New Powerplant Systems

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1 Introduction

Trends related to methanol have gained attention in recent years. Although methanol is mainly manufactured from natural gas, China produces 80% of its methanol from coal. After price increases, methanol has been used as an energy source around the world since the global financial crisis. Although more expensive than the natural gas raw material, methanol is still cheaper than crude oil. The production volume of methanol has also increased greatly [(1)]. In particular, production in China increased by 5 million tons to 61 million tons in 2012 from the previous year. Methanol is increasingly regarded as a tertiary energy source since it is being increasingly used as an energy carrier and can be produced from various raw materials, such as coal and biomass.

2 LPG Engines

Liquefied petroleum gas (LPG) is the most popular automotive fuel after gasoline and diesel, and global LPG consumption is continuing to increase every year [(2)]. Although the cost of LPG is roughly equal to gasoline in energy terms, the costs required to convert vehicles to LPG use means that the formation of markets of a certain scale is limited to countries that give preferential treatment to LPG through special tax systems or the like. The largest market for LPG is South Korea with 2.3 million LPG vehicles (14% of the total number of vehicles in the country). Consumption also increased rapidly in Turkey and Russia last year. LPG consumption in Turkey in 2010 exceeded that of gasoline [(2)].

Japan is the 6th largest LPG market in the world and has a long history of LPG use. The main merit of LPG is lower fuel cost than gasoline and application in Japan has conventionally focused on taxis that are required to drive long distances. However, energy-saving measures for gasoline vehicles have made great progress in recent years, which is affecting the cost benefits of LPG. The taxi industry is continuing to shift toward hybrid vehicles (HEVs) and other environmentally friendly cars [(3)(4)].

The scale of the taxi market is also contracting and automotive LPG consumption has been decreasing since 2008. Sales of LPG vehicles are also low and research and development activities to improve energy efficiency and performance were delayed. As a result, the performance of LPG vehicles fell behind that of gasoline vehicles. However, this situation has begun to change with the launch of a LPG vehicle equipped with an electronically controlled fuel injection system [(5)] and a dual-fuel hybrid vehicle that can use both gasoline and LPG [(6)]. Both of these vehicles are converted gasoline models.

Of all the major developed nations, the U.S. has seen the least progress in LPG vehicle adoption. However, according to a forecast by the Propane Education & Research Council (PERC), growing natural gas production is resulting in a gradual expansion in the use of LPG vehicles as the production volume of LPG derived from natural gas increases. PERC sees automotive LPG consumption roughly doubling in 2020 compared to 2012 [(7)].

In the field of LPG technology, research and development is being carried out into direct injection LPG engines that take advantage of the high octane number and volatility of LPG, which are regarded as particular advantages of LPG fuel [(7)–(9)]. Compared to gasoline engines, LPG engines can achieve a higher compression ratio and generate less particulate matter (PM), which is a key issue of direct injection gasoline engines. However, research is required to verify durability and valve seat wear. In the U.S., research and development is focusing on large LPG engines for trucks [(7)(10)]. An LPG engine has been developed based on the Navistar 7.6-liter diesel engine, which performs multi-point injection of liquid fuel into the intake manifold and carries out spark ignition. Poor low-speed torque is an issue and this research is examining changes to the compression ratio, comparisons with compressed natural gas (CNG), and the like. Mississippi State University is carrying out research and development of a diesel/LPG dual-fuel low-temperature combustion engine based on a 13-liter diesel engine [7]. The aim of this engine is to reduce NOx and PM by supplying LPG through injection valves provided in the intake manifold to form a lean pre-mixture, and then enabling self-injection and low-temperature combustion of diesel injected early in the combustion cycle.

In Germany, the Saarland University of Applied Science is performing well-to-wheel analysis related to CO_2 emissions of LPG vehicles in Western Europe. It has reported that the well-to-wheel CO_2 emissions of LPG vehicles are equivalent to CNG vehicles [9].

3 Natural Gas Engines

Terms like shale gas and unconventional natural gas have started to appear in newspapers and the like virtually every day, evidence that the world is currently undergoing a natural gas boom. There are 240 years of proven natural gas reserves, far more than crude oil reserves. Long-term and stable supply of natural gas is likely to take place into the future.

