Review Paper: Research on the Application of Alternative Fuels of Combustion Engines and Propulsion Systems Laboratory; Institut Teknologi Bandung

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Abstract

Research into alternative fuels has become urgent due to progressive depletion of reserves of liquid fossil fuels and the effect of local, regional and global emissions on the environment. This paper discusses the application of many different alternative fuels. Indonesia has large potential supplies of both non and renewable fuels, such as natural gas and liquid petroleum gas (LPG), coal producer gas as well as methanol and dimethyl ether (DME) which can also be synthesized from renewable resources. The application of renewable fuels from biomass such as biofuels including vegetable oils from many resources (palm oil, jatropha curcas, coconut, kapok (Ceiba pentandra) either as crude oil, Pure Plant Oil (PPO) or as the Fatty Acid Methyl Ester (FAME/Biodiesel) as well as Bioethanol are discussed. The effect of hydrogen as an additive to improve the efficiency of combustion of hydrocarbon fuels is also under investigation. Studies concerning the application of renewable gas fuels such as biogas and producer gas study are also reported.

Experience obtained in the development and application of alternative fuels from the laboratory stage, through field testing up to introduction into the actual market is presented in this paper. Finally conclusions to be drawn from all the experience in the application of alternative fuels are presented.

Keywords: Application of alternative fuels, Combustion Engines and Propulsion Systems Laboratory, Institut Teknologi Bandung

Introduction

This paper reviews research on the application of alternative fuels by the combustion engines and propulsion systems laboratory of the Institut Teknologi Bandung since eighties until present. 45 papers, reports and books are reviewed. For Indonesia the focus on alternative fuels has centered on the large potential [1]-[3] of conventional resources such as natural gas (CNG), LPG, coal as well as methanol and dimethyl ether which can also be synthesized from renewable resources. The application of renewable fuels from biomass such as biofuels including vegetable oils from many resources (palm oil, jatropha curcas, coconut, kapok (Ceiba pentandra) either as crude oil, Pure Plant Oil (PPO) or as the Fatty Acid Methyl Ester (FAME/Biodiesel) as well as Bioethanol are discussed. [4]-[6]. The application of alternative fuels is not limited to internal combustion engines but can also be used in fuel cells [7] and hybrid cars [8]. Renewable additives such as hydrogen to improve the efficiency of combustion hydrocarbon fuels is also under investigation [9]. Studies concerning the application of renewable gas fuels such as biogas [10] and producer gas study also reported [11], [12].

Experience obtained in the development and application of alternative fuels from the laboratory stage, through field testing up to introduction into the actual market is shared in this paper.

Non Renewable Alternative Fuels

Compressed Natural Gas and Liquid Petroleum Gas

As Indonesia is a relatively large producer of natural gas [13], a pilot project for the application of CNG in motor vehicles was initiated in 1988. A conversion kit was used to convert a gasoline engine to run on 100 % CNG [14]. Conversion of diesel engines to use CNG involves either using a conversion kit without changing the compression ratio (CR) [15], or requires major modification to decrease the CR. In former case ignition is effected by a small amount of diesel fuel but for the latter case the CR must be reduced and the fuel injection system changed with an ignition system. To optimize the conversion of a diesel engine fueled by 100 % CNG, it is important to find appropriate CR for the methane number of CNG corrected for the ambient temperature [16]. To find appropriate CR's, trial and error experiments involving much effort, time and cost are required. To avoid trial and error experiments, simulation using computer software [17] can be used to find the appropriate CR. Computer software for this purpose has been validated by experimental research [18].

One of the weak points of using a conversion kit to convert carbureted gasoline engines to a dedicated CNG engines is poor acceleration. To overcome this a means of enriching the fuel ratio while accelerating is required. [19].

Although it is one of the largest natural gas fields in the world, the Natuna natural gas field of Indonesia is characterized by high concentrations of CO_2 in the gas produced. Research activities focused on experiments using LPG in a real industrial size gas engine without any modification running on gas fuels containing high concentrations of CO_2 gas [20].

Indonesia currently is one of biggest coal producer in Asia and to replace large amount of using expensive diesel fuel for generating electricity an effort to use coal producer gas as fuel for a low cost dual fuel system for high speed diesel generator set was done [21].

