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Position Paper
for
Conventional Hydrocarbons

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このDISCUSSION PAPERは、2004年12月13-15日にタイ国クラビで開催されたAPECの「The Scenario Planning Workshop on Future Fuel Technology」での討論用として作成し、関係の方々からのご意見をいただくことを目的に作成したものである。本内容は、執筆者の見解によってまとめられたものであることに留意されたい。

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1. Introduction

Conventional hydrocarbon fuels are capturing the spotlight as alternatives to oil. Attention has grown for such fuels as natural gas, methanol, methane, and the products of gasoline reforming. It is thought that hydrogen will be used in the long run. However, there remain challenges in areas such as fuel supply, and efforts are focused on maintenance of infrastructure, handling, price, and efficiency that demand comparison with other fuels.[1]

The case for automobiles and the future for coal are of wide interest. Current examinations of alternative fuels for automobiles are summarized in **Table 1**. Methods to derive liquid and gaseous fuels from coal end with a similar mix of fuels. This paper will explore prospects for hydrocarbon fuels and clean coal technology that often yields these fuels.

Table 1 Comparison of future fuels for automobiles

Fuel	Advantages	Disadvantages
Hydrogen	Water is the only by-product of combustion - "zero exhaust gas".	Storage of hydrogen, maintenance of an infrastructure, etc.
Methanol	As a liquid fuel, it can be used in an internal combustion engine.	About 250 °C is needed for conversion and a methanol stand is required.
Gasoline reforming	Existing gas stations are used, and the fuel is burned in internal combustion engines.	About 800 °C is required for improvement of combustion. Sulfur removal will be needed to protect the environment.
Natural Gas	Compared with other fossil fuels the environmental load is low. It is distributed widely beyond the Middle East and the supply is stable. Both Gas-to-Liquids and Dimethyl Ether will be alternatives to oil-based fuels such as diesel oil.	Compared with many foreign countries, domestic maintenance and supply infrastructure are weak in Japan.
LPG – Liquefied Petroleum Gas	No particulate matter (PM) emissions yield a relatively small environmental load.	Approximately 80% of LPG is imported to Japan from the Middle East; supply stability has been a subject of discussion.

2. Natural Gas

2.1 Distribution of natural-gas resources

The proven reserves of natural gas in the world were 156 trillion m^3 in 2002 with approximately one-third in the former Soviet Union, one-third in the Middle East and the remaining third distributed elsewhere. The distribution of these resources is shown in **Fig. 1**. With approximately 65% of the petroleum being in the Middle East, regional distribution is somewhat better with natural gas than oil. Reserve production of natural gas is estimated to be 60.7 years.

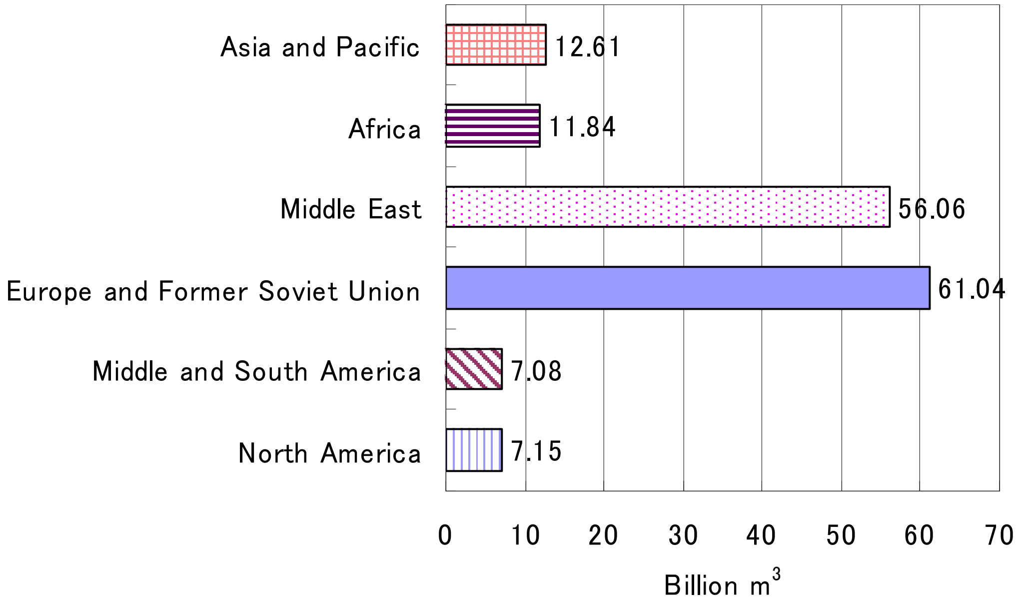

Fig. 1 Natural gas deposits classified by area (2002)

2.2 Trend in production of natural gas

Production of natural gas in 2002 was at 2.53 trillion m^3. When compared with the yearly mean growth in the production of petroleum (1.1%) and coal (0.5%) from 1990 to 2002, natural gas has shown a 2.0% rate of growth. As shown in **Fig. 2** and **Fig. 3**, approximately 30% of the world's production is in North America and 40% is in the former Soviet Union and Europe. Production in the Middle East represents approximately 9%, which is small when considering that 36% of the world's reserves are found there. This is the case because of the distance to the European demand area is further from the Middle East than production areas in the former Soviet Union. Enormous investment is needed for natural gas transport from the Middle East area. Moreover, the Middle East area invested in oil development rather than natural gas development. Pipelines from the Middle East to the large demand areas were not laid like those between the former Soviet Union area and Western Europe. Natural gas is consumed in the Middle East area, or exported as liquefied natural gas (LNG). In other cases it is incinerated by flaring or forced back into oil or oil gas fields when it cannot be sold.

The world's natural-gas market is presently strengthened as a buyer's market by production increases and planned projects in the Middle East, Europe, and Indonesia. In addition, European-American observers see a promising future for natural gas and have started tackling the guaranty issues and are looking positively on development interests. Not only petroleum interests but also oil producing countries are showing positive attitudes to development of natural gas. Furthermore, research and development is taking concrete direction in response to the new availability of natural gas through projects such as those for gas-to-liquids (GLT) and dimethyl ether (DME).

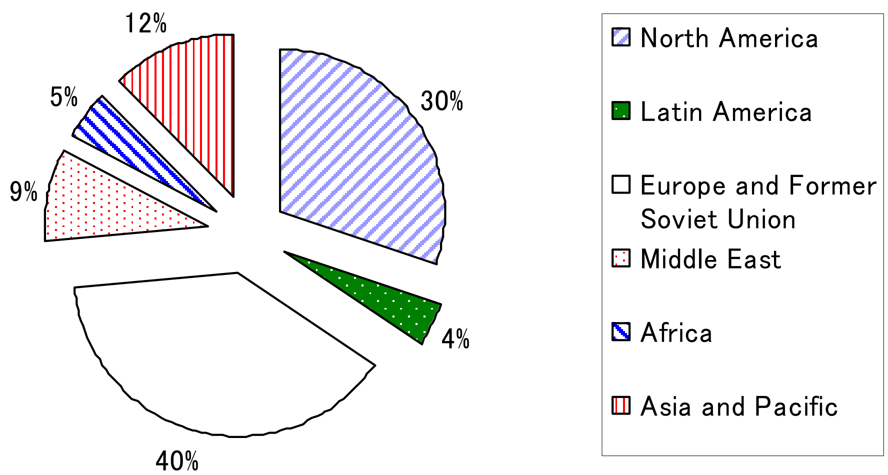

Fig. 2 Natural gas production percentage by area (2002)

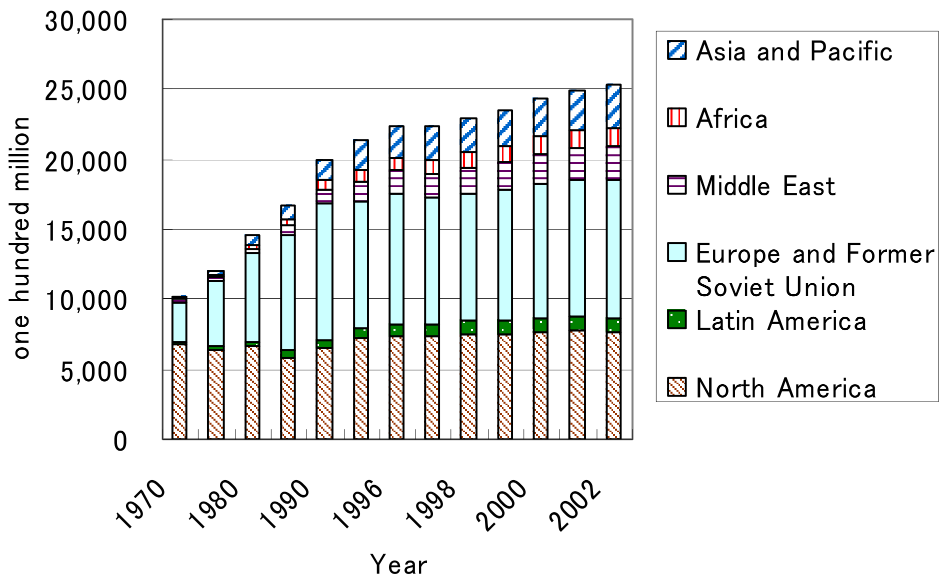

Fig. 3 Change of natural gas production volume classified by area

2.3 Prospect for supply-and-demand of natural gas

From 1990 to 2002 the world's natural gas demand, including power generation, has increased at a steady annual rate of 2%, except for the area of the former Soviet Union. The use of natural gas depends on the economical and environmental advantages of natural gas in power generation and as a fuel, when compared with other fossil fuels. Technical progress towards reduced environmental loading and combined cycle power generation is also important.

The demand charts, classified by area, reveal that 13% of Japan's primary energy supply for 2001 came from natural gas, while the respective percentages in North America and Europe are both near 23%. Natural gas is produced abundantly in these regions.