With this background, the adoption of natural gas vehicles (NGVs) is accelerating around the world. At the end of 2012, the number of NGVs increased by approximately 2.8 million vehicles from the previous year, reaching roughly 17.2 million [11]. By the end of March 2013, the number of NGVs in Japan was 42,590.

In Japan, natural gas has conventionally been used for trucks, buses, and other vehicles for urban transportation. However, large trucks in the 25-ton gross vehicle weight (GWT) class have also started to use natural gas. Currently, Japanese automakers are not manufacturing or selling large natural gas trucks for domestic use. Consequently, Kyodo, a company specializing in natural gas conversions teamed up with an engine conversion company called HKS to develop a natural gas version of the Giga, a large truck manufactured by Isuzu. So far, these companies have produced slightly fewer than 40 of these trucks. Ten trucks were purchased by Fuji Transport Co., Ltd., a transportation business in Nara city [12] for transporting international freight to Narita and Kansai International airports, and the like.

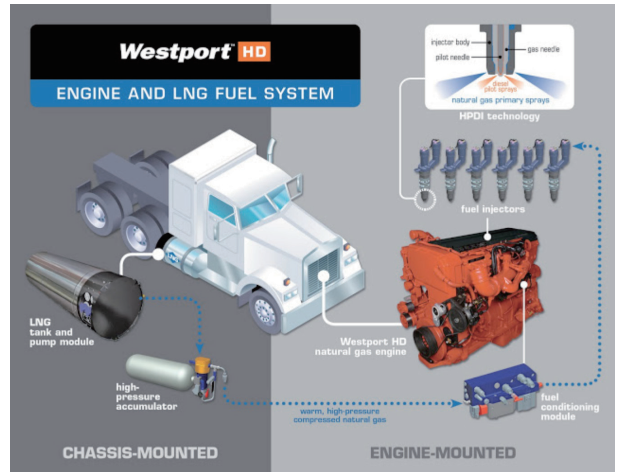


Fig. 1 Outline of HPDI system developed by Westport Power Inc.

Although Japan also uses CNG for heavy-duty vehicles, the use of liquefied natural gas (LNG), which has an energy density roughly three times higher than CNG, is expanding as a fuel for long-distance heavy-duty vehicles in Europe, the U.S., and other regions. Efforts are also under way to improve engine efficiency. The Canadian company Westport Power Inc. has developed the High Pressure Direct Injection (HPDI) system that achieves the same thermal efficiency as a diesel engine by injecting diesel and natural gas using the same nozzles and performing compression injection (Fig. 1) [13]. Volvo Trucks intends to introduce LPG vehicles installed with a 13-liter HPDI engine into the North American market in 2014 [14][15].

Basic research into natural gas engines in Japan is mainly being carried out at universities and the like. Waseda University has identified the potential of improving fuel efficiency by advancing the ignition timing. This was achieved by predicting the performance of a downsized turbocharged spark injection natural gas engine and calculating the wall temperature of the combustion chambers in steady-state and transient driving conditions [16]. Kyoto University and the Research Institute for Culture, Energy, and Life (CEL) run by Osaka Gas Co., Ltd. has investigated the effects of injection conditions (such as the quantity and timing of diesel injection and split injections) and changes to the shape of the combustion chamber on performance and exhaust characteristics in a natural gas dual-fuel engine that uses diesel as an auxiliary fuel [17].

Although Japanese automakers are showing no outward signs of developing large natural gas trucks for the domestic market, it is hoped that large trucks equipped with efficient engines will be introduced onto the market as quickly as possible.

4 Hydrogen Engines

Research into hydrogen engines has a long history. Similar to fuel cell vehicles (FCVs), hydrogen engines are a power source with zero fuel-derived CO_2 emissions. At the same time, these engines are capable of using mature basic technologies such as existing production equipment, auxiliary devices, and the like. Consequently, hydrogen engines are considered to have potential for low-cost implementation, and research is under way at universities, research institutes, and automakers around the world. The issues of hydrogen engines include suppressing abnormal combustion caused by the high ignitability of the fuel, countermeasures for high NOx emissions when operated at high power, and improving thermal efficiency. Recent research is focusing on direct injection as a means of resolving these issues.

