethanol Production plant as a demonstration for the World Summit on Sustainable Development (WSSD) held in Johannesburg in August 2002. The purpose of the demonstration was to prove the viability of renewable fuel production for rural village communities from readily available biomass materials. The construction and testing was done in partnership with Farmworks International LLC of Fredericksburg, Virginia at the Agricultural Research Council grounds in Silverton, Pretoria, South Africa.

The attached Grant Activity Completion Report and Final Report present the program and its achievements in more detail.

Contents of this report:

Grant Activity Completion Report

1. Name of Organisation	NDISWE
2. Grant Activity	FARM-SCALE ETHANOL PRODUCTION PLANT (PROTOTYPE)

3. Briefly describe the grant objectives achievements and impact as a result of the grant activities implemented during the grant period.

1. Build the TVA/US Dept. of Energy designed Farm-scale Ethanol Plant.
2. Make appropriate design changes
3. Test ethanol production to verify feasibility in rural African conditions
4. Modify taxi engine to run on ethanol
5. Develop model of rural eco-village
6. Achieve these objectives for the WSSD Conference in Sept.

4. Briefly discuss the implementation process, including lessons learned and recommendations

* Successfully achieved all objectives by establishing the plant on the grounds of the Agricultural Research Council in Silverton, near Pretoria.

Recommendations

1. Locally verifiable research needs to be done on a taxi and a diesel vehicle running under normal industrial conditions, using sustainable fuels
2. A model agri-village w/ full ethanol production capacity now needs to be constructed as a prelude to continuing discussions with PetroSA to add ethanol to their fuel production.

5. Public Dissemination: GMAC requires that all grant activity deliverable(s) of the grant activity (e.g., a report or survey) must be made available to the general public. Briefly discuss how the grants activities and results were made accessible to interested parties.

1. The plant was a show piece during the WSSD and attracted a variety of visitors, including the US ambassador to SA.
2. We made a presentation to the Fuel Policy Committee of the Gov't. and contributed a document to the Draft White Paper on Sustainable Energy.
3. We became a member of the Global Village Energy Partnership.
4. We were a finalist in the Johannesburg Climate Legacy Competition.

Signature of Grantee ____________ Date 11/7/03.

Final Report

Operation and Production Of the Village Scale Ethanol Production Plant

By

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For

United States Agency for International Development

USAID funded the construction and testing of the Village Scale Ethanol Production plant as a demonstration plant for the 2002 World Summit on Sustainable Development held in Johannesburg in August of 2002. The purpose of the demonstration was to prove the viability of renewable fuel production for rural village communities from readily available biomass materials. The construction and testing was done by Farmworks International LLC of Fredericksburg, VA at the Agricultural Research Council grounds in Silverton, Pretoria, South Africa.

USAID and Renewable Energy Strategies

USAID has a world wide strategy to promote rural development through renewable energy strategies which up to now have been limited to renewable electricity production from photo-voltaics, windmill energy or micro-turbines.

There is however a great need for the production of renewable liquid fuels from biomass for Village Scale ethanol production as a means of earning income for rural farm communities to supply urban cities as well as a fuel source for Villages themselves.

The Village Scale Ethanol Production Plant

We have constructed an operational Village scale ethanol production plant in Silverton Pretoria which was a demonstration project for the recent UN Summit on Sustainable Development held in Johannesburg. The Summit itself was a major success and our ethanol demonstration plant received tremendous interest from all over the world where various governments and aid agencies are now interested in using it for development purposes. By redesigning the unit so that it can be built and transported in 40 foot international shipping containers the unit can be massed manufactured with low cost savings and delivered as a turnkey operation usable all over the world.

Description of the Plant...

Production capability: 300,000 to 350,000 gallons per year capacity (about 100,000 liters per month)

Product: about 190 proof ethyl alcohol (up to 95% ethanol).

Feed stocks: Any starch or sugar material. Cellulose materials not usable in this design.

Factory Size: About 500 square meters required (about 5,000 sq. feet.)

Equipment includes:
9 fermentation tanks made of fiberglass
hot water tank
stillage tank
ethanol product tank
stainless steel stripping column and rectifying column
condenser unit and reflux unit
electrode steam boiler
tank agitators and motors
cooking tanks

pump units
valves, pipes, thermometers, flow , meters

Packing: Into two forty foot international shipping containers ready for assembly and operation when unpacked, easy assembly instructions including operations manual.

Cost: $200,000 ex factory. Includes the cost of the forty foot transport containers which may be kept by the buyer.

USABLE FEED STOCKS FOR ETHANOL PRODUCTION

Various tests have shown that one metric tonne of maize or sorghum (1000 kg) will produce about:
450 litres of ethanol
350 kg of high protein animal feed
400 kg of Carbon Dioxide.

CARBON DIOXIDE USAGE

We are conducting ongoing tests on the use of the Carbon Dioxide to produce algae in large ponds that have a high lipid oil content. The carbon dioxide is percolated into large algae ponds with a source of fertilizer whereby the algae then through photosynthesis utilize the Carbon Dioxide to produce large quantities of protein and oil. The oil is pressed out to be used in Bio-Diesel production and the protein is used in animal feeds. Initial results show the possibility of 50 grams of algae per day per square meter of pond area. 40% of the algae is lipid oil and about 50% is protein.

Carbon dioxide can also be sold to cold drink manufacturers or turned into dry ice for sale. This can provide important additional income for the operation of the plant.

The following information is intended only as a guide (quantities are in US gallons and pounds).

SUGAR/STARCH CONTENT vs ALCOHOL

On the average, the amount of alcohol that can be produced from a given feedstock will be about half (on a weight/weight basis) of the convertible starch or sugar content. Ethanol weighs about 6.6 pounds per gallon. A ton of grapes, for example, with a 15% sugar content is capable (assuming 100% extraction) of producing about 150 pounds or 22.7 gallons of alcohol. Corn, with 66% convertible starch should produce 660 pounds or 100 gallons. Remember, this is only an approximation and actual yield depends on many interrelated factors.