2.4 Trend for technology using natural-gas

As an alternative to petroleum as a source of energy, promotion of natural gas cogeneration is expected to yield environmental load reduction and energy conservation. The conversion of fuel from coal to natural gas in large fuel consumption type equipment, such as industrial furnaces and boilers, is aiming at curtailment of CO_2 emissions. Therefore, development of cogeneration, which is operated using natural gas under low thermal power ratio with high power generation efficiency, and a natural gas car with comparatively small heat demand are progressing in a public welfare section.

2.4.1 Clean Natural Gas (CNG) vehicle

Natural-gas fueled vehicles are classified as shown in **Fig. 4** by the storage system for the fuel. Presently, the majority of the natural-gas fueled vehicles in the world use compressed natural gas (CNG).[2]

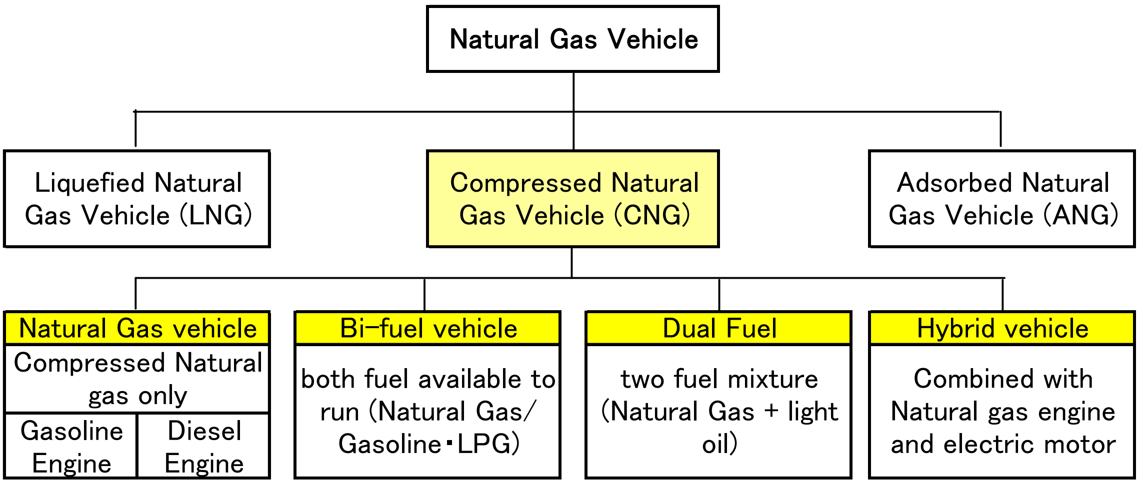

Fig. 4 Natural gas fueled vehicles

The construction of natural gas fueled vehicles is similar to that for alternative gasoline and diesel fueled vehicles, with the only difference being the fuel line.[3] It is basically the same with all the models. **Fig. 5** illustrates this system for a natural gas fueled automobile.[4]

One characteristic of natural gas fueled vehicles is their clean exhaust emissions. For example,

- The CO_2 emissions from natural gas fueled vehicles are 0.2 – 0.3 those for gasoline fueled vehicles.
- As is well known, emissions of pollutant gases such as NO_x (nitrogen oxides), which cause environmental pollution in the form of photochemical smog and acid rain, CO (carbon monoxide), HC (hydrocarbons), and SO_x (sulfur oxides) are reduced from natural gas fueled vehicles.
- Black smoke is not emitted – PM (particulate matter) emissions are nonexistent.

Comparison of the CO_2 emissions from conventional gasoline and eco-friendly automobiles is shown in **Fig. 6**. Because of proven merits, business vehicles such as buses, trash collection vehicles, delivery vans/trucks, and fork lifts are operating on and changing from gasoline to natural gas. Typically, the traveling efficiency is superior, and fuel economy equal to those for gasoline and diesel powered vehicles. Noise and vibration is improved substantially when compared with the diesel engine.

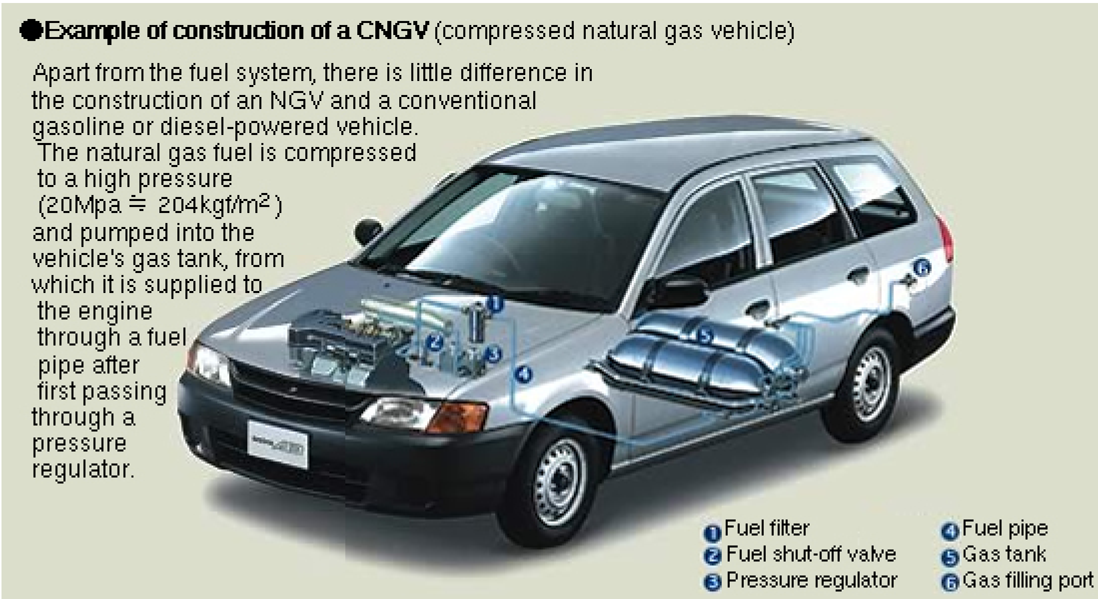

Fig. 5 The detail schematic of natural gas fueled automobile

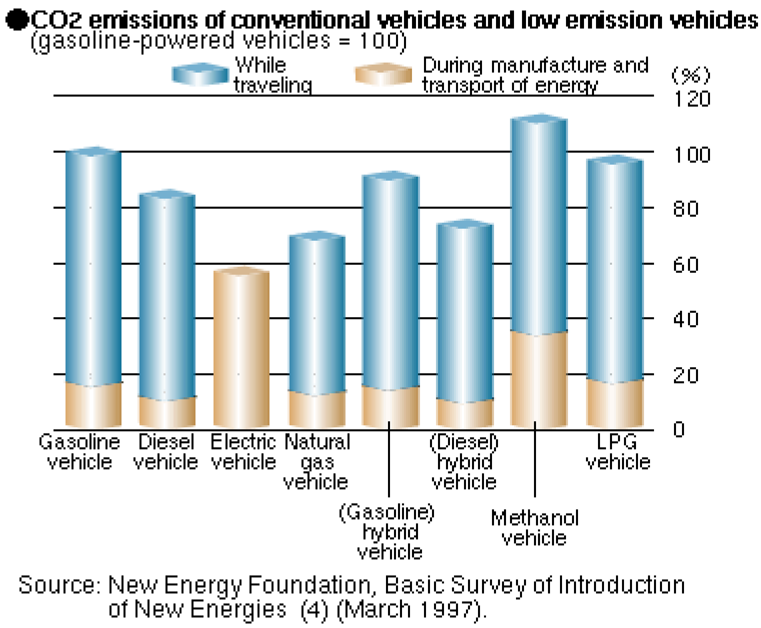

Fig. 6 Comparison of CO_2 emissions from conventional and eco-friendly vehicles

2.4.2 Gas-to-Liquids (GTL) technology

Gas-to-Liquid (GTL) processes reform natural gas into liquid fuels such as gasoline, lamp oil, and light oil. These fuels can be conveyed at normal temperature. Several GLT processes are compared in **Table 2**. Liquid fuels manufactured by GTL processes can be conveyed and stored like oil products, and can be placed in existing markets. Moreover, if less expensive manufacturing processes are established, their scale may create business opportunities in smaller gas fields. Thus, fields not making LNG or unable to support pipeline distribution may become profitable and provide products for distant consumers. GLT technologies can produce fuels that are friendly for the earth. Liquid hydrocarbon fuels, which are compounded from natural gas streams, contain negligible sulfur and particulate impurities and are candidate feeds for applications such as fuel cell electric vehicles and diesel alternative fuels.[5] [6]

Table 2 Comparison of GTL processes

Process	Place and developer	Characteristics
GTG (Gas-to-Gasoline)	1986, Commercialized in New Zealand	Methanol is manufactured using a natural gas feed to make synthetic gas. This is continuously changed into the gasoline fraction centering on perfume fellows by the so-called mobile method (Methanol- to - Gasoline process). The process has a commercialized capacity of 570,000 ton/yr.

SMDS (Shell Middle Distillate Synthesis)	Commercialized by Shell in Malaysia	Partial oxidization of the natural gas is carried out with oxygen and the products are used to make synthetic gas. Subsequently, wax and light oil are manufactured by the Fischer-Tropsch (FT) reaction. In the FT reaction, hydrogen and carbon monoxide are used to form large molecular weight hydrocarbons over a catalyst. The process has a commercialized capacity of 500,000 ton/yr.
SASOL	Commercialized in Republic of South Africa	Since South Africa was unable to import oil under the influence of a racial discrimination policy, it used coal from its own country as a raw material to produce an oil product via synthetic gas. The process is based on years of experience and original technical development. It is very competitive with modern GTL technology.
AGC-21 (Advanced Gas Conversion Technology for the 21st century)	Exxon	Although the development stage is complete, the process has not been commercialized.
Statoil	Statoil in Norway	With its large gas reserves, Norway has been developing catalysts and process reactors for a FT process to produce middle distillates from natural gas. The process continues to be challenged by catalyst performance and the ability to continuously extract the liquid product.
Rentech	Rentech, Colorado USA	In 2000, Rentech acquired a 75,000 ton/yr methanol plant in Colorado, USA for conversion into a GTL facility. The facility, which will be the first in the USA, will cost about $20M to convert. When operational (mid-2001) it produces 800-1,000 bbl/day of aromatic-free diesel fuel, naphtha, and petroleum waxes. It will cost nearly 50% less than a green-field site because the plant includes a synthesis gas generation unit.
Syntroleum[7]	Syntroleum in USA	Partial oxidization of natural gas is carried out by the auto thermal method with air. The

		FT reaction is used to form fuels from synthetic gas in the presence of nitrogen. The process is economical. Few details are available, although various evaluations have been performed since the announcement. Commercialization is planned in Australia.

