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Trends in Technical Developments for the Exploration, Development, and Production of Petroleum and Natural Gas Resources

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1 Introduction

According to Japan's projected energy supply (Table 1), in 2010, the supply of oil (including LPG) and natural gas in crude oil equivalent will be 277-253 million kl and 91-81 million kl, respectively, accounting for 46-44 percent and 15-14 percent of all energy. In 2030, these figures will reach 256 million kl and 108 million kl, accounting for 42 percent and 18 percent of all energy. Oil and natural gas are expected to account for the majority of the entire primary energy supply.

As shown in Figure 1, although worldwide confirmed and recoverable oil reserves[*1-2] are increasing annually due to discovery and development of new oilfields, deep exploration, and the integration of heavy crude oil, as well as projected improvements in recovery rates, at

Table 1 : Projected primary energy supply

unit: million kl

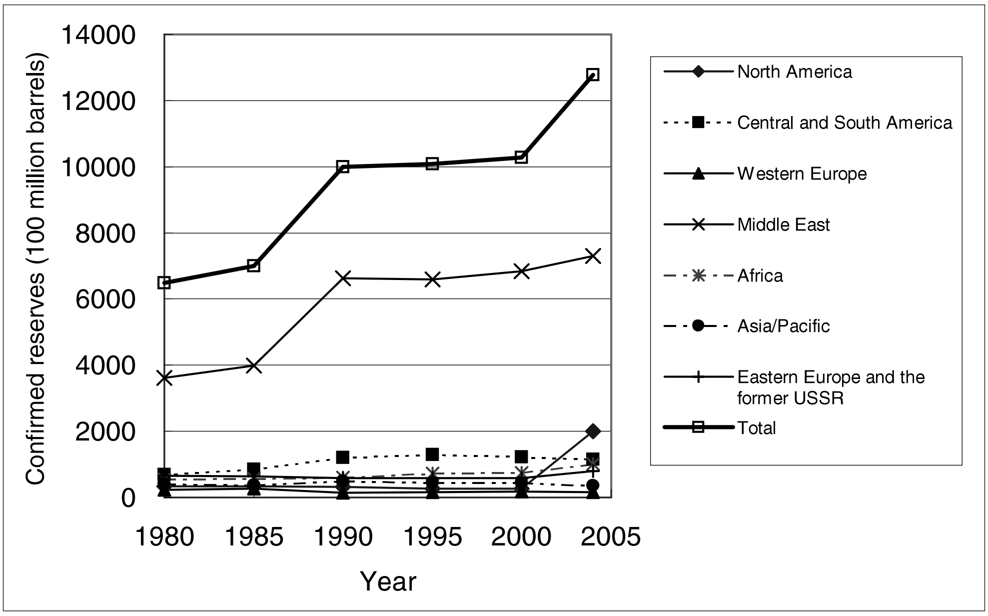
	FY 1990		FY 2002		FY 2010						FY 2030	
					Reference		Under current promotion measures		With additional measures		Reference	
Domestic supply of primary energy	512		576		602		585		569		607	
By energy type	Actual number	Percentage distribution	Actual number	Percentage distribution	Actual number	Percentage distribution	Actual number	Percentage distribution	Actual number	Percentage distribution	Actual number	Percentage distribution
Oil	271	53%	263	46%	258	43%	247	42%	About 236	About 41%	233	38%
LPG	19	4%	19	3%	19	3%	19	3%	About 17	About 3%	23	4%
Coal	86	17%	111	19%	111	18%	105	18%	About 101	About 18%	106	17%
Natural gas	53	10%	80	14%	91	15%	86	15%	About 81	About 14%	108	18%
Nuclear energy	49	10%	69	12%	85	14%	85	14%	About 87	About 15%	90	15%
Hydropower	22	4%	19	3%	21	3%	21	4%	About 21	About 4%	20	3%
Geothermal	0	0%	1	0%	1	0%	1	0%	About 1	About 0%	1	0%
New energy, etc.	12	2%	14	2%	16	3%	22	4%	About 27	About 5%	27	4%