There were several examples of reported research in 2012 both inside and outside Japan. In Japan, reports were published by the Tokyo City University and the National Traffic Safety and Environmental Laboratory (NTSEL) group, Mazda, and Kinki University. The Tokyo City University and NTSEL group proposed a combustion concept that ignites a rich mixture plume during the injection period or directly after the completion of injection (called the Plume Ignition Combustion Concept (PCC)). This concept also lowers NOx emissions by entrapping air during combustion by performing ignition during the injection period [(18)]. Mazda announced a method of improving thermal efficiency in homogeneous-charge premixed combustion focusing on practicability in a rotary engine using hydrogen as fuel. The proposed method improves thermal efficiency by shortening the combustion period and reducing exhaust loss by changing the position and number of spark plugs, and intensifying turbulence using the strong unidirectional combustion chamber flows characteristic of a rotary engine [(19)]. Kinki University identified differences in injection flow characteristics at different hydrogen injector valve pressures as part of a study into hydrogen direct injection control technology. This research also used high-speed photography to study the combustion flame. This study was carried out to facilitate comparisons with pre-mixed hydrogen combustion, and to examine the effects of the excess air ratio and hydrogen injection timing on combustion flame behavior. The results found that ignition during the injection period enables direct ignition of rich hydrogen injection flows, resulting in rapid combustion using the injection flow turbulence [(20)].

Outside Japan, the Argonne National Laboratory reported the achievement of thermal efficiency targets by optimizing the pre-mixture formation in the research of a direct injection hydrogen engine. The developed engine satisfies the thermal efficiency targets of the U.S. Department of Energy (DOE) for maximum brake thermal efficiency (45%) and efficiency at partial load with a brake mean effective pressure of 2 bar (31%), as well as NOx emissions of 0.07 g/mile. In most regions, NOx is less than 0.1 g/kWh but reaches 1.5 g/kWh at close to maximum load, indicating that further improvement of the pre-mixture is required [(21)].

5 Dimethyl Ether (DME) Engines

Field tests are continuing using two 3.5-ton DME gull-wing trucks (Fig. 2) built by the Isuzu Advanced Engineering Center and registered for commercial use (green license plates) [(22)]. The test vehicle in the Kanto region completed the field test at the end of July 2011 after driving a total of 100,000 km. As of the end of February 2012, the test vehicle in the Niigata region has driven a total of 95,000 km.

The standardization of DME as a fuel is being carried out by ISO/TC28/SC4/WG13. This WG is debating the quality of DME as a base fuel, including for automotive use. Discussion has moved from the Committee Draft (CD) phase to the Draft International Standard (DIS) phase (ISO CD16861: DME Fuel Quality). Furthermore, WG14 has performed round-robin tests of the five analysis methods described in CD16861: CD17198 (Determination of total sulfur, ultraviolet fluorescence method), CD17199 (Determination of total sulfur, Oxidative coulometry method), CD17786 (Determination of evaporation residues — Mass analysis method), CD17197 (Determination of water content — Karl Fischer titration method), and CD17196 (Determination of impurities — Gas chromatographic method. Accurate analysis was performed based on these test results and reflected into each draft. Discussion is currently continuing toward the creation of the DIS. A series of studies are due to start related to

Fig. 2 3.5-ton gull-wing DME truck.

the quality of automotive DME fuel.

6 Stirling Engines

The characteristics of a Stirling engine include the versatility to use a wide range of heat sources and quiet operation. Based on these characteristics, it has been applied as an engine for air-independent propulsion on submarines, for biomass combustion power generation, solar power generation and for combined heat and power (CHP) systems for air-independent ordinary households. There are several examples of commercially and mass-produced Stirling engines. As an example of a Stirling engine for propulsion on submarines, Kockums AB in Sweden have adopted a 75 kW class 4-cylinder double acting Stirling engine for the Swedish navy and elsewhere. The Japanese Ministry of Defense also uses these engines in the Soryu class of submarines. In the field of biomass combustion power generation, the Danish company Stirling DK has developed a 35 kW class 4-cylinder double acting Stirling engine. In the field of solar power generation, the Swedish company Cleanergy has developed a 10 kW class single acting alpha-type V-cylinder arrangement Stirling engine (formerly the SOLO Stirling engine manufactured in Germany) and Infinia Corporation in the U.S. has developed a 3.5 kW class free piston Stirling engine. Finally, in the field of CHP for ordinary households, Microgen Engine Corporation (MEC) in the Netherlands and Whisper Tech Ltd. of New Zealand have developed 1 kW class Stirling engines.