2.4.3 Liquefied Natural Gas (LNG) technology

As noted above, the world's natural-gas market is presently strengthened as a buyer's market by production increases and planned projects in the Middle East, Europe, and Indonesia. Major European and American oil companies are making positive efforts to tackle issues concerned with both oil and natural-gas rights and interests. Furthermore, oil-producing countries are also showing a positive posture towards development of natural gas opportunities. Therefore, research and development is progressing on technology such as GTL and DME, which supports the new availability of natural gases. Products from new LNG projects are summarized by country in **Table 3**.

The main ingredient of natural gas is methane. At normal temperature natural gas is a gas, but when cooled below -163 °C, it becomes liquefied natural gas (LNG). It is conventionally manufactured in large quantities and used for power generation or town gas. Immense energy is required for production of LNG, beginning with the need to cool the natural gas to -163 °C. Recently, LNG process development has led to successes as summarized in **Table 4.**[8]

Table 3 New LNG projects of principal product-gas countries

Country	Products (10 B m^3/year)	Reserves (10 B m^3/year)	New LNG Projects (10 B m^3/year)
Australia	32.7	2,550	22.8
Indonesia	62.9	2,620	27.6
Iran	60.6	23,000	33.1
Malaysia	47.4	2,120	9.4
Oman	13.4	830	4.6
Qatar	32.5	14,400	20.5
Russia	542.4	47,570	13.2
The United Arab Emirates	41.3	6,010	2.8

Table 4 Several technologies using LNG

Technology	Characteristic
Cold energy power generation system	A regeneration system that produces electric power from "cold thermal energy", which otherwise would have been disposed to the atmosphere and sea water.
Air liquefaction and separation	The power expense of air separation equipment is reduced by using "cold thermal energy".
Liquefaction of carbonic acid	Liquefied carbonic acid is efficiently manufactured using "cold thermal energy". The process has been applied in an oil industrial complex.
Air-conditioning, refrigeration and a cold storage warehouse	Environmental load reduction has been attained. Liquefaction carbon dioxide is efficiently manufactured by cold thermal. The employment start has already been carried out as effective use of energy in the oil industrial complex area.
Turbine inhalation-of-air cooling	Environmental load reduction of the object for air-conditioning, and a refrigeration and a cold storage warehouse is attained.

2.4.4 Dimethyl Ether (DME)

Dimethyl ether (DME) is a stable gas at room temperature and is easily liquefied by compression. It is handled by methods that are similar to those used for LPG. Toxicity of DME is very low and it doesn't contain the sulfur that is found in methanol. Burning DME doesn't generate SO_x and produces little NO_x. Differences in physical properties between DME and conventional fuels are summarized in **Table 5**.[9]

Table 5 Comparison of physical properties between DME and similar fuels

	DME	Methan (LNG)	Propane	Methanol	Gas oil
formula	**CH_3OCH_3**	CH_4	C_3H_8	CH_3OH	-
boiling point (°C)	**-25.1**	-161.5	-42	64.8	180~360
liquid density (g/cm^3(@20°C))	**0.67**	-	0.49	0.79	0.84
gas specific gravity	**1.59**	0.55	1.52	-	-
saturated steam pressure (atm, 25°C)	**6.1**	-	9.3	-	-
firing temperature(?)	**350**	632	504	470	250
explosion limit (%)	**3.4~17**	5~15	2.1~9.4	5.5~36	0.6~7.5
cetane rating	**55~60**	0	5	5	40~55
low heat value (kcal/kg)	**6,900**	12,000	11,100	5,040	10,200

(R&D brochure of 5t/d pilot plant)

DME is mostly used as an injection agent for sprays for paint, agricultural chemicals, and cosmetics. Approximately 10,000 ton/yr are used in Japan and approximately 150,000 ton/yr worldwide. Various DME uses are illustrated in **Fig. 7**.[10]

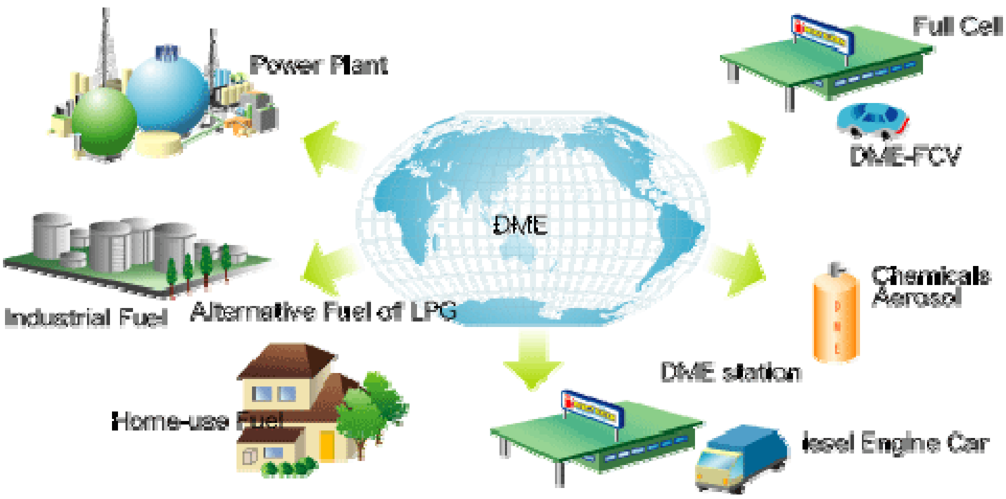

Fig. 7 Various uses of DME

DME is manufactured by a direct compounding method from products of methanol drying, hydrogen, and carbon monoxide. Since DME production begins with natural gas and uses hydrogen and carbon, it can be formed from other feeds, including organic matter such as residual oil, livestock feces and urine, and coal. Alternative production lines are illustrated in **Fig.** 8. Typical DME production processes use either the indirect synthetic method (dehydration reaction of methanol) or a direct synthetic method for producing DME from materials such as natural gas, coal bed methane, and synthetic gas made from coal or biomass. At present, DME is usually made by the indirect method and technology development towards direct synthetic methods is in progress.[11] In Japan, a 5 ton/day pilot plant was supported by the Ministry of Economy, Trade and Industry to investigate direct synthetic methods for DME production with various feeds, including coal bed methane and synthetic gas from coal gasification. The program ran for 4 years beginning in 1997.

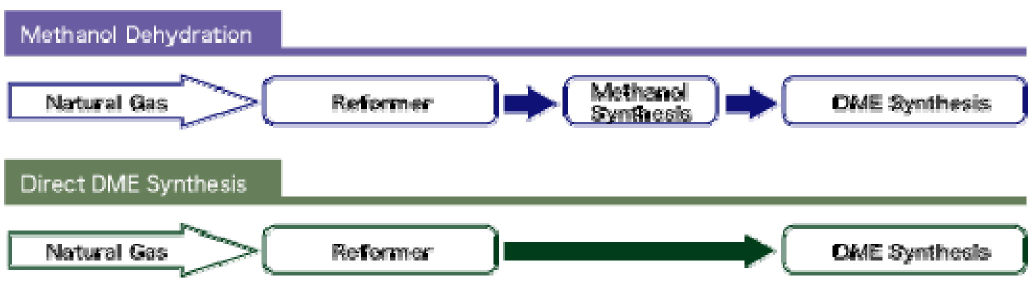

Fig. 8 DME production processes

Also in Japan, NKK started technical development in 1989 towards extensive manufacture of DME. Under support from the Agency of Natural Resources and Energy, construction of a 5 ton/day examination plant was begun in 1999 in cooperation with the Pacific Ocean Coal Mine and Sumitomo Metal Industries under the Coal Use Synthesis Center. Experiments with this plant demonstrated the world's first direct composition of DME from methane in the coal bed. Through cost comparison with other energy technologies, it was estimated that a commercial plant with at least 2,500 ton/day capacity is necessary, and future work should focus on manufacturing technology and process verification.

DME fuel has been targeted for applications such as automobiles and for distributed power on islands. Commercial plants could be sited in the minor gas fields of Asia and the Pacific Ocean area to foster utilization and spread activities in these areas. Under current investigation are uses of LPG supply infrastructures such as LPG filling stations and tanks for the supply of DME.

The oil crisis in the 1980s raised interest in processes that yield synthetic gasoline. In these processes, synthetic gas with CO and H_2 are main ingredients. These feeds can serve to compound DME. The flow charts for a synthetic gas plant and a DME composition slurry-floor reactor are shown in **Fig. 9** and **Fig. 10**, respectively.