SACCHARINE MATERIALS

The process of fermenting saccharine materials is relatively simple and straightforward. The steps involved are usually: (1) extracting or crushing, (2) pH adjustment through acid or and (3) fermentation. Dilution is usually not necessary because the extracted juices often contain less than the 20% maximum of fermentable material. Exceptions to the above are the various types of molasses that do not require extraction, but usually require dilution.

FRUITS

The following are some fruits and their average sugar content: grapes, 15.0%; bananas, 13.8%; apples, 12.2%; pineapples, 11.7%; pears, 10.0%; peaches, 7.6%; oranges, 5.4%; prickly pear, 4.2%; watermelon, 2.5%; and tomatoes, 2.0%.

Allowing 75% extraction with apples, for example, the total fermentable material would be about 9% of the original weight. On this basis, a ton of apples would yield about 13 gallons of alcohol. Assuming an 80% extraction with grapes, a ton should yield about 17 gallons. With watermelons and a 90% extraction, a ton would yield only about 3 or 3-1/2 gallons. Clearly, some materials are better than others.

In all the above cases, the percentage of fermentable material in the extracted juice is low enough so that dilution is unnecessary and undesirable. To ferment these materials, the juice need only be adjusted to the proper pH (between 4.8-5.0) and the yeast added at the usual rate of 2 pounds per 1000 gallons of mash.

Also, all of the above materials may be simply crushed or pulped instead of extracted in a press. This way the total sugar content is available for fermentation.

MOLASSES

Beet or cane molasses is the residue from the manufacture of sugar. These materials, if available, are excellent sources of alcohol. They contain 50-55% fermentable sugar, and a ton should yield between 70-80 gallons of alcohol.

Molasses with a sugar content above 15-20% will need to be diluted. Also, most molasses is naturally alkaline, and acid will be needed to obtain the proper pH value.

CANE SORGHUM

Cane sorghum is a good alcohol source because it is easily grown and averages about 14% fermentable sugar content. The main drawback to using this material is that the extraction requires heavy-duty shredding and pressing equipment. An alternate process is to shred the stalks as much as possible and dissolve the sugar by heating (not quite to a boil) with a minimum amount of water. The process must be repeated several times to retrieve most of the sugar. Note that in this type of process, two extractions of one gallon each are better than one extraction of two gallons.

A conservative 65% extraction should yield about 13-14 gallons of alcohol per ton. Acidification to proper pH is necessary.

SUGAR BEETS

Sugar beets are an excellent material for ethanol production. They contain about 15% sugar, 82% water, and the rest in various solids. The juice can be extracted in a press, or the beets can be crushed and fermented as described in the section on fruits. Because the beets contain a certain amount of starch, the addition of small quantities of malt (1-2% by weight) or enzyme will greatly improve the alcohol yield. Adjustment of pH is, of course, necessary. A ton of beets should produce 20-25 gallons or more of alcohol.

SUGAR CORN WASTES

Stalks from sugar corn contain 7-15% sugar and should be considered as an alcohol source if they are available. The stalks need to be shredded and extracted in a manner similar to sugar cane or sorghum stalks. A relatively efficient operation should yield 8-18 gallons of alcohol per ton of material.

STARCHY MATERIALS

Starchy materials generally require milling, cooking, and conversion prior to fermentation. Exceptions are materials, such as potatoes and sweet potatoes, that do not require milling, and materials, such as artichokes, that do not require conversion. Relatively high alcohol yields often offset the necessary additional manufacturing steps, and most starchy materials are good alcohol sources.

GRAINS

Grains must be milled, diluted, cooked, and converted prior to fermentation. However, they contain large amounts of potentially fermentable material. The average content of convertible starch and sugar in some typical grains are: barley, 50%; maize , 66%; oats, 50%; rye, 59%; sorghum seed, 67%; and wheat, 65%. Alcohol yield per ton is dependent on how completely the starches are converted to fermentable sugar, but should be between 70-100 gallons.

After milling, the grain must be diluted prior to cooking and fermentation. The average dilution is between 56-64 gallons per 100 pounds of grain, depending on moisture and starch content.

Cooking is accomplished by heating the diluted and premalted mash to a slow boil and holding at this temperature for 30-60 minutes. Generally, the mash is sufficiently cooked when it is soft and mushy. The mash is then cooled to 145-150 deg F and enzymes added for conversion of the starch to sugars. Malt slurry can also be used instead of enzymes. Grain is allowed to sprout which results in malt enzyme being produced – this is turned into a slurry with water being added.

On a weight/weight basis, corn or wheat will require about 8-10 pounds of malt per 100 pounds of grain. Rye will require about 10-12 pounds of malt for the same 100 pounds of grain. Other grains will fall somewhere in between. The malt slurry is stirred constantly during conversion. For wheat, the conversion will be complete in 5-15 minutes. Corn will require about 30 minutes, and rye between 30-60 minutes. The actual time, as well as the minimum amount of malt necessary, can be determined through trial mashes.

When the conversion is complete, the mash is cooled to 70-75 deg F. and yeast slurry is added. Note that most grain mashes have an acceptably low pH and often do not need much adjustment.

The following is the general procedure for converting corn with Miles Laboratories enzymes. The procedure for other materials and other enzymes will differ slightly, and the manufacturer's recommendation should be followed.

After milling, the grain is partially diluted (slurried) at a ratio of 35 gallons of water per 100 pounds of grain. The pH is adjusted above 5.5 with an optimum range of 6.0 to 6.5. "Pre-malting" or liquefaction, is accomplished by the addition of 0.3 ounces of Taka-Therm enzyme.

The mash is then slowly heated. Gelatinization will begin at about 150 deg F. and the mash will rapidly thicken. Constant stirring is necessary at this point. At about 160 deg the liquefying action of the enzyme will begin. Heating may be more rapid after the liquefying action of the enzyme begins to take effect. After the mash reaches 200-212 deg an additional 1.3 ounces of Taka-Therm enzyme is added.