Of these, the 1 kW class Stirling engines manufactured by MEC and Whisper Tech Ltd. have been mass-produced for sale in Europe. MEC has also mass-produced a 1 kW class free piston Stirling engine generator and is working on the development of a CHP unit. In cooperation with MEC, European boiler makers have already shipped more than 3,000 units of a commercialized engine with a generation capacity of 1.1 kW and a heating capacity range of 3 to 24 kW since 2010. MEC China has already produced more than 6,000 of these engines. In addition, European energy supply companies have also sold several thousand units in 15 European countries of a CHP unit for ordinary households, which uses the 1 kW class 4 cylinder stirling engine generator manufactured by Whisper Tech Ltd. This unit has a generation capacity of 1.1 kW and a heating capacity range of 6 to 8 kW.

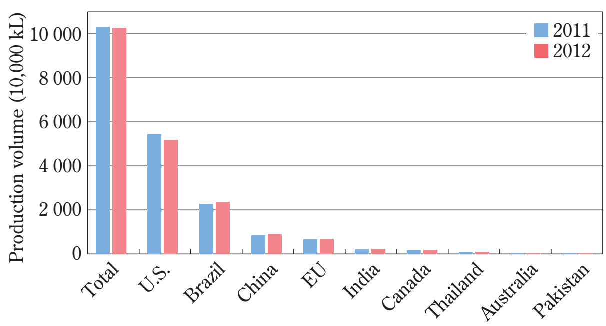
Furthermore, Infinia Corporation is close to starting mass production of a solar power generation system with a power output rating of 3.5 kW. This system uses the same company's free piston Stirling engine. Infinia built a production line and sold roughly 100 units of a provisional system for verification. Since then, the company has built 430 units for use on U.S. army bases. Based on these results, Infinia is aiming to mass produce several tens of thousand units in the next few years. Cleanergy has also installed ten units of a 10 kW solar power generation in Inner Mongolia in China using a Stirling engine developed by the same company.

In Japan, 0.2 to 10 kW class engines have been developed for relatively low-temperature waste heat and biomass combustion power generation. However, none have been commercialized.

7 Biofuels

7. 1. Bioethanol

According to statistics supplied by F.O. Licht, 2012 global ethanol production continued to decrease from the previous year by approximately 0.4% to roughly 102,590,000 kL [23]. 81% of ethanol production is used for fuel. Fig. 3 shows the production volume per country. Looking at the two major producing countries (73% of total global production), production in the U.S. fell by 4.4%, which was the first year-on-year decline on record. This was caused by a poor harvest of the maize raw mate-



	Total	U.S.	Brazil	China	EU	India	Canada	Thailand	Australia	Pakistan
2011	10 299	5 421	2 288	860	664	216	167	79	35	41
2012	10 259	5 180	2 354	895	663	234	194	97	34	50

Fig. 3 Global ethanol production in main producing countries.

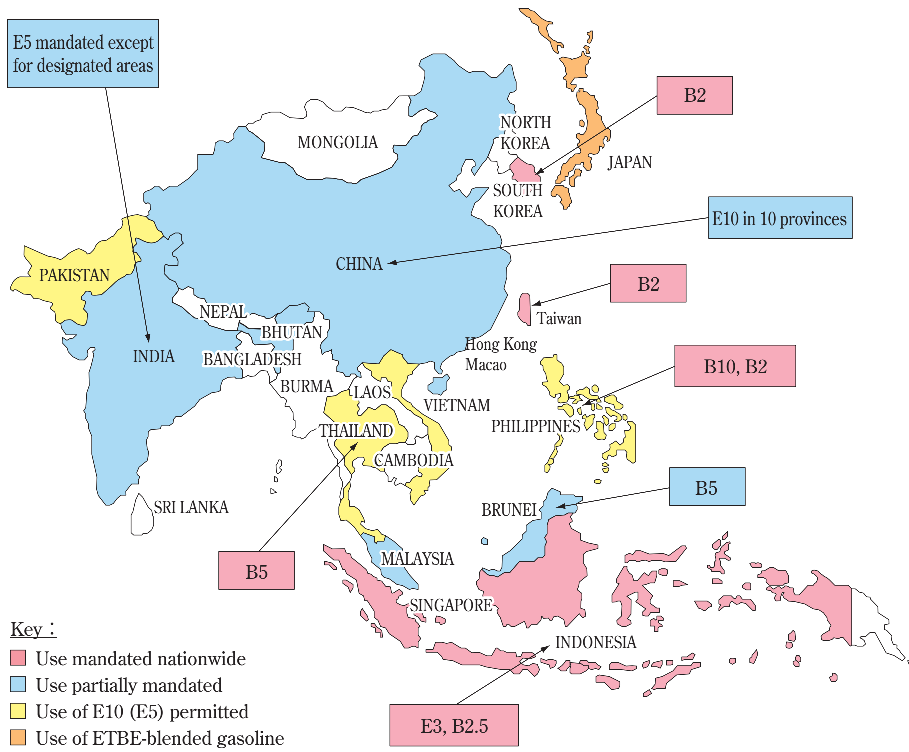
rial due to drought and lower demand for ethanol fuel. Production in Brazil rebounded slightly by 2.9%, but the issue of lower yields due to aging sugar cane infrastructure has yet to be resolved. In the U.S., the Environmental Protection Agency (EPA) finally approved the blending of gasoline with 15% ethanol (E15) to achieve the mandated volume described by the Renewable Fuel Standard 2 (RFS2) in June 2012. Sales of this fuel have also started [24]. However, the American Automobile Association (AAA) has appealed to regulatory authorities and fuel manufacturers to halt sales of E15 gasoline because of possible consumer confusion about E15 gasoline leading drivers to use the wrong fuel, potentially causing adverse effects on the engine. As a result, the fuel has yet to enter widespread use and ethanol consumption has decreased [25].

