FUEL SUBSTITUTION IN AUTOMOTIVE TRANSPORT*

by

Ibarra E. Cruz, Ph.D.**

INTRODUCTION

The purpose in writing this paper is to review the concepts and implementable ideas on alternative fuels and systems for power generation developed during this decade of the 80's. Special reference will be given to vehicle fuels since transportation accounts for a large proportion of national energy consumption and the Philippines is at present still fully dependent on petroleum-based fuels for this purpose. Information gathered comes principally from three sources: (1) the national conference of the Society of Automotive Engineers (Australasia) held in Australia in 1980; (2) the regional seminar on alternative vehicle fuels held in New Zealand in 1987; and (3) the author's own research experience in the use of alcohol, coconut oil and producer gas for internal combustion engines during the last ten years.

AUTOMOTIVE TRANSPORT IN THE 80's

At the start of the 80's, an international conference was held in Australia by the Society of Automotive Engineers in Australasia to consider the problems of the automotive industry inherited from the 70's and problems that would have grown in the 80's. The conference covered the general topics on (1) alternative fuels and engines of the future, (2) operation, maintenance and servicing the vehicles of today, and (3) a wide range of viewpoints on fuel economy and exhaust emissions.

*Paper presented at the PECC Third Minerals and Energy Forum, held at Philippine Plaza Hotel, 27-28 July 1989.

**Holder of MIESCOR Professorial Chair in Mechanical Engineering, University of the Philippines. Chairman, Mechanical Engineering Department, University of the Philippines.

At that time, the greatest challenge that faced the automotive industry was the scarcity of liquid fuels. There was a great controversy about the world's reserves of crude oil but the estimate in 1974 was some 715 billion barrels with an annual consumption of 20 billion barrels.[1] If nothing was done soon, then the reserves are not very likely to be extensive beyond the year 2000. One of the challenges that faced the automotive engineer was to improve the efficiency of vehicles.

Each liter of fuel contains about 35.2 MJ and with an efficiency of conversion of 30%, there is approximately 20 km/liter available for transport purposes. Very few cars before 1980 were able to achieve even one-third of this figure. A large 1820-kilogram car, for instance from the 70's, averaged 5.6 km/liter or an engine efficiency of 85.%.

Concepts discussed by automotive engineers in 1980 to increase the efficiency, and thereby the fuel economy of automobiles included the following:

1. The move towards smaller cars fitted with traditional power plants. This certainly would increase the fuel efficiency of vehicles but also unnecessarily increased the capital investment in the entire automotive industry, requiring re-design of not only the transmission and the engine but also the entire vehicle and factories for its manufacture.

2. Introduction of diesel engines with inherent problems of noise, lack of normally accepted performance, visible pollution and the possibility of an oil refinery imbalance in product mix. This problem of refinery imbalance has already happened in countries where there had been a dramatic shift from gasoline to automotive diesel engines.

3. Small capacity internal combustion engines fitted with exhaust turbo-charging, an ideal method for providing sufficient power for high-speed cruising. The advantage is that the engine could be used at a high effective compression ratio thus improving significantly its fuel economy. However, fuel injection have to be adopted to overcome the problems of a system which is utilized for high power demands for the majority of the car's operation.

4. The addition of devices which would increase the fuel efficiency of vehicles. A list of such add-on devices included (a) a microprocessor control on automatic gear boxes, (b) electronic ignition and fuel injection systems, (c) provision of standard LPG conversion kits for those vehicles which were used in fleet operations, as in the 5-passenger 1500-kg taxi cabs, and (c) the installation of a second epicyclic gear box - the overdrive gear which minized the engine speed and increased the torque under driving conditions where this was desired.

5. The development of smaller I.C. engines of the single-cylinder, double-cylinder or three-cylinder categories with the inherent problems of vibration, reliability and torque fluctuation.

It is evident in the variety of car models in the market these days that most of the above concepts have been implemented by the world's automotive industry.