Note 1: Please note that the energy balance sheet was revised in FY 2003 through the elimination and consolidation of some statistics beginning in FY 1990, so the actual values for final energy consumption and primary energy supply differ in some places from the previous (2001) long-term energy demand projections.
Note 2: In the previous (2001) long-term energy demand projections, the energy category "oil" under "primary energy supply changes and projections" included LPG. LPG is not included in "oil" this time.
Note 3: "New energy, etc." includes blast furnace top gas pressure recovery power generation and other forms of waste energy in addition to new energy.
Source: Reference [1] (p. 17)

current consumption rates the reserve life index is estimated at less than 50 years. By region, the integration of Canadian ultraheavy crude oil has greatly increased North American reserves, but the reserve life indexes*3 for Western Europe, Asia/Oceania, and Eastern Europe/former Soviet Union are all below 20 years.

Meanwhile, world primary energy consumption reached 9.74 billion tons in crude oil equivalent in 2003, with oil and natural gas accounting for 61 percent. Oil consumption, as seen in Table 2, also deserves attention. Consumption in Western Europe and Japan is down slightly, while it is up sharply in China and elsewhere in Asia, and up slightly in the USA and Russia. These statistics do not include India, which has become a major world consumer of oil and natural gas as its economy has grown rapidly. In 2003, India's daily oil consumption was 2.42 million barrels, competing with Germany and Russia for fourth place in the world behind the USA, China, and Japan. India's energy demand in 2030 is projected to reach 1 billion tons in crude oil equivalent. Along with China's 2.5 billion

Figure 1 : World confirmed and recoverable oil reserves



Prepared by the authors from OGJ (2004 final issue)

Table 2 : World oil consumption by country

units: 1,000 barrels/day (%)

Country/region \ Year	1985	1990	1995	2000	2003
Japan	4,435 (7.6)	5,305 (8.1)	5,784 (8.4)	5,576 (7.4)	5,451 (7.0)
China	1,810 (3.1)	2,255 (3.4)	3,390 (4.9)	4,985 (6.6)	5,982 (7.7)
Asia (not including Japan and China)	3,535 (6.1)	5,360 (8.2)	8,014 (11.6)	9,406 (12.5)	10,174 (13.0)
USA	15,170 (26.0)	16,305 (24.9)	17,725 (25.6)	19,701 (26.2)	20,071 (25.7)
Germany	2,670 (4.6)	2,710 (4.1)	2,882 (4.2)	2,763 (3.7)	2,664 (3.4)
France	1,790 (3.1)	1,910 (2.9)	1,893 (2.7)	2,007 (2.7)	1,991 (2.5)
Italy	1,730 (3.0)	1,930 (2.9)	1,987 (2.9)	1,956 (2.6)	1,927 (2.5)
UK	1,630 (2.8)	1,760 (2.7)	1,757 (2.5)	1,705 (2.3)	1,666 (2.1)
Russia	4,910 (8.4)	5,015 (7.7)	2,934 (4.2)	2,474 (3.3)	2,503 (3.2)
Middle East	2,980 (5.1)	3,395 (5.2)	4,028 (5.8)	4,320 (5.7)	4,480 (5.7)
Other	17,765 (30.4)	19,535 (29.8)	18,766 (27.1)	20,361 (27.1)	21,203 (27.1)
World total	58,425 (100.0)	65,480 (100.0)	69,160 (100.0)	75,254 (100.0)	78,112 (100.0)

Sources: BP "Statistical Review of World Energy 2004" and Reference [1] (p. 20) tons, this will account for 25 percent of projected world energy demand. Because of the large rapid increase in oil and natural gas consumption that is accompanying economic growth in these populous countries, the reserve life index shown in Figure 1 cannot be regarded with optimism.