Methanol and Dimethyl Ether

Methanol is a liquid fuel produced from natural gas which can be used to fuel internal combustion engines [22] and Direct Methanol Fuel Cells (DMFC) [7].

In internal combustion engines methanol is already used as Methyl Tertiary Butyl Ether (MTBE) as an additive to increase the octane number. However there is still little data on the use of Methanol in fuel blends with a Methanol content of more than 50 %. Methanol in DMFC's fuel cells were studied and the optimum methanol concentration investigated [7].

Dimethyl Ether (DME) has good characteristic for use as a fuel in diesel engines. DME can be produced from various raw materials such as natural gas, coke, coal, and biomass. DME could significantly reduce dependency on fossil fuels. However DME can not be used directly in diesel engine in the same way as diesel fuel. Minor modification is required in the engine's fuel system because DME is in gas form at atmospheric pressure and temperature. DME therefore has to be pressurized to maintain it as a liquid prior to entry in the fuel high pressure pump . It is necessary to find the optimum injection pressure for a specific supply pressure of DME [23]. DME properties are similar to LPG and for that reason DME can use the LPG infrastructure and thus be utilized to replace LPG as a domestic or vehicle fuel.

Renewable Alternative Fuels

Producer Gas and Biogas

Diesel engines have excellent thermal efficiency and are widely used as motive power for transportation, industry, agriculture, forestry, plantation and power generation. Consequently the incremental consumption of diesel oil is higher than for other fuel fractions.

In remote areas where plantation, forestry and wood industries are located, the cost of diesel oil is usually high due to transportation costs. On the other hand biomass waste, which is not efficiently use in those areas, is abundant. The application of the biomass waste for use by diesel engines, therefore, is a possible solutions. Further, biomass fuel is a renewable energy source. Recently renewable enegy resouces have become an important issue due to the forecast depletion of deposits of unrenewable fuel and nett zero emission of CO_2 gas from the application of biomass fuel [24].

Due to the facts mention above, a diesel engine run with gas fuel produced by gasification of biomass waste is an answer to the problem. The technology of biomass gasicifation process is approriate for remote areas, since the level of technology is intermediate.

The reason dual fuel systems are often chosen instead of gas engine systems (100% gas fuel) is because there is no need to modify the diesel engine. Moreover, it is flexible because the operation of the engine is not influenced by the quality of the gas fuel as in the case of the gas engine. It can still be operated with 100 % diesel fuel when necessary. The other important advantage is that it is not necessary to derate engine power. [11] [12].

A preliminary study to evaluate the heat and power obtainable from biogas derived from the anaerobic fermentation of Jatropha Curcas L. (JCL) cake has been completed [10]. In this study, JCL cake, the waste/by-product from the extraction of JCL oil by screw pressing unhulled JCL seed, was used as the feed-stock of a biogas reactor. The biogas reactor was initially started up using cow manure. After anaerobic fermentation stabilized the feed-stock was gradually replaced with JCL press-cake. After the content of the feed stock attained 100 % JCL press-cake, the biogas produced was used as fuel for a biogas stove and a single cylinder multi-purpose dual-fuel diesel engine. Preliminary results indicate that the productivity of a biogas reactor using 100 % JCL cake feed stock was roughly twice that of cow dung feed stock. The performance and exhaust gas emissions of the dual-fuel diesel engine including CO, HC, CO_2 and smoke levels were measured.

By producing JCL oil on-farm using a screw-press for oil extraction, and utilizing the JCL press-cake in a biogas reactor to obtain domestic heat and power, more benefits can be obtained by farmers engaged in the cultivation of JCL for a livelihood.

Biofuels

Much attention has been focused on the application of renewable fuels from biomass such as biofuels including vegetable oils from many resources (palm oil, jatropha curcas, coconut, kapok (*Ceiba pentandra*) either as crude oil, Pure Plant Oil (PPO) or as the Fatty Acid Methyl Ester (FAME/Biodiesel).

Fatty Acid Methyl Ether (FAME) or Biodiesel.
Methyl ester from fatty acid of plant oils is called "Biodiesel" and has several advantages as follows;

- It is a carbon neutral renewable energy from biomass with no incremental effect on green house gas levels,
- It is a relatively safety fuel due to higher flash point,
- It has a higher cetane number than diesel fuel.
- Smoke emissions are reduced as it is an oxygenated fuel,
- As an ultra low sulphur fuel it has low environmental impact being completely biodegradable.