ALTERNATIVE VEHICLE FUELS

The seminar on alternative vehicle fuels held at the University of Canterbury, Christchurch, New Zealand in 1987 looked systematically at the various fuels which had been examined in New Zealand as gasoline substitutes[2]. The major alternative fuels discussed were:

1. Compressed Natural Gas;
2. Liquefied Petroleum Gas;
3. Synthetic Petrol from Natural Gas;
4. Biogas;
5. Alcohols (methanol and ethanol);
6. Vegetable Oils.

Of interest to the Philippines as alternative vehicle fuels are biogas, the alcohols, vegetable oils and producer gas.

BIOGAS

Work on biogas production at the Invermay Research Centre was described together with numerous biogas production plants in New Zealand producing biogas from a wide range of feedstocks including plant wastes, abbatoir wastes and milk processing effluent. Large anaerobic fermentation installations at the Christchurch Drainage Board (the counterpart of our Manila Water and Sewerage System) were described and the various uses of biogas were discussed including treatment and compression of the gas to run a fleet of 70 vehicles.

Biogas in the Philippines is more commonly used for stationary engines to generate electrical and mechanical power. A good example is Maya Farms, a food-processing plant in the vicinity of Manila which generates about 70,000 tons of animal manure annually from 50,000 pigs and 20,000 ducks. At conversion rates of 0.26 to 0.30 cubic meter of methane per kilogram of volatiles in the dry manure, a daily production of about 8,000 cubic meters of biogas is possible. Maya Farms in fact produces 5,600 m^3/day which is sufficient to meet all its heat, refrigeration and electrical power requirements[3].

ALCOHOLS IN GASOLINE

Alcohols as substitute vehicle fuels can be justified by the abundance of cheap primary materials from which they are produced. Methanol in New Zealand is produced from natural gas at the world's largest methanol plant at SynFuels Limited. In this plant, methanol is used as raw material for the production of 1600 tonnes/day of synthetic gasoline.

A number of biomass options for vehicles fuels were studied at the Agricultural Engineering Institute at Lincoln College, Canterbury (ethanol from beets), the New Zealand Forest Research Institute (ethanol from wood by acid hydrolysis) and at the Department of Mechanical Engineering of Canterbury University (rolling road tests of methanol-fueled vehicles).

In the Philippines, ethanol comes principally from sugar cane. Usage of ethanol-gasoline blends (15 to 20 percent anhydrous ethanol) was tried in the islands of Negros and thence Panay during the period of September 1980 to the end of 1985[4]. The experiment was generally received unfavorably in view of inadequate preparation and campaign, and poor performance of the fuel blends as perceived by the users. The chief complaints as elicited in a subsequent consumer survey have been:

(1) Cold startability was unsatisfactory;

(2) Less accelaration and power;

(3) Other problems such as high evaporation losses, frequent fuel filter clogging, engine stalling, dirt and carbon deposition.

Some of the complaints had valid basis but others were perhaps biased perceptions of users who resented the government's imposition of the experiment in their region. For instance, fuel filter clogging, a common complaint, was primarily caused by alcohol disolving dirt in old fuel tanks, leading to engine stall or loss of power due to a fuel-starved engine when the filter became clogged. In cases where this problem surfaced, thorough cleaning of the fuel tank and replacement of alcohol-incompatible materials in the fuel system usually prevented recurrence.

The Philippine alcogas program was patterned after that of Brazil where anhydrous ethanol was blended with gasoline, thus minimizing the deficiencies of hydrous alcohol-gasoline mixtures. In Brazil, anhydrous alcohol-gasoline blends have proven to meet acceptable standards of reliability, performance and minimal metal corrosivity.

The sales of alcogas in the Philippine in 1980 to 1984 varied from a minimum of 20,000 kiloliters in 1980 to a maximum of 47,000 kiloliters in 1981. This was small compared to Brazil's ethanol production of 165 million gallons in 1975 to 2,442 million gallons (9.244 million kiloliters) in 1985. It was also apparent that by 1985, Brazil was producing and using more hydrous alcohol (1,722 million gallons) than anhydrous alcohol (720 million gallons). This was due to the increasing use of straight alcohol (hydrous) instead of blends (anhydrous).