After the mash has been held at a slow boil for 20-30 minutes, an additional 33 gallons of water is added to complete dilution and cool the mash.

When the mash has cooled to 135-140 deg the pH is adjusted to 4.2 with acid and Diazyme L-100 enzyme is added at a ratio of 4 ounces per 100 pounds of grain. This enzyme completes the conversion in about 30 minutes and, after cooling to 70-80 deg, the mash is fermented in the usual manner.

JERUSALEM ARTICHOKES

Jerusalem artichokes deserve special mention as a source of alcohol because they contain between 16-18% fermentable material. In addition, the starches present can be converted without the use of malt or enzymes if cooked for a sufficient length of time. A ton should yield about 25 gallons of alcohol. To prepare artichokes for fermentation, they should be crushed to a pulp and cooked for 2-3 hours. If the starch test indicates that some unconverted starch is still present, conversion with small amounts of either malt or enzyme might be needed. Shorter cooking times are possible if a greater amount of malt or enzyme is used. For example, a 30 minute cooking time should be sufficient with a conversion using 3-6% malt or the equivalent amount of enzyme. Dilution is not necessary because the root usually contains 79-80% water. After cooking, the pH is adjusted and fermentation commenced in the usual manner.

POTATOES and CASSAVA

Potatoes contain between 15-18% fermentable material and are a traditional source of alcohol. On the average, a ton of potatoes will yield about 22-25 gallons of alcohol. Damaged or sprouted potatoes are not objectionable, and the use of sprouted potatoes will reduce the amount of malt or enzyme required for conversion.

Commercially, potatoes are usually cooked with steam, under pressure. An acceptable alternate method is as follows: The potatoes should be shredded or cut up and placed in the cooker with as little water as possible; cover the cooker and steam until the potatoes are reduced to a soft mass. Pre-malting to reduce viscousness is a definite advantage. After cooking, the mash is cooled to the conversion temperature. Usually only 3-4 pounds of malt per 100 pounds of potatoes are all that is required. The mash must be constantly stirred during conversion, which will take about 15-20 minutes.

Because cooking and conversion times will vary, depending on starch content and the like, test mashings and the use of the starch test is recommended. Once converted, the pH should be checked and the mash fermented in the usual manner.

For specific procedures for the use of enzymes to convert potatoes, consult the manufacturer. Otherwise, about half the amounts listed in the corn recipe should be sufficient.

Cassava is even a better tuber for producing ethanol as it has a very high starch content and is easily grown in Africa even under dry conditions in poor soils.

SWEET POTATOES

Sweet potatoes average about 22% starch and 5-6% sugar for a total of 27-28% fermentable material. A ton should yield up to 40 gallons of alcohol. Sweet potatoes are cooked and converted in a manner similar to potatoes with the exception that they contain only about 66% water and some dilution is necessary.

ETHANOL AND ENGINES

As we envisage that most use of the ethanol produced will be for fuel consumption it is important that an explanation be provided as to how ethanol acts as fuel for engines. An important implementation strategy for Rural Villages operating the plant is to combine in partnership with urban taxi operators to sell ethanol produced by the community for use by taxi operators. This provides valuable cash income for the Village.

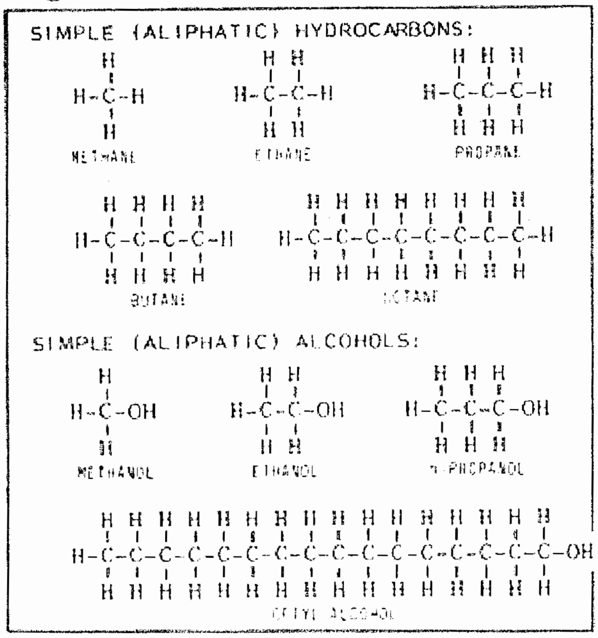
BASIC FUEL THEORY

It is important in our report also to make mention of basic fuel theory which needs to be included in the Village Scale Ethanol production plant manual.

CHEMICAL COMPOSITION

Alcohol and gasoline, despite the fact that they are from different chemical classes, are remarkably similar. Gasoline is mostly a mixture of "hydrocarbons". Hydrocarbons are a group of chemical substances composed exclusively of carbon and hydrogen atoms. This is a very large chemical class containing many thousands of substances. Most of the fuels we use such as coal, gasoline, kerosene, fuel oil, butane, propane, etc. are chiefly hydrocarbons. Referring to Figure 1-1, the simplest member of this group is methane which consists of a single carbon atom and four hydrogen atoms. Next comes ethane with two carbons and six hydrogens. Propane has three carbons and butane has four. The substances just named are gases under ordinary conditions. As we add more carbons to the hydrocarbon molecule, the chemicals formed become liquids: pentane, hexane, heptane, octane and so on. As we continue with even more complex molecules, the substances get progressively oilier, waxier and finally solid.

Figure 1-1: CHEMICAL STRUCTURES



Alcohols can be thought of as hydrocarbons in which one of the hydrogen atoms has been replaced by a "hydroxyl group" which consists of a hydrogen atom bonded to an oxygen atom. Thus methane becomes the simplest alcohol, methanol. Ethane becomes ethanol, propane becomes propanol and so on. Like hydrocarbons, there are many alcohols of ever increasing complexity.