The immense biodiversity of Indonesia provides more than two dozen of fatty-oil yielding plants that may be exploited to produce Biodiesel.

1.Palm (Elaeis guineensis) is the most potential of the edible oils. Palm oil is now already produced and marketed in very large quantities, because it is edible and is high yielding (+/- 3 ton/hectare/year). Direct Injection (DI) diesel engine performance, exhaust gas emissions, and some of fuel properties have been studied for Biodiesel from Crude Palm Oil (CPO) and Refined Bleached Deodorized Palm Oil (RBDPO), and these fuels blended with diesel fuel [25]. It was found that both of Biodiesel fuels and their blended fuels with diesel oil had increased brake specific fuel consumption (BSFC) levels, but the exhaust emissions (CO, CO_2, HC and smoke) were better than for diesel fuel. Both DI and IDI [26] engines were used for this research. These fuels were also used for a 2200 km fleet road test with 2 passenger cars and 2 trucks and compared with the performance of neat petrodiesel fuel [27]. Parameters evaluated before and after road testing were fuel consumption, exhaust gas emissions, fuel injection equipment, and engine lubricant.

2 Physic Nut (Jatropha Curcas) is one the most potential sources of non edible plant oil. Physic nut seed oil is practically unexploited commercially, although it has the potential to replace or substitute for palm oil as the raw material for biodiesel during the periods of high food sector demand.

The effect of Biodiesel fuel from Jatropha Curcas Oil in direct injection (DI) diesel engines on the components of the engine influenced by fuel before (injection pump, injector) and after the combustion process (piston crown, cylinder head) were studied [28], [29]. The test bed procedure used was that commonly used for injection cleanliness evaluation adopted by World-Wide Fuel Charter (December 2002) [30]. Exhaust gas emissions such as Nitrogen Oxides (NOx), Carbon Monoxide (CO), Brake Specific Fuel Consumption (BSFC), and engine lubricant before and after the test were also measured.

A single cylinder direct injection diesel engine fueled with pure Biodiesel from Physic Nut oil and blends (B10, B20, B50) with diesel fuel was used to compare engine performance and engine exhaust gas emission by comparison with diesel fuel [31]. The results from this research show that Biodiesel fuel from Physic Nut oil and its blends with diesel can give comparable engine performance for parameters Torque (T), Fuel Volumetric Consumption (FVC), Brake Specific Energy Consumption (BSEC) and Thermal Efficiency (ηe). Engine exhaust gas emissions of Total Hydrocarbon (THC), Carbon Monoxide (CO) and Smoke Emissions were reduced significantly when engine was run with Biodiesel fuel. Biodiesel use resulted in slight increases of Nitrogen Oxide (NOx) emission.

Much research has been focused on the use of Biodiesel and its blends in stationary DI Diesel engines. Only a few studies using of Biodiesel and its blends in Automotive Diesel Engines or Indirect Injection Diesel Engines have been done. The effects of Biodiesel and its blends on an automotive IDI Diesel engine by comparison with local commercial Diesel fuel [32] were studied in an experiment. Jatropha curcas methyl ester (JCME) and its blends had slightly lower torque, power output, and thermal efficiency, but slightly higher brake specific fuel consumption than Diesel fuel. In exhaust gas emission tests JCME and its blends significantly reduced HC, CO and Bosch Smoke Number but NOx emission slightly increased. The results indicated that B10 was the optimum fuel for the test engine.

A similar study carried out using both POME and JCME with a DI engine yielded similar results [33].

3 Coconut (Cocos Nucifera) is an edible oil, but because it is widely distributed all over Indonesia in areas where it is often difficult to provide fossil fuels which are consequently high in price, it even becomes feasible to use coconut oil for fuel. Coconut Methyl Esther (CME) was field tested in vehicle and fishing boat engines as a fuel for use in remote areas [34]. In the vehicle the road test B 30 CME was used as fuel for 15.000 km, and in fishing boat engine B 100 CME was used for 200 hours. Results indicated that as long as the Biodiesel quality was according to Indonesian Biodiesel standard SNI 04-7182-2006, there were no significant differences in engine operation during the test by comparison with diesel.