Japan's policy is to reduce energy consumption. However, until renewable energy becomes available in terms of both price and volume, Japan must have agile overall policies to secure the primary energy supply necessary to maintain its economic growth and the livelihood of its people. Therefore, along with the development of renewable energy, Japan should adopt balanced policies that secure fossil resources. Japan must make careful and thorough preparations in the event of a sharp jump in the prices of crude oil and oil products and avoid the current overexcitement regarding the securing of rights to oil and natural gas resources. Obviously, securing primary energy supplies reflects a country's overall power. In Japan's case, strategies based on its technical and industrial expertise must be reviewed and strengthened adequately. Japan is internationally competitive with regard to industry, technology, and human resources in oil and natural gas resource exploration (mineral exploration), development, and production, so cooperation with resource-rich countries to secure economic and stable resources is an important strategy.

Exploration, development, and production of oil and natural gas are carried out today through international collaboration and division of labor. This is led by upstream and downstream businesses with national policy companies in oil-producing countries and the world's major oil companies (the majors described in Chapter 5 form the core, with an increasing number of national or large corporations from various countries) as project owners. Exploration, development, and production work are generally carried out with companies specializing in various technical areas, civil engineering and construction companies, and local service companies forming contracting teams dominated by two major service companies (Halliburton[*4] and Schlumberger[*5]) for projects. In other words, projects are divided into owner companies that obtain the rights to resources and lead projects, project participant companies that expect some rights, and service companies that cooperate to move projects forward with advanced upstream technologies. The owner companies judge the economics and politics of resource acquisition, development, and production, and orchestrate the knowledge of the service companies. The service companies develop highly reliable upstream technologies and provide various development services under the leadership of the owner companies. Verification and implementation of technologies is completed during the projects. At the same time, owner companies must have international project experience and the ability to effectively organize service companies with comprehensive advanced upstream technologies in order to acquire highly profitable economic rights.

Due to the recent international situation, bidding on and participation in overseas projects by Japan's trading companies and oil development, refining, and engineering companies is increasing, but in terms of leadership, scale, and economics, they cannot be considered powerful in comparison with the activities of the major oil companies or emerging nations. Japan also needs a strategy to utilize its outstanding industrial expertise to develop and apply advanced upstream technologies. Japan must pay attention to the increasing number of emerging industrialized nations and major consuming nations utilizing huge national owner corporations and acquiring upstream technologies to apply to new developments.

Against this background, this report takes an overview of the exploration, development, and production technologies that are considered the upstream sector of resource technology and the status of development. It clarifies the position of Japan, and offers proposals to prepare for the near future. Looking at these technologies and current technical developments, the advanced nations of Europe and the USA with their major oil companies and very specialized technologies, resource-rich emerging nations with their remarkable technical growth and major consuming nations must all be kept in mind.

2 Overview of Exploration, Development, and Production Technologies

Table 3 shows an outline of the workflow from the beginning of an oil or natural gas project through production and abandonment. Each step, including mineral exploration, test drilling, development, production, and abandonment proceeds over a long period of decades. Various technologies at each stage advance in parallel, and work advances sequentially to the next major stage of investment based on evaluation of each preceding stage.

As depicted in Table 3, various fundamental technologies are developed, verified, used, and implemented at each stage. All technologies are adjusted to the geological conditions in the development area, oil and gas deposit conditions, and distance to market. They are tested for effectiveness, improved, and finally completed as the optimum technologies for specific oilfields. In order to maintain technical superiority, it is therefore necessary to have considerable experience and a record of achievements in oilfield development. At the same time, continual challenge of the latest technologies is also essential to securing superiority. Currently, most established and applied technologies are operated by the above-mentioned Halliburton and Schlumberger. They have even adopted and commercialized technologies developed in Japan. In the long-term, Japan needs to consider always the challenge of participating to this international system and becoming competitive to them. In fact, efforts in that direction can be seen in emerging oil producing countries.