Alcohol appear somewhat more viable as motor fuels when used straight instead of in blends. The two major problems of blends are sensitivity to water contamination resulting in phase separation (gasoline floats on top of alcohol) and high vapor pressure (volatility) which leads to vapor lock in fuel systems. These problems are not present when using straight alcohol. A specially designed engine must be used incorporating the following changes:

(1) Increased intake manifold to provide sufficient capacity (3.7 to 6.7 times higher) to vaporize the alcohol to obtain good cylinder-to-cylinder distribution.

(2) Increased compression ratio to provide better fuel economy and take advantage of the higher octane number of alcohol. In view of this, stronger pistons and special valve seats must be provided to withstand the greater stress.

(3) Larger carburetion system to provide larger quantitites of fuel compensating for the lower heat content of alcohol.

(4) New distributor system with compatible ignition advance curve, higher capacites of batteries and alternators, and heavier duty spark plugs for more efficient combustion.

(5) Coating of tanks with chemical nickel, alcohol resistant pumps or cadmium-plated for protection against corrosion, and fuel system parts that are compatible with alcohol.

It is obvious that an alcohol fuel program involving use of straight alcohol in specially designed engines would mean major capital investments which the Philippines could ill afford at present. A transition from anhydrous alcohol blends to straight hydrous alcohol could be the use of 50% hydrous alcohol blended to 50% gasoline.

A Philippine experiment monitoring for a year the performance of four stock vehicles using this 50-50 mixture and three control vehicles using gasoline, was recently concluded[9] Reports indicate that the problem of material incompatibility in the fuel system is serious and has to be resolved if reliable operation on hydrous alcohol is to be achieved. A 1988 Mitsubishi Lancer which has travelled some 30,000 kilometers on the 50-50 mixture exhibited thermal efficiencies comparable to that of premium gasoline but the carburetor made of zinc-aluminum alloy was continuously corroded by the hydrous alcohol blend and had to be cleaned every 4 or 5 days to remove oxidized material that frequently clogged the fuel jets. Otherwise, the car has been running satisfactorily with an average performance of 7 kilometers per liter of the fuel mix. Modifications made to the engine had been limited to enlarging the fuel jets in the carburetor to make up for the smaller heat content of the alcohol blend. The heating value of the blend was 25% less than that of gasosline. The test vehicles' average fuel economy (expressed in kilometers per liter) ranged from 18% to 22% lower than those of the control vehicles which used gasoline. The cost of using the alcohol blend, based on 1989 prices, was P0.78 per kilometer as compared to P0.63 for premium gasoline.

VEGETABLE OILS IN DIESELS

In developed countries the opinion advanced that vegetable-based fuels are not likely to have a major impact on the overall transport fuel supply problem because of agricultural limitations. However the use of this substitute may have a profound beneficial effect on the country's agricultural programs.

In the Philippines, the government's desire to assist the ailing coconut industry led to the formulation of the Coco-Diesel Program in late 1980, in which crude coconut oil was blended with diesel fuel for use in automotive and heavy transport diesel engines[5].

A limited fleet test using five passenger buses of the Pantranco North Express, Inc. equipped with MAN diesel engines and five units of the Metro Manila Transit Corporation equipped with Hino and Fiat engines, was conducted and monitored for seven weeks by the Ministry of Energy in 1981. The coconut oil-diesel blend used was 30% crude coconut oil and 70% diesel oil. The results indicated an average fuel economy of 2.32 km/liter when using the coco-diesel blend for an aggregate distance of 48,898 km as compared with that of 2.49 km/liter when using pure diesel fuel. This is equivalent to a 5% decrease in fuel economy when using the 30% coconut oil-diesel blend.