4. Kapok Nut (Ceiba Pentandra L) is a non edible oil. Kapok trees are also widely distributed throughout Indonesia but not utilized as an energy source [35]. Biodiesel from Kapok seed oil was tested with a DI diesel using standard test procedures including engine injector nozzle coking test CEC F-23-A-01. Fuel consumption and smoke emissions increased. Nozzle tip deposits were very thick, assumably caused by the content of Cyclopropenoid. Hydrogenation would be required to crack the Cyclopropenoid structure before transesterification to solve this problem .

Crude Oil and Pure Plant Oil (PPO)

Early in the research stage Crude Jatropha Oil (CJO) was considered to be suitable as a fuel oil based on its visual properties. The greatest difference between CJO and diesel oil is in viscosity. The high viscosity of CJO may contribute to the formation of carbon deposits in Compression Ignition Engines (CIE). Incomplete fuel combustion results in reduced engine life. Reducing the viscosity of CJO oil by preheating or dilution with diesel fuel was studied in engine tests [36], [37]. To investigate the suitability of CJO oil as alternative fuel and examine emissions, 2 tests of performance and exhaust gas emission, and a long-term durability test of CIE in a DI engine were conducted. In performance and exhaust gas emission tests, JO10 was similar to diesel fuel. Its oxygen content is an advantage in improving combustion. Exhaust gas emission increased slightly because its slightly higher viscosity influences fuel atomization. JO1O is a promising alternative fuel because it's performance and exhaust gas emission are similar to diesel fuel. JO100 gave lower performance and higher emission compared to diesel fuel because of its high viscosity. Using JO100 the engine was difficult to operate. The long-term durability test indicated that JO10 resulted in operational problems including increased exhaust gas emission (HC, Particulate matter), injector coking, piston and liner erosion. Maintenance frequency would be increased substantially including changing or cleaning of the injector nozzles at 125 hour intervals, thus increasing the cost of operation. Dilution of lubricating oil and friction caused by ring sticking and deposits in the combustion chamber would reduce the lifetime of engine components. The main concern is the fuel quality and composition. The content of phosphorous compounds in JO10 was found to be significant affecting the combustion process and exhaust emission. A degumming process to reduce the phosphorous level is therefore required to improve the fuel quality of Crude JO.

Diesel engines can be operated on either pure plant oil (PPO) oil or Biodiesel. The Biodiesel process increases the cost of production as many processes are needed, whereas PPO only needs degumming to decrease phosphorous content and deacidification decrease acid number. Potential resources of PPO in Indonesia include coconut, palm, and jatropha, because they are tropical plants with a high population throughout the country. Various PPO's have been investigated [38],[39]. Test fuels including pure coconut oil (PCO), pure palm oil (PPaO), pure jatropha oil (PJO) [40], and diesel fuel for comparison. Each PPO was blended with diesel fuel with composition 50%-volume and heated to 60 ^oC, to decrease the viscosity by 1/10. Trials using a small DI diesel engine for 17 hours endurance tests under various operating conditions were conducted according to engine test bed procedures for DI diesel and engine injector nozzle coking test. PPO's are characterized by high viscosity, low volatility, and low energy content. All PPO's had higher BSFC's before the endurance test by comparison with diesel fuel, but at the end of the test all PPO had BSFC similar to diesel fuel due to decreased friction between engine components. However combustion of PPO's was not as complete as that of diesel fuel because of poorer spray characteristics, evidenced by low CO_2 and high UHC, CO, O_2, and opacity emissions. The phosphorus content, unsaturated fatty acid content, and low combustion quality of PPO, result in higher engine deposits than for diesel fuel. Even though the PPO's had been degummed the residual phosphorous content contributed to deposit formation. Deposits from PPO's were between 140-290% more than from diesel. However PPO's exhibited antiwear properties on the plunger and injector due to the lubrication effects of the fatty acid content. PCO had the best antiwear property of the test fuels.

Further investigation of the combustion and exhaust gas emissions of a DI CIE using Jatropha Curcas L.oil as CJO (JO) and PJO/Degummed Jatropha Oil (DJO) were studied in [41]. Of all the tested fuels, DJO10 was found to be closest to Diesel fuel in performance, exhaust gas emission and its combustion process (ignition delay).