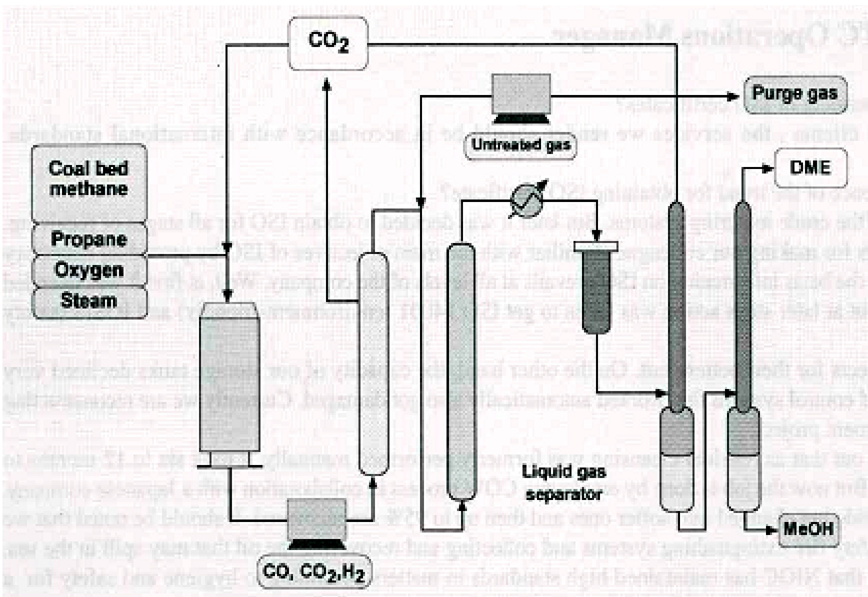

Fig. 9 Schematic for a synthetic gas plant for DME production (5 ton/day)[12]

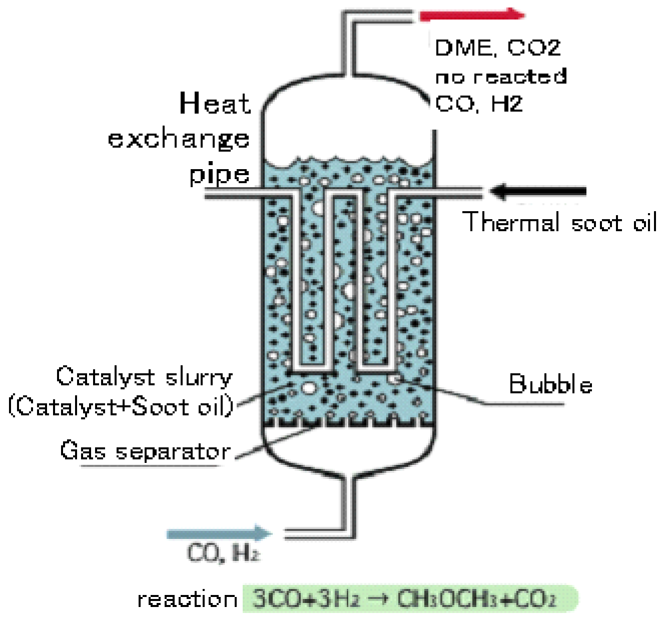

Fig. 10 DME composition slurry-floor reactor

This research and development has achieved anticipated results and work began in 2002 on construction of a 100 ton/day pilot plant. The larger plant will begin operation in 2004.

2.4.5 Methane Hydrate

Methane hydrate is currently being examined as a next-generation energy resource to replace oil and natural gas. Methane hydrate is an ice-like substance with the moisture child connoted methane in the basket (cluster) made by the hydrogen bond. Although methane hydrate is confined in the stratum and exists as a solid, it can be released as natural gas. Research and development of methane hydrate have placed emphasis on making solid methane hydrate decompose to produce methane and by-products such as hydrocarbons. If methane is extractable, development of use will follow that for natural gas. **Fig. 11** shows that methane hydrate is distributed globally in the earth's surface and concentrated on the submarine deposition layer and permafrost layer zone of the continental margin.[13]

The levels of NO_x or SO_x emitted when gases from methane hydrate are burned are unknown, but as natural gases the emissions will be cleaner than those from oil and coal. However, high releases of CO_2 from burning methane for a period of 100 years draw attention to global warming and its influence on the environment.[14] Moreover, when methane hydrate gas production is developed, new environmental impacts will emerge.

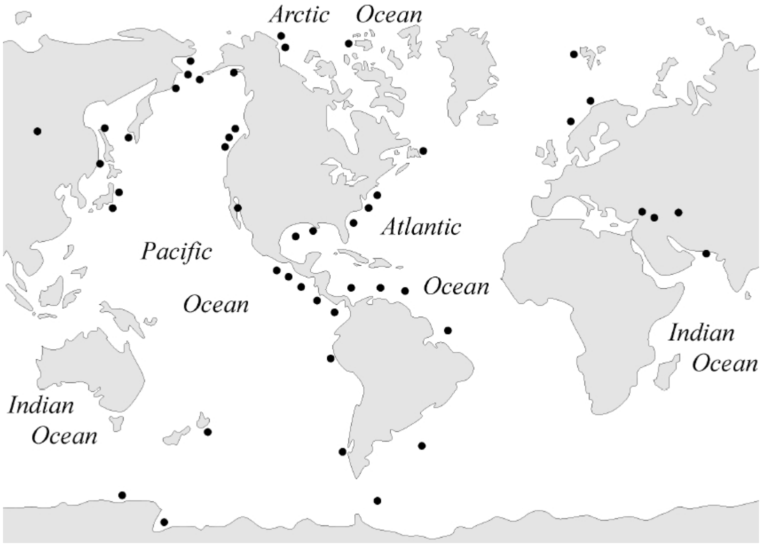

Fig. 11 Worldwide distribution of gas-hydrates

These include the emission of methane, water generation as a by-product, influence on marine organisms, and stability of the foundation (land subsidence after mining and possibility of a submarine landslide) beneath the sea. Large-scale mining beneath the sea can lead to landslides and calls for monitoring of the ocean space environment with apparatus and sensors. Research into such technology and that for monitoring methane in real time is underway.

2.5 Future R&D of natural-gas technologies

Although natural gas is presently conveyed and used in the form of LNG, as mentioned before, development of new processes for GTL and DME will be examined. As for the use of natural gas in applications such as power generation, diesel engines, fuel cells, and noncommercial uses, the objectives for development are focused on simplified handling and liquefaction.

3. Liquefied Petroleum Gas (LPG)

LPG is composed of liquefied petroleum gas (C_3H_8) and butane (C_4H_{10}). Through liquefaction, gas volume is reduced by a factor of 250 for storage and transport. LPG has many commercial and residential applications such as the cassette cylinder, writer, and spray. LPG is imported with crude oil and natural gas from the Middle East and especially Saudi Arabia. It is also commercially produced in Japanese refineries. LPG is an excellent source of clean energy:

- It produces very little CO_2 when compared with oil or coal combustion.
- It contains almost no sulfur or nitrogen.
- It produces no particulate matter emissions or ash.
- Its by-products do not yield ozone-layer depletion.
- Propane has 2.5 times and butane 3.3 times the caloric value per volume of natural gas.

3.1 Distribution of LPG production

The production of LPG in 2002 was about 210 million ton, and increased from 120 million ton in 1985 – see **Fig. 12**. The gas separated from refining oil occupies the largest market share (40%), followed by associated gas (35%), and crude oil (25%). The market share for North America was 38.4% in 1985, but this decreased to 28.4% by 2002. Still, North America remained the largest producer of LPG. The Asian area has shown production growth from 10.7% in 1985 to 18.6% in 2002, while the African area has grown 3.8% in 1985 to 7.6% in 2002.

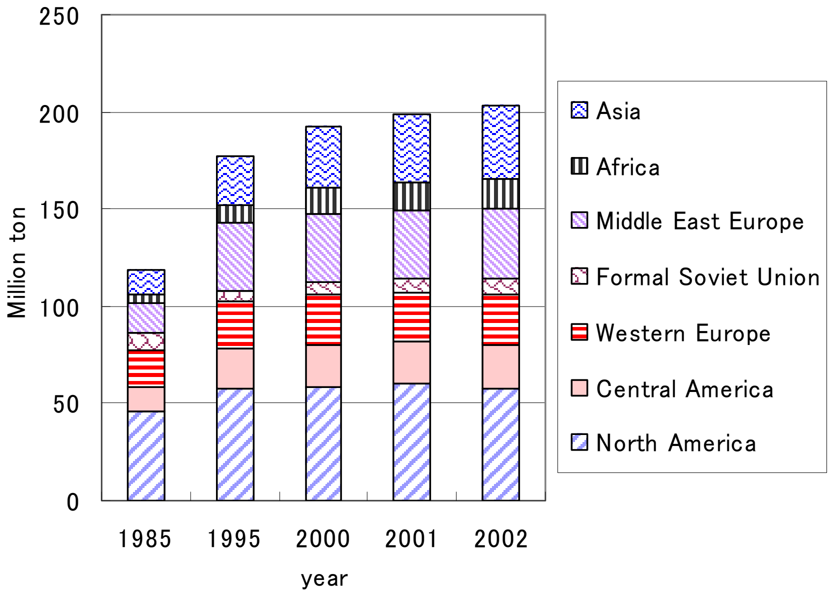

Fig. 12 Worldwide production of LPG

3.2 Trend for consumption of LPG

The worldwide demand for LPG is approximately 210 million ton, and is increasing at an average annual rate of 3.4%, exceeding the demand for natural gas since 1995.

Although North America satisfied 38% of worldwide demand 1985 and was the largest demand area, demand for LPG has increased in other areas. As of 2002, North America consumed only 28.7% of worldwide demand – see **Fig. 13**. The Asian area has tripled its demand and passed North America in 2001 to become the largest demand area. Demand for LPG rose from 19.5% of worldwide demand in 1985 to 29.7% in 2002. The market for cars using LPG is increasing and about 9 million vehicles will establish an approximately 16 million ton market in the world in 2002.