2-1 Mineral exploration

Table 4 summarizes typical mineral exploration technologies. Mineral exploration methods utilizing the characteristics of each type of technology are used to determine sites for test drilling. Seismic explorations using artificial earthquakes, technology for the final stage of determining sites, are particularly important. Improvement and advancement in both hardware and software aspects of the technology are underway.

2-2 Drilling

Currently, rotary-type drills are used for test and production well drilling. Table 5 describes

Table 3 : Oil and natural gas project flow

	Process	Technology	Costs
Year 0	Mineral exploration	Regional geological survey Remote sensing Preliminary survey of subject area Application for mining rights, negotiation and bidding, acquisition of mining rights Aerial geological survey Geophysical exploration Geochemical exploration Seismic exploration Comprehensive analysis of all explorations	Mineral exploration investment
3-5 years	Test drilling	Determination of test well locations Test well drilling Analysis of source rock and reservoir rock data Analysis of logging and well data Overall assessment, examination of profitability, renunciation of mining rights	Test drilling investment
6-10 years	Develop-ment	Oilfield development plan Drilling of development wells Placement of production equipment	Development investment
	Production	Production/sales	Operating costs Reinvestment to expand production competence
	Abandon-ment	Abandonment and equipment removal	Abandonment costs

Prepared by the authors

Table 4 : Overview of mineral exploration technologies

Preliminary survey	Assessment of geology through literature surveys and purchased materials Political and economic site survey
Resource exploration	Detection of sedimentary land from surface condition through remote sensing using exploration satellites
Geophysical exploration (gravity, magnetism)	Estimation of underground geological structures through measurement of gravity and magnetism over a wide area to obtain an overview of land with sedimentary layers differing from surroundings in gravity and magnetism
Seismic exploration	Artificial earthquakes are generated and the seismic waves reflected back from strata surfaces are captured by seismographs to examine the depth and shapes of the boundaries between underground formations. Earthquakes are generated using vibrations from compressed air in oceans and from gunpowder or steel plates on land. The observed reflected waves are digitized and processed by computer.

Prepared by the authors from Reference [2]

Table 5 : Drill mechanisms

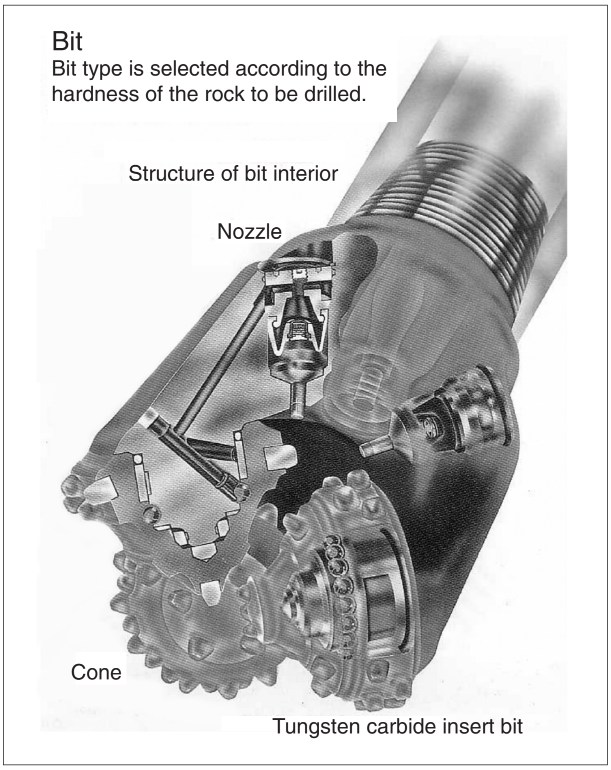
Drill mechanisms	Mechanisms for raising and lowering drill and casing pipes
Rotary mechanisms	Mechanisms to rotate drill pipe and drill bits using a rotary table
Mud circulation mechanisms	These mechanisms provide a liquid seal to resist underground pressure, preventing oil and gas blowouts while also preventing well walls from collapsing. Circulation of mud brings cuttings to the surface.
Safety/blowout prevention mechanisms	Mechanisms to seal off pressure inside wells that could cause gas or oil blowouts

Prepared by the authors based on Reference[2]

their mechanisms. As depicted in Color Chart 1, a bit is located at the tip of the drill. Optimum control of bit drilling direction and speed in accordance with the strata is important, while the bit materials and construction are important for drilling precision, efficiency, and life. Bits have a complex structure, so materials development technology and precision machining are both necessary.