In addition a study of combustion of Jatropha Curcas Linn.Oil (Crude; Degummed; Fatty Acid Methyl Ester) as a fuel in a direct injection diesel engine was done [42][43]. The summary of conclusions drawn from the experimental data were as follows:

a. JO100 and DJO100 have low cetane indexes and very high viscosity. Lower engine performance and high exhaust gas emission were found. However, these fuels can be used in emergencies.

b. Blends of JO10 and DJO10 improved engine performance, and reduce exhaust gas emissions at low engine load. However, NO_x emission tends to increase.
c. Biodiesel B100 and its blend B10 can be used directly on conventional diesel engines without any problem. Biodiesel significantly reduced exhausts gas emission. Further, using B10 gives better engine performance.
d. The use of B100 and B10 results in shorter ignition delay (ID). Other fuels had longer ID's by comparison with standard diesel fuel.
Apart from use as diesel engine fuel, vegetable oils included CJO can used as fuels for cooking-stoves. Indonesia as tropical countries already has vast variety of oil plants and almost plant-oils that are liquid at ambient temperatures can be used as cooking fuel. Plant oils are bio-degradable and handling is both simple and safe. Almost of the plant oils can be used in modified kerosene pressure stoves which are available in the market. Basically, there are alternatives for use of plants oil in the stoves. Either the plant oils which have the similar fuel characteristic to kerosene can be used as is, or the plant oil can be modified to improve fuel characteristics to suit the type of stove. Alternatively the stove can be modified to fit the characteristics of the crude plant oil. The latter method in discussed in [44].

Bioethanol

Bioethanol is a single component fuel, hence the variation of feedstock has no effect on the final product. It's effect on the engine is not significant as long as certain quality standards are met and the engine is designed or adapted to accommodate a certain bioethanol content fuel. Consequently research is more on application aspects such as six month road tests for cars [6], or comparing cars with carburetor and fuel injection fuel systems using chassis dynamometers [4]. Tests using the EURO 2 standard which has two cycles, urban and extra urban. Car were tested using different blends of fuel; BE 0 (0% bioethanol), BE 5 (5% bioethanol) an BE 10 (10% bioethanol). Results of experiments show that emission concentrations for the Urban Cycle were higher than for the Extra Urban Cycle. Blended fuel with bioethanol reduced emission of Particulates, CO and CO_2 and also resulted in reduced fuel consumption for each type of car. Emission reduction was most prominent in the car with carburetor system.
Test bench study of an unmodified four stroke motor bike engine with BE 0, BE 5, BE 10, and with BE 85 and BE 100 after minor modification of the orifice of the carburetor were conducted [5]. BE 85 and BE 100 performed better, higher percentage of bioethanol producing higher Brake Specific Fuel Consumption (BSFC)

Experience from the Laboratory Stage, Through Field Testing Up to Introduction TO the Actual Market

From long experience in research on the application of alternative fuels, it is clear that the strategy of technology to apply alternative fuels depends on the designed requirements of the prime mover to match the characteristic properties of the fuel used and the characteristic properties of possible alternative fuels. When the designed fuel requirement of the prime mover is matched with the charact

eristic properties of an alternative fuel, the prime mover will operate as designed. But when the properties of an alternative fuel do not match, the prime mover will be operate outside (*off design)* designed operation condition and naturally the output (performance:

power, fuel consumption, efficiency, etc., emission: exhaust gas emission, noise, etc., life time) will also be affected.

There are two ways to solve this problem, firstly the prime mover designed requirement for fuel characteristics may be converted (adapted) to match the characteristic properties of alternative fuel or the characteristic properties of alternative fuel may be converted (adapted) to match the design fuel requirements of the prime mover. This concept is illustrated in Fig. 1, The most important requirement for the interface is the standard which must be met to satisfy requirements of both sides. Which choice to use and how far to convert each, depends on many factors, including technical, location, economic, social and political aspects. For example in the case of biofuel for a high technology engine which has a designed requirement for high quality fuel, fuel conversion (adaptation) to a vegetable based oil may require transesterification to produce FAME to fulfill the high quality standard of fuel needed. But, for a stationary diesel engine where the operation condition is relatively constant the required level of fuel quality may be relatively low, so a PPO with a lower production cost may be a suitable fuel. However, adapting the engine to use the PPO fuel may require the addition of a fuel heating system, a 2nd fuel tank and a switching system to enable starting of the engine on diesel to warm up the engine and heat the PPO fuel and switch back to diesel before stopping the engine to flush the fuel system with diesel.