The main effort in Japan to use biofuel was the Project for Developing Soft Cellulosic Resources Utilization Technology run by the Ministry of Agriculture, Forestry and Fisheries (MAFF), which ended in 2012. This project has now been succeeded by three Model Demonstration Projects of Local Biofuel Use [26]. Other examples include a biofuel project in Okinawa prefecture that supplied approximately 40,000 kL of E3 in 2012. As of April 2013, E3 is available in 46 service stations [27]. The Japanese Ministry of the Environment also constructed a bioethanol production facility on Miyako-jima that ended trial operation in 2011. This facility has been restarted with Japan Alcohol Corporation as the designated managing entity with operations entrusted from the city government [28]. On November 30, 2012, an emissions reduction methodology related to switching from fossil fuels to bioethanol was approved by the Domestic Credit Certification Committee, enabling the application of the Japan Verified Emission Reduction System [29]. Service stations selling bio-gasoline blended with ethyl tertiary butyl ether (ETBE) increased by 11% across the whole of Japan to 3,440 (as of May 2013) [30].

Asahi Group Holdings, Ltd. and the National Agriculture and Food Research Organization Kyushu Okinawa Agricultural Research Center (NARO/KARC) have developed bioethanol production technology with substantially improved sugar cane to sugar conversion productivity using a reverse production process [31]. Research is also examining bioethanol production that does not compete with food sources. The Research Institute of Innovative Technology for the Earth (RITE), Honda R&D Co., Ltd., and the U.S. National Renewable Energy Laboratory (NREL), which is a national laboratory of the DOE, have started joint research into the production of biofuels from maize stalks and leaves and sugar cane lees (bagasse), with the aim of achieving practical adoption in 2016 [32][33]. In Brazil, the GraalBio company has built the first commercial-scale ethanol plant in the southern hemisphere in the state of Alagoas (production capacity: 82,000 kL/year) to manufacture ethanol from cellulosic resources such as bagasse. Operation is scheduled to start in the fourth quarter of 2013 [34]. In Thailand, Japan's New Energy and Industrial Technology Development Organization (NEDO) has consigned a trial project for bioethanol technology to Sapporo Breweries Ltd. and Iwata Chemical Co., Ltd. This technology produces bioethanol from the tapioca-like residue of cassava roots after starch extraction. Production has started with an annual production capacity of 80 kL [35].