In September 1982, implementation of a nation-wide coco-diesel program using a blend of 5% crude coconut oil and 95% diesel oil was started. In these proportions, the specifications of the blend hardly differed from those of pure diesel. A potentially serious problem however emerged in the bulk handling, trans-shipment and storage of the coconut oil diesel blends. Microbial growth, which led to the build-up of filamentous, slimy materials that clogged fuel filters, was attributed to the use of crude coconut oil highly contaminated with fungi, bacteria and yeasts. Multiplication of these microbes was enhanced by the presence of water in the fuel.

The use of a semi-refined coconut oil, with less free fatty acid, a lower moisture content and a lower microbial load, apparently controlled this problem. A fleet test of 168 passenger buses, conducted for 10 months using a blend of 5% semi-refined coconut oil (cochin grade) in diesel fuel did not result in the same microbial problem previously encountered. The problem however was the high cost of refined coconut oil which subsequently improved in its world market price, thus making its use as diesel substitute uneconomical.

PRODUCER GAS IN INTERNAL COMBUSTION ENGINES

Initial research studies at the University of the Philippines on the use of producer gas in internal combustion engines showed that coconut shell charcoal was good fuel for a small downdraft gas producer supplying gas to a small diesel engine[6]. At the rated capacity of 5 brake horsepower, the engine ran on 90 percent of the input fuel energy from producer gas with a net calorific value of 130 Btu/cu ft. Only 10% of the fuel input was diesel which amounted to 90% displacement of an imported fuel with an indigenous one.

One practical application of producer gas for shaft power was in farmland irrigation. Early in 1980, the Farm Systems Development Corporation (FSDC) established an affiliated company, the Gasifier and Equipment Manufacturing Corporation (GEMCOR) which mass-produced charcoal gasifier for stationary engines for irrigation purposes and later on for other uses including that for vehicles. When charcoal was used as fuel, problems in cleaning the producer gas before using in engines were minimized. The gas producer units for stationary engines worked well for a time although when problems arose later on, back-up service from GEMCOR was slow in coming. More often than not, the engines were run on straight diesel rather than on a combination of diesel and producer gas as a result of minor break-downs in the gasifier system. When GEMCOR embarked on manufacturing numerous models including units for mobile or vehicle applications, the problems were compounded which led eventually to the failure of the venture.

ENGINES OF THE FUTURE

A look into what is possibly the transport engine of the future could be encouraging with respect to energy conservation and pollution control and challenging in so far as research opportunities are concerned.

AN ALL-ELECTRIC VEHICLE

In 1980, an electrical vehicle which could reduce pollution in urban commuting was envisioned to have a top speed of 80 km/h with a range of 30 kilometers covered within an hour[1]. The limitations were lack of power output which was limited to 40 Wh/kg of battery mass. The vehicle therefore sufferred from a lack of both high speed and hill climbing capabilities.

A standard lead-acid battery produces 45 kJ/kg, thus at 80 km/h, 11 kg/km is required. A range of 30 km is practical with a mass of 330 kg or approximately 25% of the total mass of the vehicle. This range may be increased to 50 km in lower speed driving if regenerative braking were effective. The 330 kg battery would require some two hours to charge from a 10 ampere 240V circuit after completing 30 km of travel.

By 1988, Asea Brown Boveri[7] has developed an electric drive system which, on reaching technical maturity, would allow a typical family saloon to be driven at a top speed of 120 km/h. The drive system combines a high-energy sodium-sulphur battery, a component unit containing the power electronics and on-board computer, and the motor/gearbox. The target stored energy of the sodium-sulphur battery is 32 kWh for a complete discharge in two hours, at an energy density of about 120 Wh/kg compared to the lead-acid battery's maximum potential of 40 Wh/kg. In city traffic a range of 200 kilometers is claimed to be possible. As a standard vehicle component, a battery charger has been developed which can be connected to every AC power socket at 16 A and 200 V.