COMBUSTION PROPERTIES

One of the most important properties of a fuel is the amount of energy obtained from it when it is burned. Referring to Figure 1-2, note that the hydrocarbon octane, which represents an "ideal" gasoline, contains no oxygen. In comparison, all of the alcohols contain an oxygen atom bonded to a hydrogen atom in the hydroxyl radical. When the alcohol is burned, the hydroxyl combines with a hydrogen atom to form a molecule of water. Thus, the oxygen contained in the alcohol contributes nothing to the fuel value.

Figure 1-2: PHYSICAL PROPERTIES of ALCOHOL and GASOLINE

	TYPICAL REGULAR GASOLINE	OCTANE*	METHYL ALCOHOL	ETHYL ALCOHOL
Chemical Formula	Complex	C_8H_{18}	CH_3OH	C_2H_5OH
Molecular Weight	Complex	114	32	46
Heating Value (Btu/lb)				
High Value	20,250	20,570	9,770	12,780
Low Value	19,000	19,080	8,640	11,550
Latent Heat of Vaporization (Btu/lb)	140	143	474	361
Specific Gravity (60°F)	0.745	0.702	0.796	0.794
Stoichiometric Ratio	15:1	15.1:1	6.45:1	9:1
Boiling Temperature (°F)	100-400	258.2	148.5	173.3
Octane Number (Research)	80	100	106	106
Energy of Stoichiometric Mixture (Btu/ft³)	94.8	95.4	94.5	94.7

*Can be considered as "ideal" high-test gasoline

The relative atomic weights of the atoms involved are: hydrogen, 1 ; carbon, 12; and oxygen, 16. Since methyl alcohol has an atomic weight of 32, half the molecule cannot be "burned" and does not contribute any fuel value. As expected, methanol has less than half the heat value (expressed in Btu/lb) of gasoline. Ethanol, with 35% oxygen, is slightly better with 60% of the heat value of gasoline.

If the heating value of methyl and ethyl alcohol were considered alone, they would appear to be poor choices as motor fuels. However, other redeeming qualities such as "latent heat of vaporization" and anti-knock values make alcohol fuels superior, in some ways, to gasoline.

When a fuel is burned, a certain amount of air is required for complete combustion. When the quantity of air and the quantity of fuel are exactly balanced, the fuel air mixture is said to be "stoichiometrically" correct. Again referring to Figure 1-2, the stoichiometric ratio for gasoline is 15:1 or 15 pounds of air for each pound of gasoline. The figures for methyl and ethyl alcohol are 6.45:1 and 9:1 respectively. On a practical level, this means that to burn alcohol effectively, the fuel jets in the carburetor must be changed or adjusted to provide 2.3 pounds of methanol or 1.66 pounds of ethanol for each 15 pounds of air.

Referring to the last entry in Figure 1-2, an interesting fact is that if we provide the correct stoichiometric mixture and then compare on the basis of the energy (in Btu's) contained in each cubic foot of the different fuel/air mixtures, the fuels are almost identical: gasoline 94.8 Btu per cubic foot; methanol 94.5 and ethanol 94.7! This means that gasoline and alcohol are about equal in what is called "volumetric efficiency" when burned in a correctly adjusted engine.

VOLATILITY

Another important quality in a motor fuel is "volatility", or the ability to be vaporized. As previously noted, methyl alcohol contains less than half the heat value of gasoline and ethyl alcohol contains only about 60%. The next higher alcohol, propyl alcohol with three carbon atoms, contains only 26.6% oxygen and thus about 74% of the heat value of gasoline. It is apparent that the more complex the alcohol, the closer its heat value comes to that of gasoline. Cetyl alcohol (Figure 1-1), for example, contains only about 6.6% oxygen and thus has about 90% of the heat value of gasoline. However, this alcohol is a solid wax! It can't be conveniently vaporized and mixed with air in an engine and so is useless as a motor fuel. Consequently, in considering alcohol fuels, a compromise must be made between heat value and volatility.

Closely related to volatility is a quality called "latent heat of vaporization". When a liquid is at its boiling point, a certain amount of additional heat is needed to change the liquid to a gas. This additional heat is the latent heat of vaporization, expressed in Btu/lb in Figure 2-2. This effect is one of the principles behind refrigeration and the reason that water evaporating from your skin feels cool.

Referring to Figure 1-2, gasoline has a latent heat of about 140 Btu/lb; methanol, 474 Btu/lb; and ethanol, 361 Btu/lb. In an engine, vaporization of the gasoline fuel/air mixture results in a temperature drop of about 40 degrees Fahrenheit. Under similar conditions, the temperature drop for ethyl alcohol will be more than twice that of gasoline, and for methanol the drop will be over three times as great. These temperature drops result in a considerably greater "mass density" of the fuel entering the engine for alcohol as compared to gasoline. The result is a greatly increased efficiency for alcohol fuels. To visualize why, remember that at a given pressure, the amount of space a gas occupies is directly proportional to the temperature. For example, if one pound of a gas fits into a certain container at a given pressure and the temperature is cut in half, the container will now hold two pounds of the gas at the same pressure. In an engine, a stoichiometric mixture of methanol and air would be over three times colder than the same gasoline/air mixture. This means that there is now over three times (by weight) as much methanol in the cylinder. Now, even though methanol has only half the heat value of gasoline, the net gain in "volumetric mass efficiency" is over three times. So, for example, if the gasoline/air mixture in a given engine cylinder produces 100 Btu on each stroke, the same engine would produce 150 Btu per stroke with methanol. This power gain due to increased volumetric mass efficiency is the primary reason for the popularity of methyl alcohol as a racing fuel. With ethanol the effect isn't quite as dramatic, but the greater heat value partially offsets the lower latent heat. Overall, this power increase with alcohol fuels considerably mitigates the liability of low heat value.