Drilling circulates mud along a drill pipe. The mud is slurry water composed of water, bentonite, a viscosity regulator, a filtration regulator, a lubricant, an ion regulator, a pH regulator, and a density regulator (barite). This serves to bring the drill cuttings to the surface, thereby transmitting underground data. This facilitates geophysical exploration. In this case, the muddy water prevents the stratum from collapsing and the gushing of liquid inside the stratum, cools the bit, and lubricates the drill stem. The development of mud therefore played an important role in making deep drilling possible. Along with land drilling and marine platforms, the pipes that link bits with the surface are also the culmination of advanced technologies in materials and structures, including their operation, data transmission, and strength. Fundamental technologies include civil engineering technology such as that used to stabilize the walls of the hole.

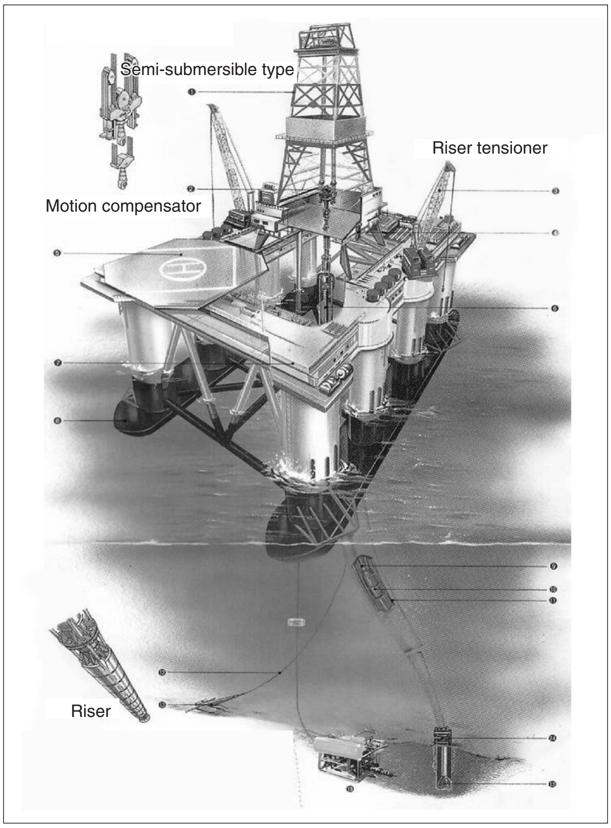
Color Chart 1 : Drill bit structure



Source: Reference [3] (p. 20)

Color Chart 2 shows the typical structure of a marine oil drilling rig. The chart shows a semi-submersible rig. The floating area is kept relatively small, lessening the impact of wave action so that stable drilling is possible even in heavy seas. Position is maintained with anchors

Color Chart 2 : A typical marine oil drilling rig



Source: Reference [3] (p. 24)