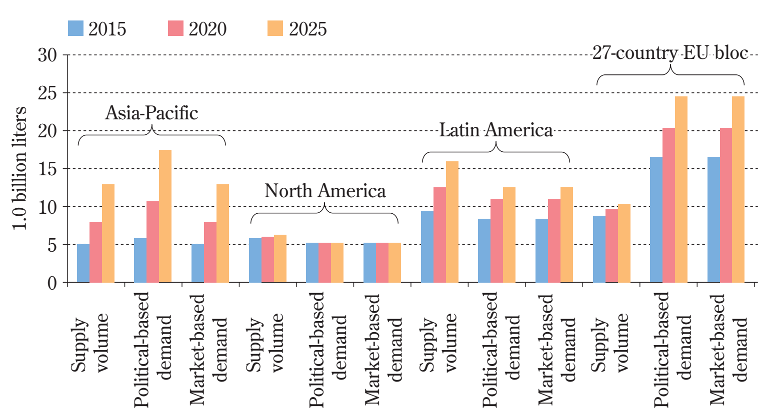
7. 2. Biodiesel fuel

In 2012, a number of automotive conferences held in Japan covered research and development trends related to biodiesel fuels such as fatty acid methyl ester (FAME). At the Spring Annual Congress and Exposition of the Society of Automotive Engineers of Japan (JSAE), two papers were presented about diesel combustion related to fatty acid ethyl-hexyls and the like. At the JSAE Autumn Congress, a total of five papers were presented, including one that described research into the addition of antioxidants and cold flow properties to FAME and the effects of this process on fuel properties and diesel emissions. Four papers were presented at the 50th Internal Combustion Engine Symposium in Sapporo, including one



Source: Hart Energy's Global Biofuels Center, July 2012

Fig. 4 Mandated use of bioethanol and bioethanol fuels in Asia in 2012.



Source: Hart Energy's Global Biofuels Center, June 2012

Fig. 5 Future biodiesel supply and demand in main regions.

that described research related to the intermittent spray combustion characteristics of methyl ester biodiesel fuel. Two papers were presented at the 8th International Conference on Modeling and Diagnostics for Advanced Engine Systems (COMODIA) in Fukuoka covering a wide range of research from fuel properties, combustion reactions, engine performance and lubrication, to issues such as deposits and countermeasures.

In addition, five papers were presented at the International Symposium on Alcohol Fuels (ISAF) in Cape Town, covering research related to fatty acid ethyl ester, the B3 biodiesel blend, ethanol, and 3-component blended biodiesels. Research is under way into the use of bioethanol diesels including ED95, i.e., a 95% blend of ethanol used to run a high-compression ratio diesel engine.

2012 also saw changes to biodiesel fuel quality standards. On March 30, Japan amended its diesel quality control law with the issuance of Ordinance 26 by the Ministry of Economy, Trade and Industry (METI). Previously, an increase in the acid number was recognized as a measure of oxidation stability in the quality assurance items for B5 diesel. In this method, the acid number was measured after a certain period after the sample fuel was held at a constant temperature and bubbled with oxygen. The increase from the initial value was then calculated by the ΔTAN (total acid number) method. The measurement method was changed in the new law. The sample fuel is placed in a sealed container, pressurized with oxygen, and heated. The relationship between time and internal pressure is recorded and the time taken for the internal pressure to drop by a maximum of 10% is now used to evaluate oxygen stability (i.e., the PetroOXY method). The standard value is 65 minutes or more.

Fig. 4 illustrates biofuel usage trends based on the use situation of FAME and bioethanol in Asia. Excluding Japan, Asian countries are increasingly mandating the use of directly blended fuels. Fig. 5 shows the trends for biodiesel supply and demand from the current time to 2025. Although slow or zero growth is expected in North America, market demand is expected to multiply by 2.5 times in Asia. Demand should also rapidly increase in the 27-country EU bloc, but supply is forecasted to lag behind.

References

(1) Chemical Economy, "Methanol: The Effect of Shale gas is Watched", Ministry of Economy, Trade and Industry: Indices of Industrial Production, March 2013, p. 61−64

(2) World LP Gas Association, Autogas Incentive Policies, 2012

(3) The Nikkei, March 20, 2012

(4) J-CAST News, May 11, 2012

(5) Nikkan Jidosha Shimbun, January 12, 2011

(6) The Nikkan Kogyo Shimbun, December 6, 2011

(7) Alan McEwan (PERC), Propane Autogas Advanced Engine Reserach Projects, 5th International DME Conference, April 19, 2013

(8) Cheolwoong Park, et al. : SAE 2013-01-1323

(9) World LP Gas Association, AUTOGAS UPDATE, January 15, 2013, http://www.worldgas.com/mediaroom/236/78/Well-to-Wheels-analysis-shows-Autogas-carbon-emissions-are-on-a-par-with-CNG