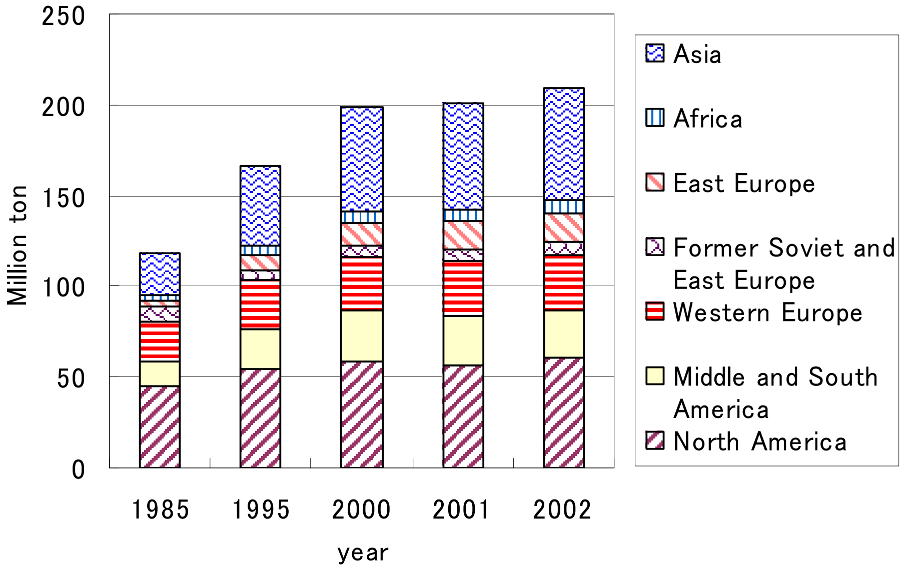

Fig. 13 The trend of the LP gas consumption in the world

3.3 Prospect for supply-and-demand of LPG

According to a consulting firm, LPG supply and demand in the world increases at an average annual rate of 2.2%. It is predicted to reach 310 million ton in 2020. While North America (26.5%) and Western Europe (9.2%) will reduce their market share, Asia will show growth to 33.1%. Growth is seen in home business use and materials development. As the supply of LPG in the world increases to 310 million ton in 2020, it is predicted that the supply from North America area (26.1%), the Middle East area (20.4%), and the Asian area (19.0%) will account for two-thirds of world supply. Consequently, the demand-and-supply balance will become as shown in **Fig. 14**, while export from the Middle East area will increase, and the Asian area will increase imports.[15]

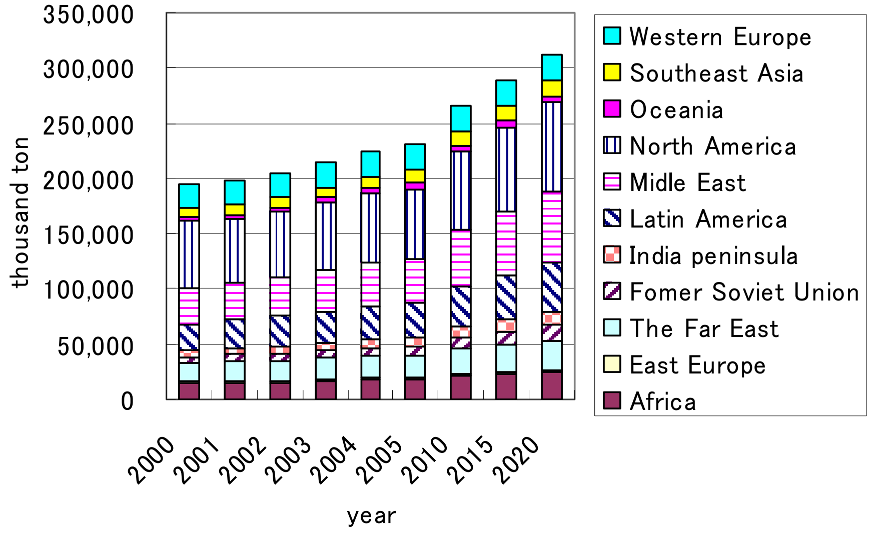

Fig. 14 The prospect for future demand of LPG

3.4 Trend for technology using LPG

The demand for LPG gas has been leveling-off over the past ten years. Home business use is growing and accounts for approximately 40% of demand. Industrial use remains large, while town-gas usage is seeing a conversion to natural gas and its market share is reduced. The market share for cars forms approximately 8% of the whole LPG demand, and although use in taxis is important now, expansion to freight vehicles is expected. The outline of this system is shown in Fig. 15. Cogeneration is an advanced electric power supply method that obtains electricity and heat through the use of LPG.[16]

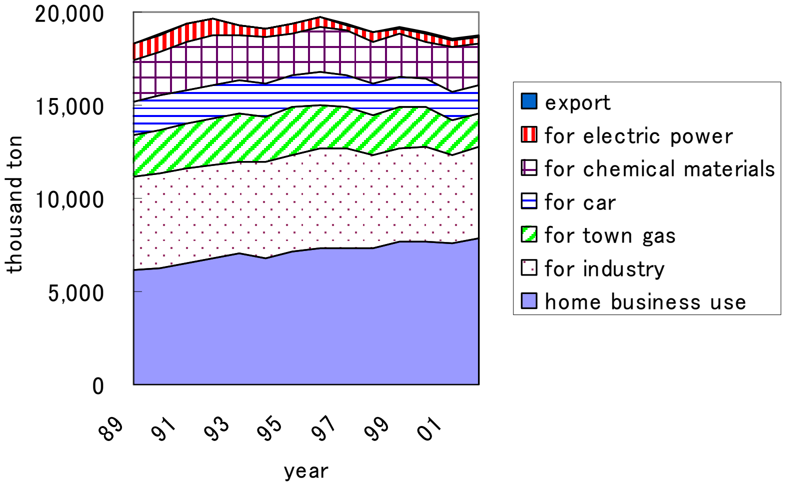

Fig. 15 Demand for LGP by application

3.4.1 Co-generation

LPG is expected to serve small-user markets such as homes and small businesses. A noteworthy technology is a fuel cell system for efficient distributed power generation. Air pollutants such as NO_x and SO_x can be sharply abated in comparison with conventional power generation equipment, and adoption of the technology yields reduced distribution costs or, at least, burden on bulk supplies. The LPG solid high polymer type fuel cell development supports this objective, and an example is illustrated in **Fig. 16.**[17]

Since a fuel cell directly transforms chemical energy to electrical energy, it yields higher efficiency than cogeneration by gas engine or gas turbine. The power generation efficiency of a commercial phosphoric acid fuel cell is approximately 40% of exhaust thermal efficiency, and overall efficiency for power generation is approximately 80%. That is, power generation and usable thermal energy from the exhaust each result from approximately 40% of the fuel's energy.

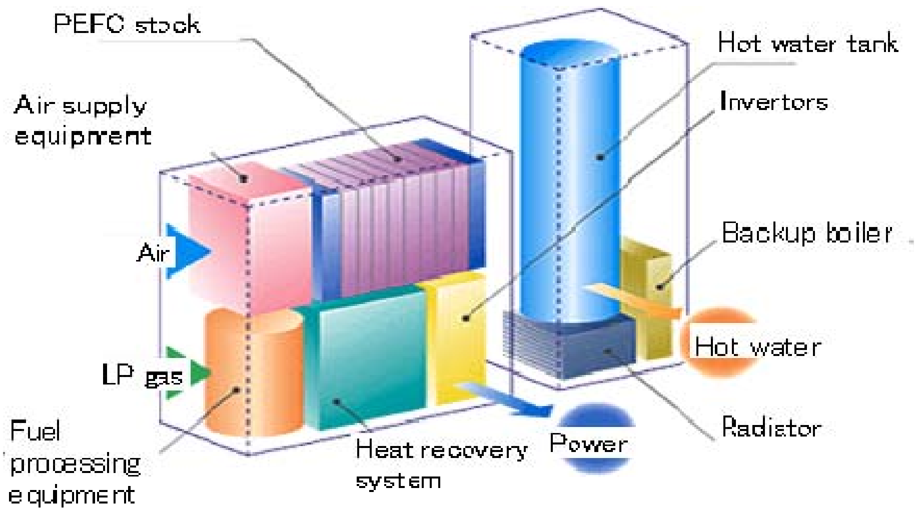

Fig. 16 LPG solid high polymer type fuel cell (home fuel cell)

Fuel cells produce heat and electrical energy by chemical reactions and release negligible gaseous emissions to the environment, when compared with gas engines and gas turbines. As shown in **Fig. 17**, fuel cells are also used as efficient hot-water heaters and to generate electricity to be returned to the commercial power system. LPG, as a feed material, is reformed by hydrogen in the fuel processing equipment, and electricity is generated in a PEFC stack by the chemical reaction using hydrogen and the oxygen in the air. Moreover, heat from the fuel processing equipment or PEFC stack can serve the hot-water supply demand for the home or a back-up boiler.

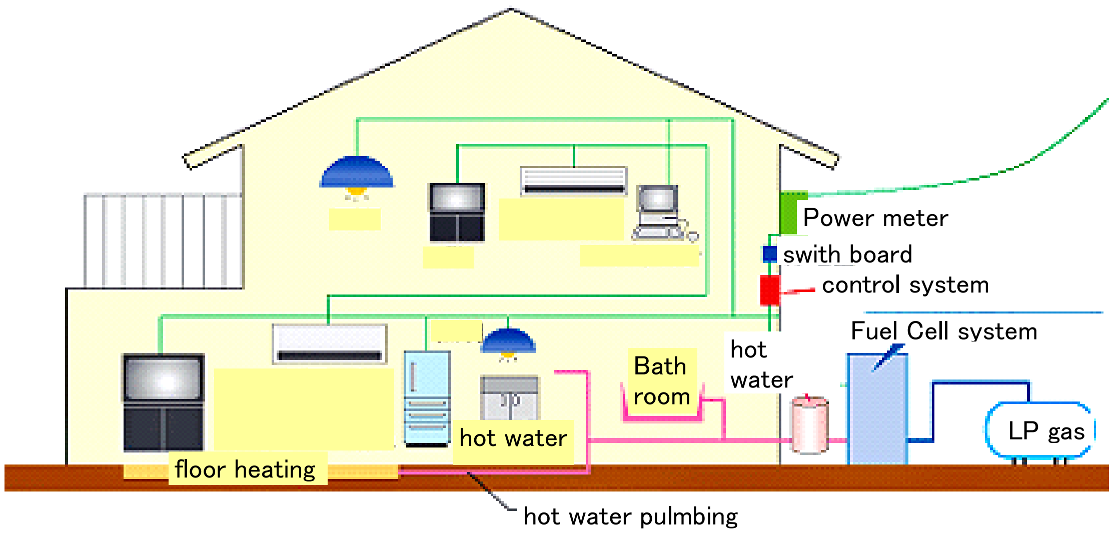

Fig. 17 Outline for a domestic hot-water supply system

3.4.2 LPG vehicle

Currently, fuel cells are capturing the spotlight for the latest electric vehicles. A typical outline for such as system is shown in **Fig. 18**.