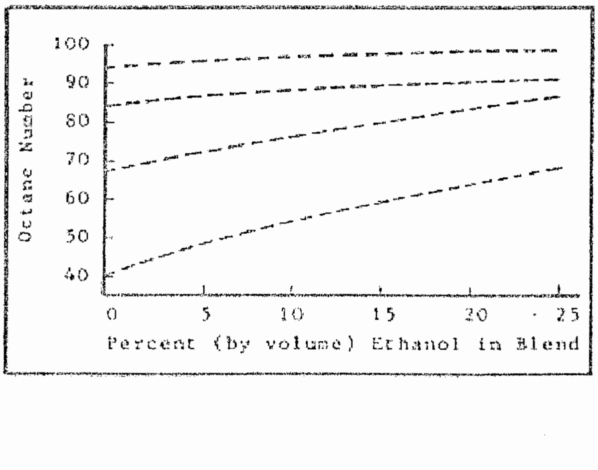
However, the increased cooling due to latent heat sometimes creates a problem in an engine converted to run on alcohol. Once vaporized, a certain amount of heat is required to keep the fuel from condensing back to the liquid state before it reaches the cylinder. To accomplish this, an engine is designed to provide this heat to the intake manifold. Alcohol, because of its greater latent heat, requires more heat than gasoline. This is one of the reasons that racing engines have short path manifolds and multiple carburetors. The shorter the distance the fuel must travel to the cylinder, the less chance of condensation and fuel distribution problems. On a practical level, most engines that have been converted to alcohol supply enough heat once they are warmed up. The main problem, as with high performance racing engines, is in starting a cold engine. This problem and the related fuel distribution problem will be discussed later in more detail.

OCTANE RATINGS

If a certain fuel is burned in an engine in which the compression ratio can be varied and this ratio is gradually increased, a point will be reached when the fuel will detonate prematurely. This is because as a gas is compressed, heat is generated. If the explosive fuel/air mixture in an engine cylinder is compressed enough, the resulting heat will cause it to detonate. Since gasoline engines are designed so that the mixture is detonated by the spark plug at the beginning of the downward movement of the piston following the compression stroke, pre-ignition or "knock" occurring during the compression stroke is undesirable. Indeed, severe knock can quickly overstress and destroy an engine.

Since greater compression ratios in an engine mean increased power per stroke and greater efficiency, the ability of a fuel to resist premature detonation is a desirable quality. The "octane" numbers assigned to fuels are based on the pure hydrocarbon, octane, which is considered to be 100. At the other end of the scale, n-heptane is considered to have an octane rating of zero. The octane number of an unknown fuel is based on the percentage volume of a mixture of octane and n-heptane that matches it in pre-ignition characteristics. In practice, these tests are conducted in a special test engine with variable compression. As noted in Figure 2-2, alcohols have a relatively high anti-knock or octane rating. As noted in Figure 2-3, alcohols have the ability to raise considerably the octane ratings of gasolines with which they are mixed. The effect is greatest on the poorer grades of gasoline. A 25% blend of ethanol and 40 octane gasoline will have a net increase of almost 30 points! This increase is one of the major advantages of "gasohol". The ability to increase octane rating means that: (1) a lower (therefore cheaper) grade of gasoline can be used to obtain a fuel with a certain octane rating; and (2) the use of traditional pollution producing anti-knock additives such as tetraethyl lead can be eliminated. The addition of about 10-15% ethanol to unleaded gasoline raises the octane rating enough so that it can be burned in high compression engines that previously could not use unleaded fuel. This use of ethanol is not new, of course, because ethanol was the original gasoline additive for increasing the octane rating. The term "ethyl" used to describe a high-test gasoline comes from ethyl alcohol, not tetraethyl lead!

Figure 1-3: OCTANE INCREASE of ALCOHOL/GASOLINE BLENDS



WATER INJECTION

During World War II, the military made extensive use of water injection in high performance piston aircraft engines. Later, water injection was used by both civilian and military jet aircraft to provide extra thrust, principally on takeoff. Even today, water injection systems are available that can be installed in automobiles. The fact is that, within certain limits, these systems actually do increase power. Referring back to Figure 1-2, note that the latent heat of vaporization for gasoline is about 140 Btu/lb and for ethanol about 361 Btu/lb. Water has a latent heat of about 700 Btu/lb! Therefore, if a little water is injected into the carburetor in the form of an ultra-fine mist, the latent heat of the water will cool the charge and increase volumetric efficiency. In addition, when the charge is fired in the cylinder, the water will turn to high-pressure steam and provide additional power due to the pressure exerted by the steam. There are definite limits, however, to the amount of water that can be injected. Too much will cause excessive cooling and misfiring.

The use of water injection with a gasoline fueled engine requires a separate metering and injection system because water and gasoline do not mix. Ethanol and water, however, do mix and the benefits of water injection can be had simply by adding the desired amount of water to the alcohol in the fuel tank.

EXHAUST COMPOSITION

In theory, a hydrocarbon fuel when burned should produce only water and carbon dioxide (CO_2) as exhaust gases. Carbon dioxide, of course, is completely non-poisonous being the gas we exhale when we breathe, the bubbles in carbonated beverages, and the gas plants turn back into oxygen during the photosynthesis cycle.

However, such ideal combustion rarely occurs even in the most perfectly adjusted engine. What is actually produced is a large amount of poisonous carbon monoxide (CO) and other complex (and undesirable) emissions arising from impurities like sulfur and additives such as lead or phosphorus.

Pure alcohol when burned under ideal conditions also produces, in theory, only carbon dioxide and water. Again, in practice, varying amounts of carbon monoxide are also produced. However, the amounts of carbon monoxide are usually much lower than with gasoline. In addition, alcohol fuel will contain no sulfur and no additives, and will not produce the related, undesirable combustion by-products. Pure alcohol fuels are extremely clean burning.