Figure 2 : Reservoir assessment methods

Mud logging
- Detection of oil/ gas reservoirs

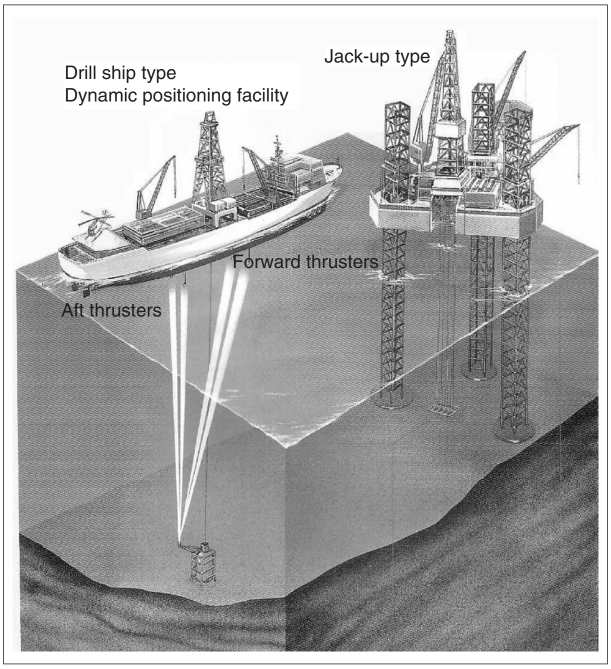
Core cuttings
- Detection of oil reservoirs
- Lithofacies survey (sandstone, mudstone, volcanic rock…?)
- Fossil survey (determination of geological age) (determination of deposit environment)
- Survey of reservoir rock competence (porosity, permeability, oil saturation)
- Survey of source rock competence (quantity, quality and maturity of kerosene)

Wireline logging
- Survey of strata depths and lithofacies
- Survey of geological structures (strata slope)
- Survey of reservoir rock competence (porosity, oil saturation, permeability)

Test oil/gas from reservoir
- Type of fluid (oil, gas, water?)
- Production capacity survey (fluid pressure, permeability, obstacles to completion)
- Component analysis of extracted fluid

Source: Reference [3] (pp. 28-29)

Color Chart 3 : Other drilling equipment



Source: Reference [3] (p. 25)

and mooring cables.

The types of marine drilling equipment depicted in Color Chart 3 have also been put into practical use. Equipment with high cost-performance in accordance with the site's topography, ocean conditions, climate, environment, and so on can be selected. Large surface, submerged, and ocean bottom structures are the fruits of ocean civil engineering.

2-3 Logging technology

Test drilling allows various types of logging within wells, enabling the detection or prediction of oil and gas reservoirs. Logging technologies are summarized in Figure 2. Table 6 briefly describes logging technologies. Mud, core, and wireline logging are used. There are companies that specialize in the various logging technologies. When a reservoir is struck, test oil or test gas is brought up, and production capacity is estimated from the type and density of the liquid, as well as liquid pressure, permeability, and flow speed.