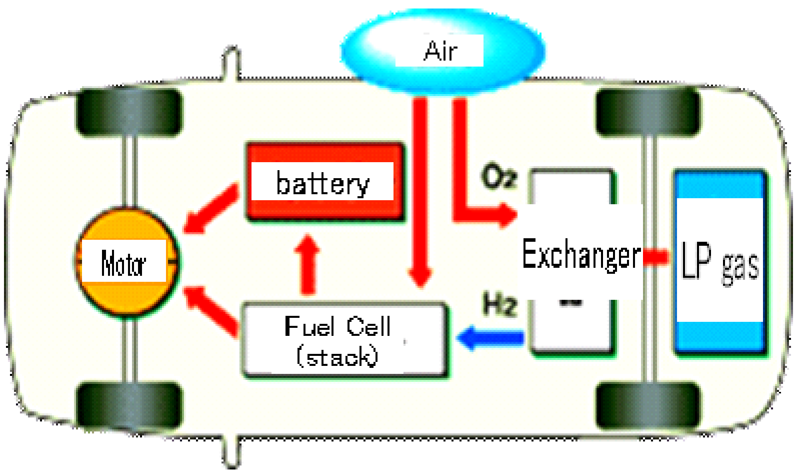

Fig. 18 Fuel cell system for cars

Hydrogen is the fuel for a fuel cell and its source can be methanol, LPG, natural gas, gasoline, light oil, lamp oil, etc. Aside from hydrogen storage in the vehicle, there are difficulties with generating hydrogen from the various fuels - each fuel has its practical merits and demerits. LPG as a feed material is second only to gasoline in availability and development for storage on vehicles. Challenges in using LPG remain, as CO_2 is released in forming hydrogen from LPG[18]. However, NO_x and SO_x are not emitted and the noise level is small in comparison with that from diesel engines.

Technical development has centered on replacement of diesel cars by those fueled with LPG. Local government in Japan is replacing diesel cars, public buses, and garbage collection trucks with LPG vehicles. The use of LPG in taxi vehicles for approximately 20 yr without accident has proven safety. Gasoline and LPG fueled vehicles compare favorably from a cost standpoint. LPG yields perfect combustion, so that no CO gas is emitted. No lead and negligible sulfur and benzene are emitted as with gasoline and diesel engines.

Recently, the LPI (Liquid Petroleum Gas Injection System) car was developed by Vialle Alternative Fuel Systems BV in the Netherlands. The Bi-fuel arrangement for this car is shown in **Fig. 19**. The car uses a conventional gasoline injection system and supplements it with alternative fuels. Electronic controls are used to adjust the quantity of gas so that its combustion efficiency is high. There are advantages as follows:

- At low mpg operation it is almost equivalent to a gasoline vehicle, and is 10 – 20% low mpg from the conventional LPG cars.
- When LPG is used, the output is more than from a gasoline-fueled vehicle.
- The exhaust gas is cleaner than from LPG cars.
- It can run a Bi-fuel vehicle, i.e., LPG and gasoline with both as fuel, and it is possible to use all the LPG in its tank.

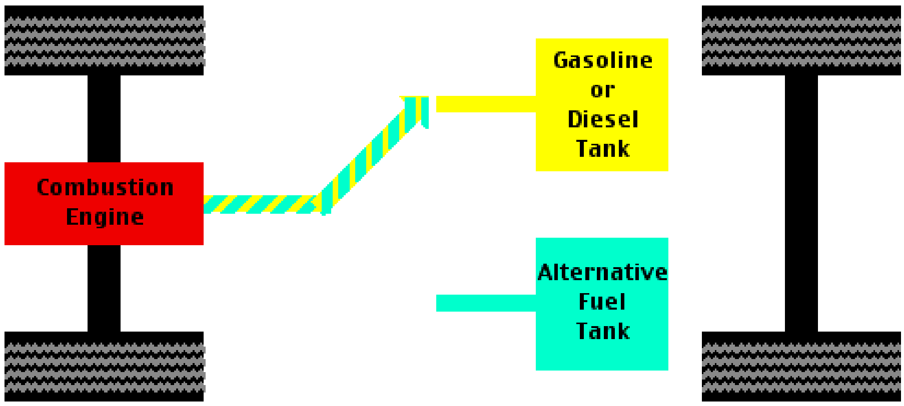

Fig. 19 Bi-fuel system

3.5 Future R&D of LPG technologies

The environmental load of LPG is relatively small. As with natural gas, there is no emission of particulate matter (PM). Distributed power from fuel cells using LPG are efficient and can secure stable supply. They produce little CO_2 emissions under abnormal operation. Use of LPG should be promoted for broad use in cogeneration and fuel cells. Since infrastructure cost of LPG is inexpensive, applications in many countries are expected.

DME has similar qualities to LPG, so application development of either serves both. The LPG industry has know-how and existing infrastructure to support research and development.

4. Coal

4.1 Distribution of coal resources

Coal is distributed more widely than oil and natural gas. It has a big merit in Japan, because it is produced in Pacific Rim countries such as China, Australia, and Indonesia. Also, coal's reserve production stands 204 years – longer than those for energies based on oil and natural gas. The distribution of coal reserves is illustrated in **Fig. 20.**[19]

4.2 Trend in demand for coal

The amount of coal (including lignite) consumed in the world in 2002 was 4,741 million ton. Of this coal, 888 million tons was lignite. The consumption of lignite showed a 1.8% annual growth, while the other coals showed a 2.1% growth in consumption. The distribution of coal consumption is summarized in **Fig. 21**.

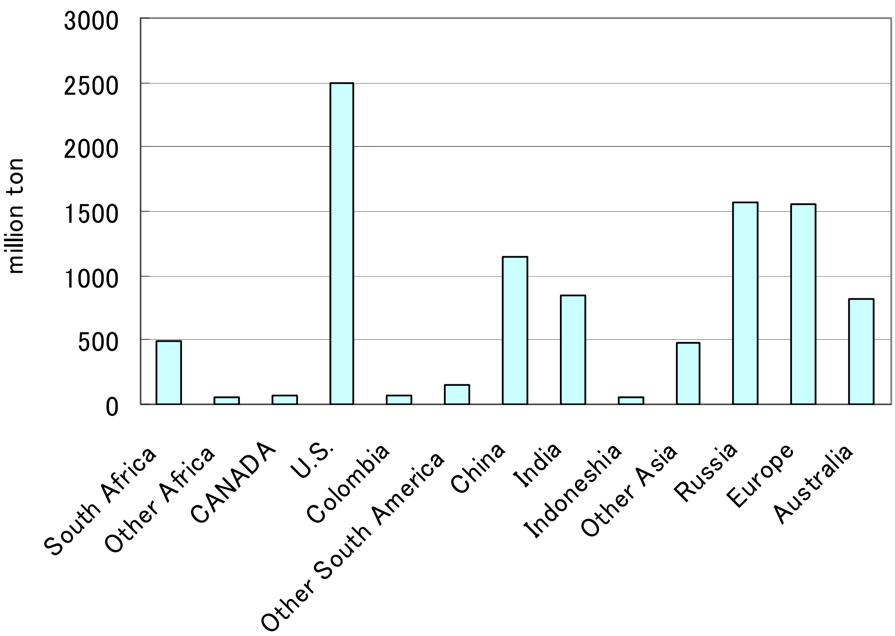

Fig. 20 Recoverable coal reserves of the world

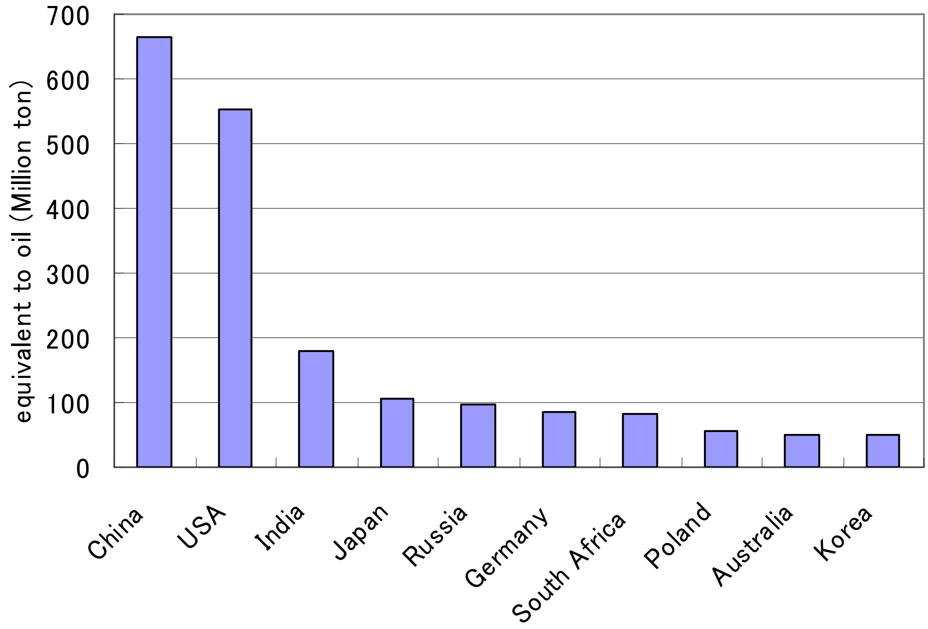

Fig. 21 Coal consumption in the world (excluding lignite)

China (26.4%) and the United States (20.5%) consume nearly half (46.9%) of the coal (including lignite) – see **Fig. 21**. China's consumption has started to increase again in recent years, although the amount of coal consumption has been decreasing from a peak in 1996.[20]

4.3 Prospect for supply-and-demand of coal

IEA has projected the largest growth in demand for coal to be in China, and that this will encourage overall growth in demand in the Asian area. On the other hand, we can see that the growth in other areas is small (**Fig. 22**). Coal supply increases are expected in China, the USA, India, etc., while decreases are predicted in the OECD Europe area.[21]