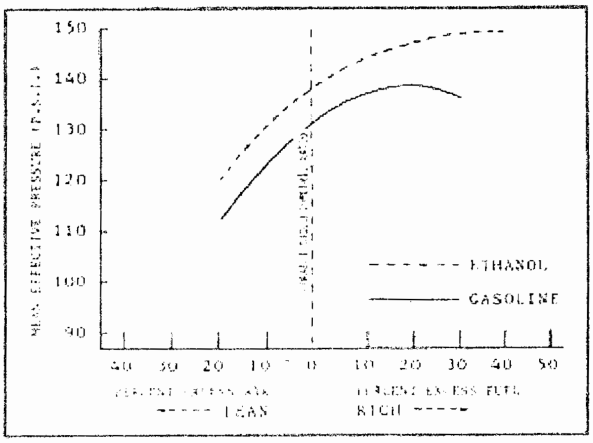
Many studies have been made to determine whether alcohol/gasoline blends have any positive effect on emissions. In general, the data show that no great changes occur in blends of 20% or less. What happens is simply that in a 10% alcohol/gasoline blend, for example, about 10% of the gasoline emissions are replaced with alcohol emissions. Since alcohol does burn considerably cleaner, the amount of emission improvement is proportional to the amount of alcohol in the blend.

Pure alcohol, as an anti-pollution fuel, would easily meet and exceed all emission requirements without the need for exotic and costly exhaust plumbing and catalytic converters. With alcohol blends, the chief advantage would be in the use of ethanol to replace lead and other undesirable compounds used to raise the octane number.

ENGINE PERFORMANCE - STRAIGHT ALCOHOL

Having looked at a few of the basic factors which influence the performance of fuels in an engine, let us now examine some actual engine tests. Figure 1-4 is a plot of 198 proof (99%) ethyl alcohol as compared to gasoline. "Mean Effective Pressure" in the graph is a direct indication of the power produced. The increased mean effective pressure (M.E.P.) of alcohol at all mixture ratios is the most noticeable difference between the two fuels. This increase in M.E.P. is due mainly to the greater volumetric efficiency that results from the high latent heat of vaporization of ethanol and the resulting greater mass density of the fuel/air mixture.

Figure 1-4: ENGINE PERFORMANCE of ETHANOL vs GASOLINE



Note that the M.E.P. of ethanol increases with mixtures having up to 40% excess fuel, whereas for gasoline, the maximum pressure is reached at 20% excess fuel. It would seem that to achieve maximum power from an alcohol-burning engine there would be a temptation to burn very rich mixtures. Fuel economy aside, it should be noted that the rich mixtures necessary to obtain maximum M.E.P. are accompanied by incomplete burning of the fuel and the resultant lowering of overall thermal efficiency. The lean limits for alcohol and gasoline, therefore, are about the same, and both fuels develop maximum thermal efficiency at about 15% excess air. With mixtures leaner than 15% both fuels loose thermal efficiency.

Figure 1-5: HORSEPOWER COMPARISON of ETHANOL vs GASOLINE

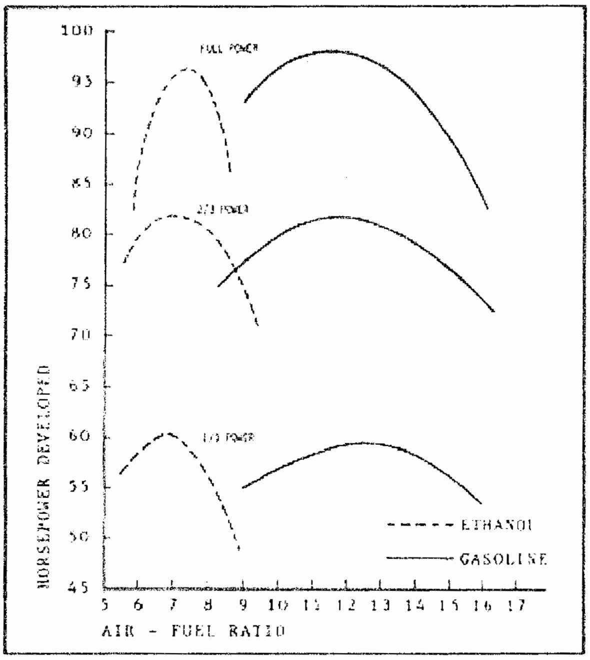


Figure 1-5 compares engine horsepower and air/fuel ratios for ethanol and gasoline in a six cylinder engine. The fuels in this case were 190 proof (95%) ethanol and "regular" gasoline having a specific gravity of 0.745. In the tests, air was supplied to the intake manifold at a constant 100 degrees Fahrenheit, and the carburetor needle valve was adjusted to provide the desired fuel/air ratios. The 2/3 and 1/3 loads were established by adjusting the throttle to give the same manifold pressure for both fuels.

The smaller air/fuel ratios for ethanol in comparison with gasoline are evident. In this test with the air supplied at the same temperature for both fuels, the correct fuel/air mixture should produce about 2% more power from gasoline than ethanol. However, alcohol, with its greater latent heat, requires more manifold heat to remain completely vaporized. In another test where this additional heat was supplied, the correct alcohol/air mixture gave 8.6% more power with ethanol! Note also that the test depicted in Figure 1-5 was run with alcohol that contained 5% water. This benefit of water injection probably inflated the alcohol power results to a certain degree. However, the main point illustrated is that the two fuels are remarkably similar in performance in a correctly adjusted engine.

ENGINE PERFORMANCE - ALCOHOL BLENDS

Although alcohol blends can be made from both ethanol and methanol, the primary interest seems to be in the direction of ethanol. Methanol and gasoline have a limited miscibility (mixability) while ethanol and gasoline can be mixed in all proportions. Economic reasons also dictate the interest in ethanol since it is more readily made from renewable resources. In addition, ethanol is a slightly superior motor fuel alternative under most conditions.

Economics aside, a major advantage of blends is that up to a certain concentration (somewhere between 10 and 20%) they can be used with absolutely no modification of the engine.

Figure 1-3, as discussed under Octane Ratings, illustrates another major advantage of alcohol blends, namely the ability of alcohol to raise the anti-knock quality of the gasoline with which it is mixed. This means, of course, that lower, cheaper grades of gasoline can be used to obtain a fuel with the desired octane rating, and the use of pollution producing additives can be eliminated. This is a significant advantage from the economic standpoint because the manufacture of high-octane blending stocks is expensive. Also, as previously mentioned, it is possible to raise the octane rating of unleaded gasoline so that it can be used in engines that previously required high-test leaded gasoline.