(10) Alberto Boretti, et al. : SAE 2012-01-1983

(11) The Gas Vehicle Report, http://www.ngvjournal.com/en/

(12) http://www.fujitransport.com/news/120920_news.pdf

(13) http://www.westport.com/is/core-technologies/hpdi

(14) http://www.volvotrucks.com/trucks/na/en-us/news_and_events/news_releases/_layouts/CWP.Internet.VolvoCom/NewsItem.aspx?News.ItemId=140963&News.Language=en-gb

(15) http://www.westport.com/news/2012/volvo-trucks-unveils-13-liter-natural-gas-engine-for-north-america-with-westport-hpdi-technology

(16) Kikusato, et al. : A Numerical Study on Evaluating the Performance of a Turbocharged Spark Ignition Natural Gas Engine, JSAE Annual Congress Proceegings, No. 121-12, p.1−6

(17) Kang, et al. : Effects of Injection Conditions and Combustion Chamber Geometry on Performance and Emissions of a Natural-Gas Dual Fuel Engine, JSAE Transaction, Vol. 43, No. 2, p. 473−478

(18) Masakuni Oikawa, et al. : Optimization of Hydrogen Jet Configuration by Single Hole Nozzle and High Speed Laser Shadowgraphy in High Pressure Direct Injection Hydrogen Engines, International Journal of Automotive Engineering 3, p. 1−8 (2012)

(19) Nizar Jaber, et al. : Amelioration of Combustion of Hydrogen Rotary Engine, International Journal of Automotive Engineering 3, p. 81−88 (2012)

(20) Tabata : Measurement of Hydrogen Jet Combustion in an Engine using Direct High-pressure Gas Injection Valve, The 23rd Internal Combustion Engine Symposium, 20123872 , No. C2-04 , p. 1 (2012)

(21) Nicholas S. Matthias, et al. : A Hydrogen Direct Injection Engine Concept that Exceeds U.S. DOE Light-Duty Efficiency Targets, SAE 2012-01-0653 (2012)

(22) Takase, et al. : Verification Test of DME Medium Duty Trucks and its Practicality, JSAE Annual Congress Proceedings, No. 71-12, p. 7−10 (2012)

(23) F. O. Licht GmbH, World Ethanol & Biofuels report, Vol. 11, No. 17, p. 339−357 (2013)

(24) Environmental Protection Agency (EPA), Fuels and Fuel Additives, E15 (a blend of gasoline and ethanol), http://www.epa.gov/otaq/regs/fuels/additive/e15/

(25) American Automobile Association (AAA), News Room, Suspend Sale of E15 Gasoline, http://newsroom.aaa.com/2012/12/suspend-sale-of-e15-gasoline/

(26) Ministry of Agriculture, Forestry and Fisheries Website, Project for Establishment of Biofuel Production Bases, http://www.maff.go.jp/j/budget/review/pdf/new0005_sai.pdf

(27) Full-scale Biofuel Popularization Project commissioned by the Ministry of the Environment (MOE) Website, http://www.eco-biofuel.go.jp/

(28) The Ryukyu Shimpo, July 18, 2012, http://ryukyushimpo.jp/news/storyid-194039-storytopic-4.html

(29) Ministry of Agriculture, Forestry and Fisheries Website, http://www.maff.go.jp/j/press/shokusan/bioi/121203.html

(30) Petroleum Association of Japan Website, http://www.paj.gr.jp/eco/biogasoline/

(31) Asahi Group Holdings Website, News Release, The World's First Development of Bio-ethanol Production Process which Tremendously Increases Sugar Production, October 9, 2012, http://www.asahigroup-holdings.com/news/2012/1009.html

(32) The Nikkei Web, May 12, 2012, http://www.nikkei.com/article/DGXNASGG0100A_S2A510 C1 MM0000 /?dg=1

(33) The Nikkei Web, December 12, 2012, http://www.nikkei.com/article/DGXNZO49681850 X11C12A2TJM000/

(34) GraalBio to build first cellulosic ethanol plant in Brazil, May 25, 2012, http://www.chemicals-technology.com/news/newsgraalbio-cellulosic-ethanol-plant-brazil

(35) New Energy and Industrial Technology Development Organization Press Release, First Demonstration Project on Technologies to Produce Bioethanol from Tapioca Residue in Thailand (December 17, 2012), http://www.nedo.go.jp/content/100511968.pdf