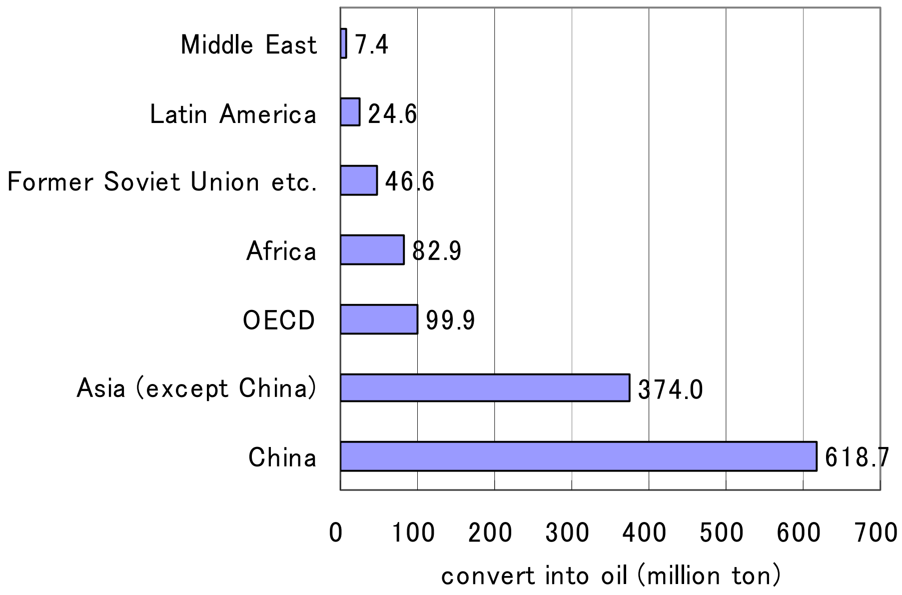

Fig. 22 Worldwide growth in demand for coal (2000 to 2030)

4.4 Trend for technology using clean coal

Environmental loads of coal, such as CO_2 emissions, are large compared with those from oil or natural gas. The development and spread of coal-use technology (clean coal technology: CCT) which support a cleaner environment are important (**Fig. 23**).

It is necessary to promote development of clean-coal technologies such as coal gasification combined cycle power generation (IGCC) and coal gasification fuel cell combined cycle power generation (IGFC). This will lead to reduced CO_2 emissions through improvement in combustion efficiency of power plants. In Asia and the Pacific Ocean area, where the greatest increase in coal demand is expected, it is important to encourage transfer of clean coal technology to developing countries. The aim is to accept expanded coal use in developing countries, while protecting the environment, taking measures against global warming, and applying a clean development mechanism (CDM).

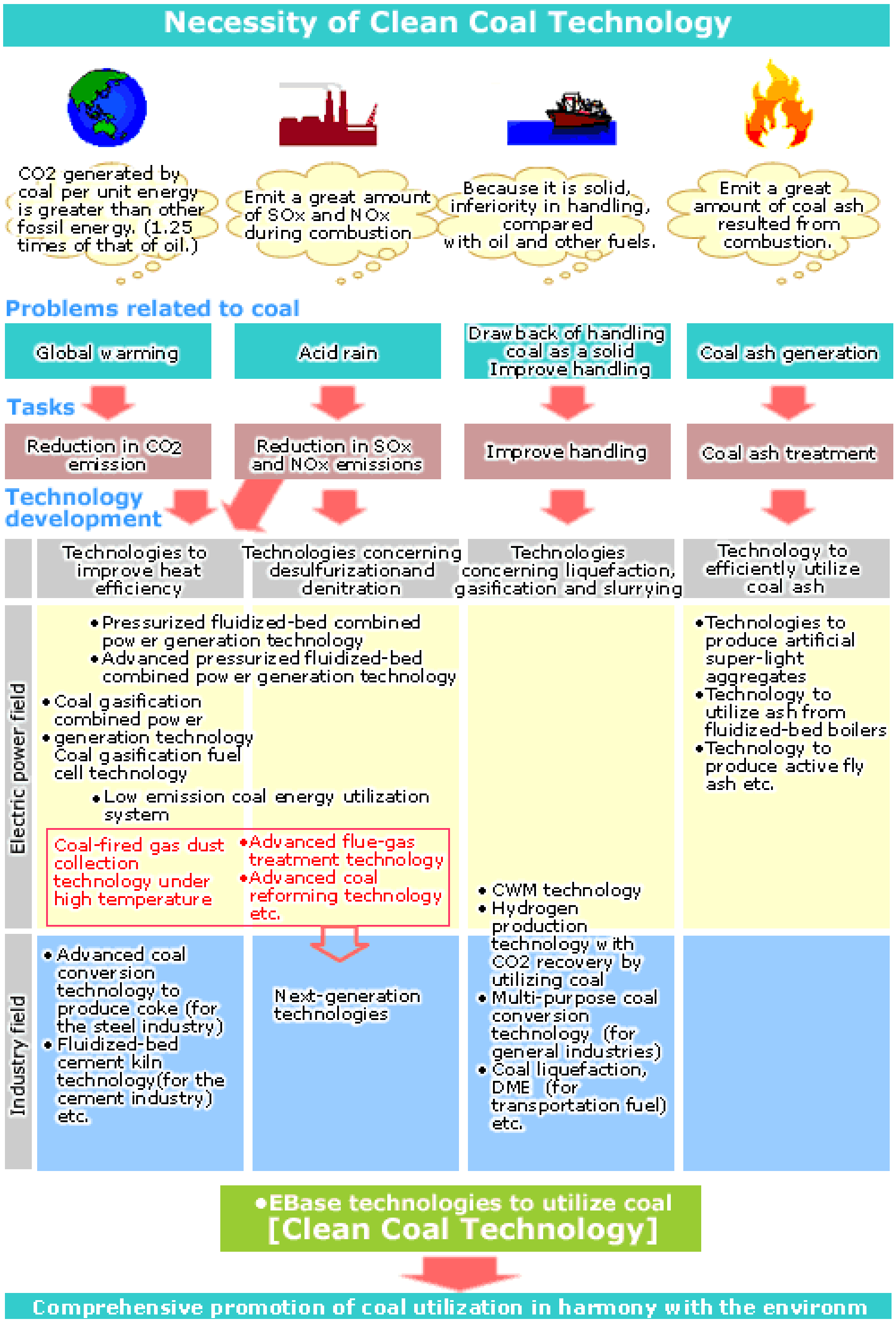

Fig. 23 Outline of the main clean coal technology[22]

Clean coal technology is summarized by the following:

- Improving thermal efficiency by IGFC and IGCC technologies and reducing CO_2 emissions.
- Adopting technology to abate NO_x and SO_x emissions, and achieve CO_2 separation recovery and fixation.

- Adopting advanced technology such as coal liquefaction, gasification, liquefaction, and slurry conversion.
- Adopting technology for the effective use of coal ashes.

Approaches in each of these areas are described below.

4.4.1 Technology for the improvement in thermal efficiency

Several technologies are commercialized or near commercialization:

① Supercritical pressure pulverized coal thermal power generation is commercialized.

② Extra super critical pressure pulverized coaled coal thermal power and

③ Pressurized Fluidized Bed Combustion (PFBC) Combined Cycle system are near-term technologies.

④ Integrated Coal Gasification Combined Cycle (IGCC) system, as shown in **Fig. 24** should reach commercialization around 2010.

⑤ The coal gasification fuel cell power generation system is expected around 2020.[23]

If the end efficiency for thermal-power-generation/transmission is 38% and CO_2 generation is set to 100 by Japanese average (1997 levels), the efficiency of the above mentioned processes ① to ⑤ and the amount of CO_2 generated by them will be ① 40% 95, ②41% 93, ③42% 90, ④46% 83 and ⑤54% 70 when commercialized. It turns out that power generation efficiency improves with technology development from ① to ⑤, and CO_2 generation is reduced.

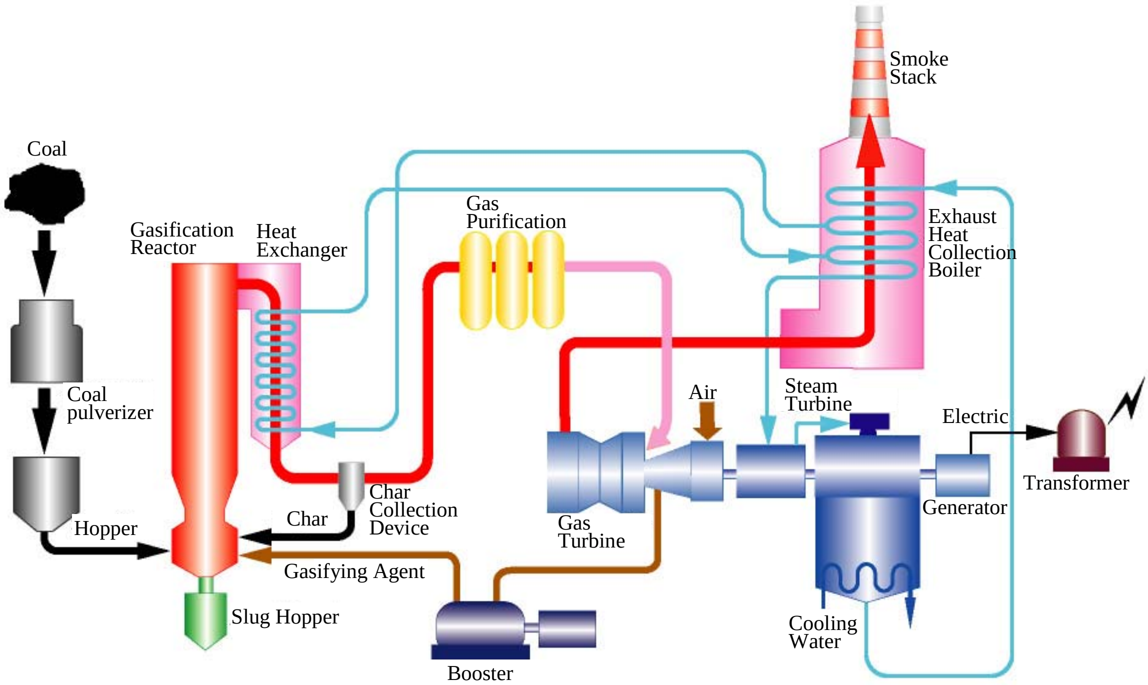

Fig. 24 Integrated Coal Gasification Combined Cycle system

4.4.2 Technology for environmental improvement

Environmental improvement is achieved through clean coal technology and technology for pollutant abatement. In Japan, technology exists for control of sulfur oxides (SO_x) and nitrogen oxides (NO_x) found in combustion exhaust gases. There is also technology to separate, collect, and fix CO_2 emissions from large-scale generation sources.