Alcohol blends do have one relatively minor drawback. The presence of even small amounts of water in the blend will cause a portion of the alcohol and gasoline to separate. At room temperature, less than 1% water can do the damage. As the temperature is lowered, amounts as small as 0.01% can cause separation. However, various substances such as benzene (benzol), acetone, and butyl alcohol can be added to the blend to increase water tolerance. Closed fuel systems, now in use, prevent moisture from forming inside the gas tank.

UTILIZATION OF ALCOHOL FUELS

METHODS OF UTILIZATION

Alcohol fuels may be utilized in three basic ways: as a blend with gasoline; as a straight, unblended fuel; or as an alcohol/water mixture in an injection system. Each method has certain advantages and disadvantages.

ALCOHOL BLENDS

Alcohol blends have the advantage that up to a 10, 20 or even 25% concentration of alcohol may be used without modification to the engine. The actual concentration that may be used varies with each engine type, but generally a four-cylinder engine will tolerate a stronger blend than a six or eight. Small single-cylinder engines, such as lawn mowers, can often be run on pure alcohol by merely adjusting the mixture control screw. Even with larger engines, slight modification such as adjusting the carburetor and, perhaps, advancing the timing a little may allow the use of blends in the 25-40% range. If you are producing your own blend, you have the advantage of being able to use the cheapest gasoline available and ending up with a good, high octane fuel.

The blending of alcohol however requires that the water be removed – new technology has been developed through the use of zeolites in molecular sieves that take out the water from the ethanol to give a 100% ethanol product that can be blended with gasoline.

PURE ALCOHOL

The advantages of burning relatively pure 80-95% alcohol are several. First of all, because the drying step is unnecessary, you should be able to produce the fuel for less than the cost of gasoline. Secondly, there will be little, if any performance penalty, and by leaving 5-15% or more water in the alcohol you also gain the benefits of water injection. The only disadvantage is the trouble and expense of modifying your engine(s) to burn alcohol and the lack of dual-fuel capability.

The principal engine modification is the enlargement of the carburetor jet(s). If you are a reasonably competent mechanic, you should be able to do the job in a couple of hours at a very small cost.

In addition to the carburetor jets, there is also the problem of cold starting. As mentioned earlier, alcohol has a higher latent heat of vaporization than gasoline and requires more manifold heat to keep the mixture in the vapor state. With most engines there will be no problem that can't be solved by installing a higher temperature thermostat since the engine runs fine as soon as it is warmed up. However, the engine will be difficult to start, especially in cold weather. The easiest solution to this problem is simply to start the engine on gasoline and, after it has warmed up, switch to alcohol. To accomplish this, merely install a small gasoline tank located, perhaps, under the hood and a selector valve mounted in some convenient location near the driver.

It is also desirable to replace the automatic choke with a manual control. Also, switching back to gasoline prior to shutting down the engine will aid in restarting. A more complex solution to this problem would be to install a priming pump and manifold heater glow plugs similar to those found on diesel engines. Other alternatives are to preheat the fuel or squirt an easily volatized liquid such as pentane into the carburetor. The addition of about 8% pentane directly to the alcohol in the fuel tank will also solve starting problems in below zero weather.

Another problem, also related to latent heat, is that of fuel distribution. Larger engines are more likely to encounter this problem than small ones. What happens is that there is insufficient heat to keep the fuel vaporized and some of it liquefies before it reaches the outer cylinders. This causes misfires and general poor performance. Simple solutions include insulating the intake manifold or installing a higher temperature thermostat. Heating the fuel before it enters the carburetor also helps, as does heating the intake air. The ultimate solution is, usually, to install multiple carburetors and a short-path manifold. However, you are likely to encounter this problem only in engines that are, by some design fault, prone to the same poor fuel distribution with gasoline.

It must be stressed that, although most engines are easily converted to alcohol, each engine is different. Some people have been able to successfully run Volkswagens and Hondas on alcohol merely by adjusting the jets and playing with the timing a little.

Turbocharged engines present no special conversion problems once the jets, etc. have been enlarged. Alcohol and turbochargers then work very well together. Fuel injected engines are another matter. Texas Tech. University in 1980 registered a patent that will allow for the easy modification of fuel injection engines to run on either gasoline or ethanol. The conversion then cost about $350 and was easily accomplished.

DIESEL ENGINES

Contrary to the opinion of most "experts", diesel engines can be run on pure alcohol. The main problem is in the lubrication of the injectors. This is solved by the addition of 5-20% vegetable oil (or other suitable lubricant) to the alcohol. It is also possible to make a diesel "gasohol" with up to 80% alcohol. Since alcohol and oil will not mix when water is present, both the alcohol and the oil must be anhydrous. Different engines may also require adjustment of the metering pump for optimum performance. Diesel engines, especially turbocharged diesels, may also be run with an alcohol/water injection system as described later.

ENGINE MODIFICATION

The following are some specific guidelines to assist in the modification of a carburetor. Remember that there are many different types and makes of carburetors, and that a certain amount of experimentation will be necessary.

First, of course, you will have to remove the carburetor from the engine, clean it, and disassemble it to a point where you can remove metering jet(s). This will involve removing the air horn from the float valve and disconnecting any linkage. Next you must locate the main jet (or jets on a multi-throat model). Most carburetors have removable jets. They are almost always brass and are threaded into place.

With the jet removed, the next step is to measure its diameter. This is best done with a micrometer. You will want to enlarge the area of the jet about 27% for ethanol and 40% for methanol. Suppose, for example, your jet is 0.054" in diameter. The formula for the area of a circle is 3.14 (pi) times the square of the radius. The radius is half the diameter, so we multiply 0.027 x 0.027 x 3.14 to get an area of 0.002289 square inches. Multiply this times 1.27 (for a 27% enlargement) and we get 0.00291 square inches. Working the formula in reverse we get a diameter of 0.06087 inches. This is close to a #53 drill which is slightly too small. Since it is easier to enlarge a hole than to make one smaller, a wise choice for the first trial in this instance would be a #53 drill.