Clearly, when an engine designed for a certain fuel is converted to run on an alternative fuel, it is very important to see that the designed need of the engine for the characteristic properties of the fuel is matched by the characteristic properties of the alternative fuel. Consequently it is very important to establish effective standards for alternative fuels.

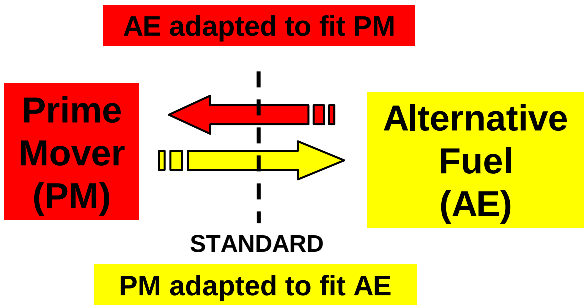

Fig. 1. The Concept of Using Alternative Fuel (AE) on Prime Mover (PM)

To apply research results from laboratory stage in the actual market it is not only necessary to meet technical requirements by means of field testing, but also necessary to overcome economic, social, political and environmental barriers, especially for a strategic commodity such as a fuel [45]. The experience of Biodiesel in Indonesia is a very rare example in which case the product came from a research program in Institut Teknologi Bandung, (Academic) which started at the beginning of year of 2000 and continued on through to application in the actual market by Pertamina (Business) in mid 2006 and then the establishment of a national program by Government.

The journey of Biodiesel is really a valuable experience following on from other experiences with products of research such as producer gas, CNG etc., which did not succeed in reaching the actual market as the economic, social, and politic barriers were not surmounted even though the technology barrier had been passed. Even though it is already in the market, the elements of Academic, Business, Government and Non Government Organization (ABGNGO) need to take care that the infant product – biodiesel – survives in the free market, as Indonesia has a large potential to produce biodiesel for the future.

Another example of a special market for Biodiesel is a sort of captive market established by ITB, PT Ganesha Energi 77 (PT GE 77) and PTP IV in North Sumatra. The business scheme involved ITB as Biodiesel technology supplier and consultant to PT GE 77 which constructed a Biodiesel plant with capacity 15 ton/day to produce Biodiesel for PTP IV. The feedstock (CPO) is supplied to PT GE 77 by PTP IV.

Recently another business scheme based on a captive market was started by ITB, INDOSAT, PT Industri Tanaman Energi (PT INTE) and Koperasi Setia in a fossil fuel remote area on Sumbawa island. This island is a dry land area with short rainy season and has large areas of idle land. In this scheme the biodiesel technology supplier and consultant is ITB. INDOSAT provided partial support using INDOSAT Corperate Social Responsible fund to capitalize with a loan to PT INTE to build a Biodiesel plant with capacity of 1.5 ton/day and supply Koperasi Setia with 25 manually operated oil presses for the extraction of CJO from Jatropha Curcas seed. PT INTE purchases CJO from farmer members of Koperasi Setia, processes it to Biodiesel and sells the product to INDOSAT Base Transceiver Station (BTS) and local fishermen. The BTS is powered by a small diesel engine. Koperasi Setia is a cooperative group of farmers growing Jatropha Curcas to supply feedstock (CJO) to PT INTE. It is responsible to distribute and sell by installment the oil presses as well as to provide planting materials and advisory services to member farmers.

Clearly this alternative fuel business is still in it's infancy and needs guidance to become a mature business scheme but it a good illustration of the role of ABGNGO in introducing, developing, and guiding the establishment of new alternative fuel products.

Conclusion

From long experience in research and the application of alternative fuels, it can be concluded as follows:

1. Indonesia due to geographic and demographic factors has many potential alternative fuels that may, in an economically and environmentally friendly way, solve not only domestic energy needs but also have a potential for export, provided the industry developed effectively.
2. When prime movers designed for a certain fuel are to operate on an alternative fuel, it is very important to see that the designed need of the engine is matched with the characteristic properties of alternative fuel, by either modifying the engine, the fuel, or both if necessary.
3. Establishment of a set of standards for alternative fuels is a matter of high priority.
4. Academia can develop new alternative fuels and prove them technically, but economic, social, political and environmental barriers need to be surmounted before they can enter the market.
5. The role of ABGNGO is very important for the introduction, development, and guidance of new alternative fuel products into the actual market.

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