CO_2 injection holds promise for improved crude oil recovery at oil fields (EOR process) – see **Fig. 25**.[24] Research towards technical development is complete and shows that methane collects in the coal bed as clean energy while fixing the CO_2 that would otherwise lead to global warming if released to the atmosphere.

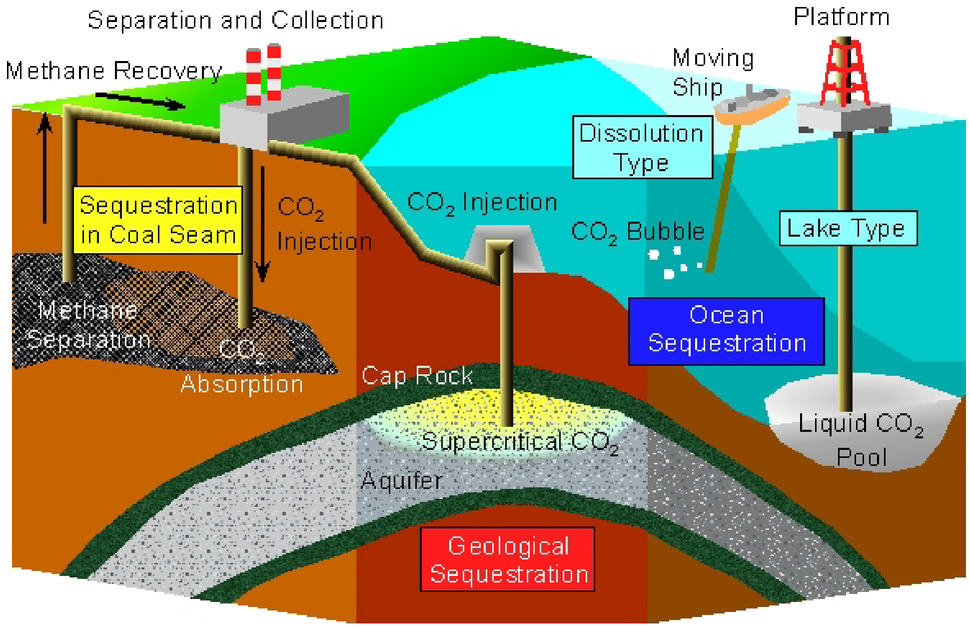

Fig. 25 Overview of CO_2 sequestration technology

4.4.3 Technology for improvement of conventional fuels

Coal-use improvement often depends on technology to produce

- coal high functional-materials such as methanol, ammonia, and activated carbon,
- automobile liquid fuel of added value,
- home fuel such as light oil and lamp oil, and
- DME as a LPG alternative fuel.

A process flow model is illustrated in

Fig. 26. Coal handling technology can include the development of Coal-Water Mixtures (CWM) and Coal Cartridge Systems (CCS). CWM typically employs 7:3 pulverized coal-water suspensions. CCS is a total system technology that includes controlled pulverization, sealed transportation, and batch processing of the combustion ashes.

Both are technologies at the actual proof stage.

As noted in an earlier section research has demonstrated the direct formation of DME from synthetic gases obtained through coal gasification.

4.4.4 Technology for effective use of coal ashes

It is important to find uses for coal ashes. Studies on the use of coal ashes as cement materials, base course material, and land improvement material has already been performed. In the near future, technologies are anticipated for manufacturing artificial super lightweight aggregates, uses of flow floor boiler combustion ashes, and fly ash activation.

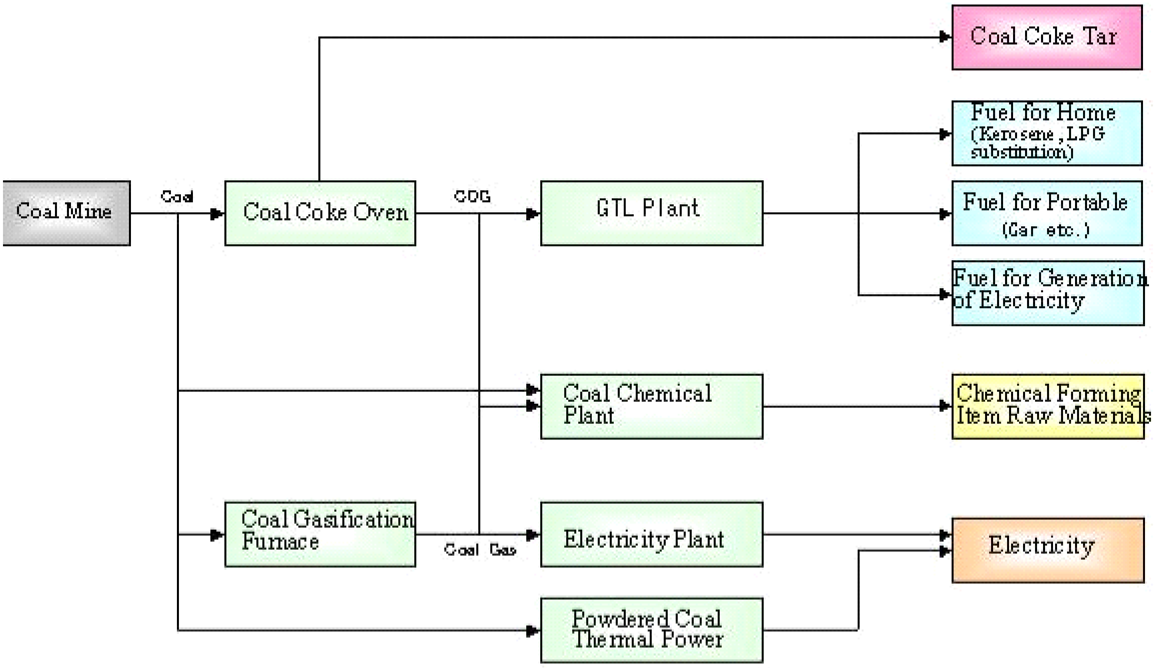

Fig. 26 Coal practical use energy and a functional-materials chain[25]

4.5 Future R&D in coal technologies

In order to advance the use of coal, technology must be developed that improves combustion efficiency, draws hydrogen from coal, and puts coal ashes to good use.

Coal use is linked to global environmental problems, and Asia and the Pacific Ocean area will be looked on for their rising demand for coal. For this reason, the model enterprise of a circulation flow floor boiler (China) and an advanced concentrating-coal system (Vietnam) have been undertaken for the purpose of promoting clean coal technology.[26]

5. Concluding Remarks

In this paper, we reviewed the present scope and status of hydrocarbon fuels which hold potential to replace oil. The continued use of oil poses challenges:

- New oil fuels with reduced environmental loads are needed.
- New oil stripper technology is needed.
- Clean fuel conversion processes for heavy crude strippers are needed.
- Advanced integrated technical development is needed for oil-refining to reduce environmental loads and improve processes.

IEA predicts future oil demands in the Asian area, including China, to increase greatly and there will be additional advancement in other areas as shown in **Fig. 27** (prediction of this clause is hereafter based on an IEA prospect).[27]

Research and development is needed for improved processes for production and use of fuels and for environmental controls. Processes that are inherently more environmental-friendly should receive greatest attention.

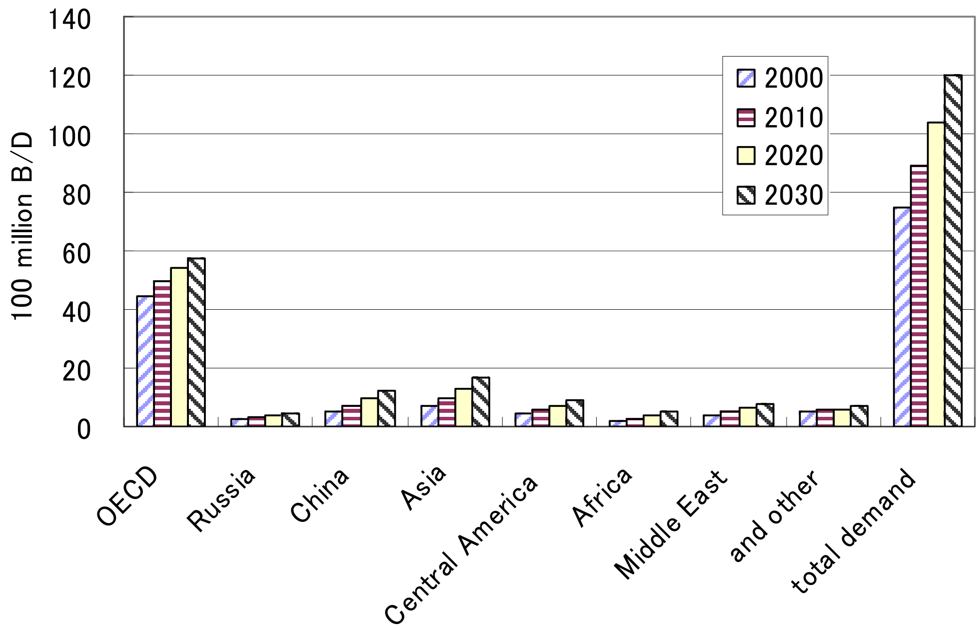

Fig. 27 Global growth of oil demand（from 2000 to 2030）

Energy supply and demand, infrastructure, maintenance, and related environmental issues vary among countries. Therefore, we should take regional needs into consideration as much as possible. Finally, technical development should consider needs of the next generation and environment.

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