Carefully drill out the jet, reassemble the carburetor, and reinstall it on the vehicle. The vehicle should then be run on alcohol as a test. Start the engine and slowly enrich the mixture (using the idle screw adjustment) until the engine starts to stall. Then adjust the idle until the roughness evens out. Take the vehicle for a short test drive, and then pull the spark plugs. If the tips are white, the mixture is too lean, and the main jet will have to be further enlarged. If they are wet, the mixture is too rich, and you have made the jets too large. In addition, if the mixture is too lean, the engine will backfire and miss.

It will also burn the valves if left in this condition. On the other hand, if the hole is too large, the mixture will be too rich and you will waste fuel. It may be necessary to make several trials before the perfect jet size is found for your particular engine. In addition to the main jet, some carburetors will also require a slight enlargement of the idle circuit jet. This is accomplished in the same manner as above except that a smaller percentage of enlargement will usually suffice. Note that this modification isn't always necessary. Often merely backing out the idle adjustment screw will be enough.

If the engine still doesn't run properly, there are several other things you can try such as advancing the timing a little, disconnecting the vacuum advance line, and closing the spark plug gaps a little. If you have an engine where it is impossible to modify the carburetor, for one reason or another, (an excess of emission "plumbing", for example) you can usually replace your carburetor with an earlier model. Usually, the older the carburetor, the easier it is to convert. Also, it is possible to purchase adjustable jets for many carburetors, or your carburetor may already have such jets. Adjustable jets make it easier to change from alcohol to gasoline and vice versa should the need arise.

COMPRESSION RATIO CHANGES

Increasing the compression ratio of the engine will be impractical for most people, because of the expense and work involved ... however, this modification will do a great deal to improve engine performance and economy. Just like a timing advance, a compression ratio hike will take advantage of the potential that alcohol has to offer as a fuel. Optimally, the ratio can be increased to 14- or 15-to-1 ... but even a nominal increase - to perhaps 12-to-1, a figure that some manufacturers have already offered in the past for premium gasoline use - will result in a vast improvement over the standard 8- or 8.5-to-1 that most manufacturers incorporate into their engines today.

If you intend to convert an automobile that already has a compression ratio of 10-to-1 or better, it probably won't pay to make any internal changes. However, if the engine you're considering needs an overhaul, it would be wise to modify it regardless of its compression ratio.

The most inexpensive way to increase your compression ratio is to install a set of high compression pistons. The forged units are designed to pack the air/fuel charge tightly into the combustion chamber for increased power, and have special relief notches built into their heads for valve clearance. Be cautioned, however, that some engines may not tolerate a 15-to-1 compression ratio with standard connecting rods and bearings ... these components, too, may have to be replaced with high-strength competition grade parts.

Another way of increasing compression ratio slightly is by "milling" (planing) the surfaces of the cylinder head and/or block. With some engines, this may result in only a 1/2-point ratio increase ... with others, slightly more. It would be best to check with your local engine rebuilder or automotive machine shop to determine exactly what you'll gain with your particular model engine before you go to the trouble of dismantling it.

INITIAL USE OF ALCOHOL FUEL

An engine altered as outlined will run well on alcohol. Nonetheless, there are certain things to be aware of as you begin to make use of the new fuel. First, remember that the alcohol will act as a cleansing agent ... and - as such - will not only clean out your tank, fuel lines, and filters, but will also purge your engine's internal parts of built-up carbon, gum, and varnish deposits.

In effect, what this means is that suddenly a lot of filth will be floating around in your fuel ...

and it may be enough to clog your fuel filter to the point of not allowing any fuel to pass. By the same token, loosened internal engine deposits can foul the spark plugs badly ... so if your vehicle begins to function poorly soon after your conversion, check these two areas first.

In addition to the fact that alcohol is a cleaning agent, it is also a solvent ... and this means that certain types of plastics used in the fuel system of your vehicle may be attacked by it. Actually, most of the plastics deterioration problems associated with ethanol fuel are caused by the substances used to denature it - such as acetone or methyl ethyl ketone - rather than the alcohol itself. If you manufacture your own alcohol and denature it with gasoline, deterioration problems will be reduced to a minimum.

Most vehicles manufactured prior to 1970 used stainless steel or brass components in their fuel systems ... hence there is little chance of parts failure. In cars that use plastic components, however, there are several areas of potential deterioration: Within the fuel tank, both the float and the strainer on the fuel intake tube may be plastic ... replace them if necessary. The fuel lines themselves - if they are the clear, flexible type - may also soften ... you can install neoprene hose in their place. The fuel pump diaphragm may also be subject to failure ... either replace it with a piece of spring steel, or replace the entire pump with an electric gear-type model available from your auto parts store. (Jaguars and Alfa-Romeos also use all-metallic pumps if you're willing to pay the price.) Plastic in-line fuel filters should be replaced with metal ones. Many modern carburetors use plastic float needles, seals, and floats that need to be replaced.

Of course, not all plastics are subject to corrosion, and neither are all types of rubber. Generally, butyl rubber (like the type used in inner tubes) should be avoided. Neoprene, however, holds up well even at higher temperatures, and might only present a problem (because of swelling) if it's used as a tip on carburetor float needles.

One final thing to be aware of when burning alcohol in your vehicle is that the new fuel does not contain the additives which the engine has become used to over the years ... specifically the leads which help to lubricate the valve seats. Of course, any car built in 1975 or later is already equipped with hardened valves and seats, so there should be no problem with them ... but even vehicles of other years can tolerate alcohol fuel safely.

One reason for this is that water in the alcohol acts as a "cushion" and lubricant for the valves ... but if you are still wary of using alcohol fuel in its pure form, you can add up to 1% kerosene or diesel fuel to your alcohol supply. This will provide the lubrication of petroleum fuels with a minimum of pollution.