HYBRID VEHICLES

A hybrid vehicle is one which utilizes an internal combustion engine, flywheel storage and in some cases electric energy storage. A typical hybrid car will weigh 1500 kg, have a top speed of 130 km/h, an all electric range of 8 km when using its lead-acid batteries alone, a braking regenerative efficiency of 40% and is expected that in suburban driving, the average fuel performance will be 14 to 17 km/liter excluding the all electric operation. The car is powered by a 1.3 liter four cylinder overhead cam engine, contains a 40 kg flywheel operating at a maximum speed of 7800 rpm with an energy storage of 200 kJ, and carries a battery pack weighing 100 kg. If a sulphur-sodium battery pack could be used, the all electric range can be increased to 24 km.

STEAM CARS

Efficient Rankine cycle steam cars (thermal efficiency of about 20%) powered by small 30 to 50 kW steam engines can be produced with little development of today's technology. The adiabatic expansion efficiency of small steam engines has to be improved by solving the scaling problem and lubrication constraint. Boilers are already available to burn liquid fuel at efficiencies of 85-92%. Coal oil mixture as fuel for the boiler is possible.

HYDROGEN CARS

There are two main reasons for looking at hydrogen as automobile fuels in the future:[8]

(1) Hydrogen burns to water without forming CO_2. There is a remote possibility that we may one day no longer accept the increasing concentration of CO_2 in the atmosphere, if an alteration of the climate should be proved;

(2) It would be wise to conserve depletable mineral oil. Hydrogen can be produced from renewable energy sources, e.g. electricity derived from ocean thermal energy conversion.

There are three main areas where hydrogen as an automotive fuel demands special solutions:

(1)The storage system - should it be under pressure in bottles, liquified in insulated tanks or condensed in hydrides?

(2) The heat engine - should it be gas turbines, stirling engines or steam engines?

(3) The filling station - shall it dispense super cold hydrogen from filling station pumps, or refill by exchanging empty pressure bottles or hydride containers with filled ones?

It is obvious that there are many unknown and unsolved problems arising from hydrodgen as automotive fuel and much investment in research and funds will still be required.

REFERENCES

Scarcity of Liquid Fuel - SAE's Greatest Challenge, by Prof. Keith Bullock, Proceedings of the 1980 Society of Automotive Engineers Australasia National Conference "Automotive Transport in the 80's", Gold Coast, Queensland, Australia 11-15 July 1980.

Report on Seminar on Alternative Vehicle Fuels, University of Canterbury, Christchurch, New Zealand, 9-14 February 1987.

Bioenergy - An Overview, by Ibarra E. Cruz, Proceedings on the Regional Training Workshop on Bioenergy, 22-28 February 1988, Asian Institute of Technology, Bangkok, Thailand.

Alcohol Fuel Blending, Marketing and Utilization, Proceedings of Science and Technology Workshop on the National Alcohol Program, sponsored by PCIERD and UNESCO, Manila Garden Hotel, 23-24 March 1987.

Coconut Oil as Diesel Fuel Extender - the Philippine Experience, by I. E. Cruz & A. C. Santos, Selected Article, Abstracts of Selected Solar Energy Technology, Vol. VI, No. 2, 1984, pp. 20-24.

Philippine Experience in the Development and Utilization of Biomass Energy Through Thermal Gasification, by Ibarra E. Cruz, Proceedings of the ASEAN Workshop on Thermal Conversion of Biomass, 26-28 September 1988, Prince of Songkla University, Hatyai, Thailand.

A New 'Prime Mover' For Electric Cars, ABB Review, 2-88, P.O. Box 58, CH-5401 Baden, Switzerland, pp. 9-14, 1988.

Hydrogen as Fuel for Motor Vehicles, by Hans Joachim Foerster, Proceedings of the 1980 Society of Automotive Engineers Australasia National Conference "Automotive Transport in the 80's", Gold Coast, Queensland, Australia 11-15, July 1980.

Production, Usage and Determination of Long Term Viability of Algas as Fuel for Motor Vehicles, Terminal Report, Industry and Technology Development Institute, Department of Science and Technology, Manila, March 1989.