2-4 Production

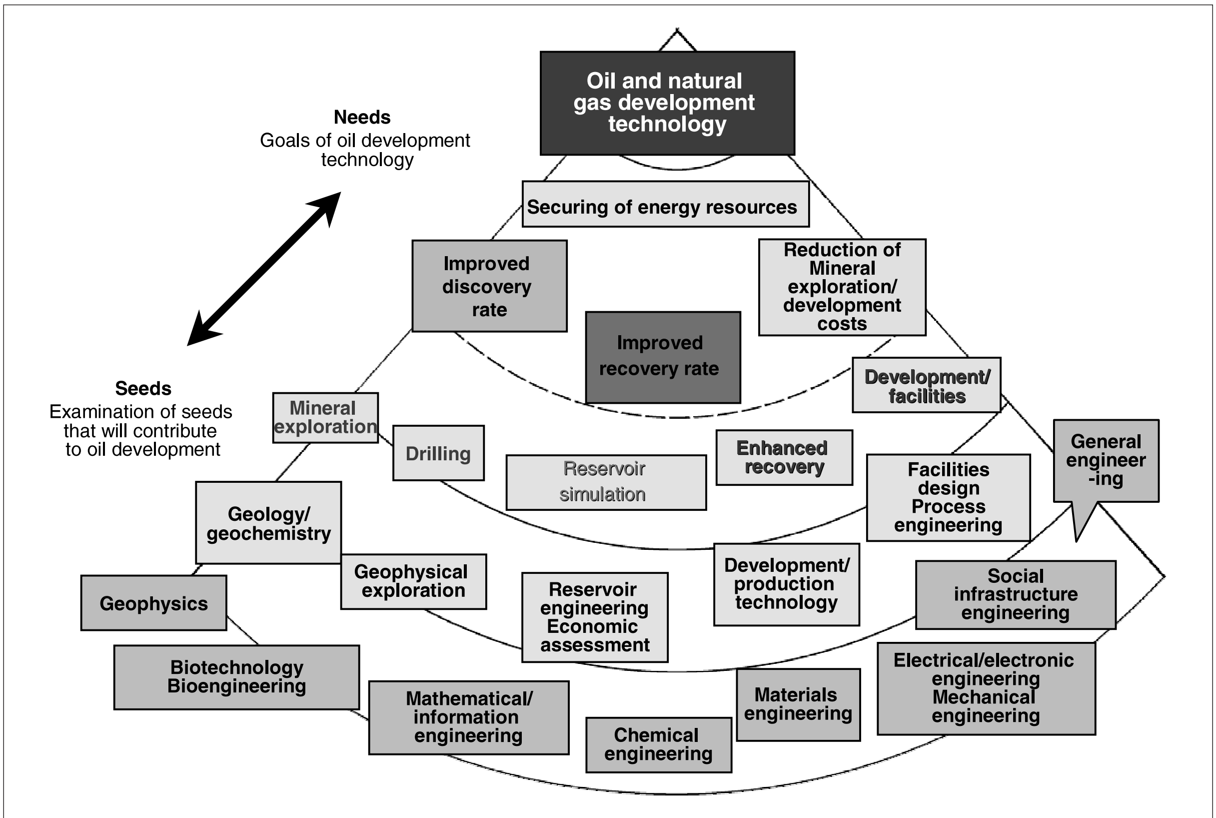
Oil and natural gas extracted from underground are separated into oil and gas, and then further refined by removal of water and salt. Crude oil or gas is allowed to flow into production wells drilled into the reservoir and flows through

Table 6 : Logging and test oil

Mud logging	Cuttings brought up from the well bottom by mud circulation are examined, and oil and gas are chemically detected.
Core logging	Rock and other content are extracted from strata and chemically analyzed.
Wireline logging	After completion of drilling, wirelines are lowered and the physical properties of strata are sequentially measured. Reservoir porosity and oil saturation rates are sought with electrical radioactivity logging.
Drill stem logging	Strata judged hopeful through the above logging are isolated with rubber packers and oil and gas are brought to the surface.
Collection of oil, gas, and water from test wells	Pressure within the test well casing is lowered, causing oil, gas, and water to come to the surface for collection, enabling well bottom pressure and production capacity to be ascertained.

Prepared by the authors

Figure 3 : Overview of oil and natural gas development technology



Source: Reference [4]

steel oil well pipes to the surface, where control equipment at the well mouth called a Christmas tree sends it to separating equipment and storage tanks. Control at the well mouth uses valves and flow controllers comprising thermometers and pressure gauge chokes.

Flowing wells, pumping wells, and gas lift wells are different types of production wells. Flowing wells are those where gas and water pressure in the reservoir cause the oil to flow naturally. This pressure declines during production, so methods such as drawing out the crude oil with a pump, or injecting gas to lighten the oil's specific gravity to assist flow are used to extract the oil.

3 Advances in Technologies for Mineral Exploration, Development, and Production

Chapter 2 provided an overview of mineral exploration, development, and production technologies. In light of the direction of current and future technical advances, it will be worthwhile to take a look at the engineering and basic science that links those needs and seeds. Figure 3 is an overview of technology provided by Professor Kazuo Fujita of the Shibaura Institute of Technology. Along with the integrated nature of science and technology in this area, it is necessary to continue a cycle of ideas, demonstration, application, and commercial improvement and verification that can be established based on proper understanding of their advanced nature and future direction.

3-1 Latest technologies for mineral exploration

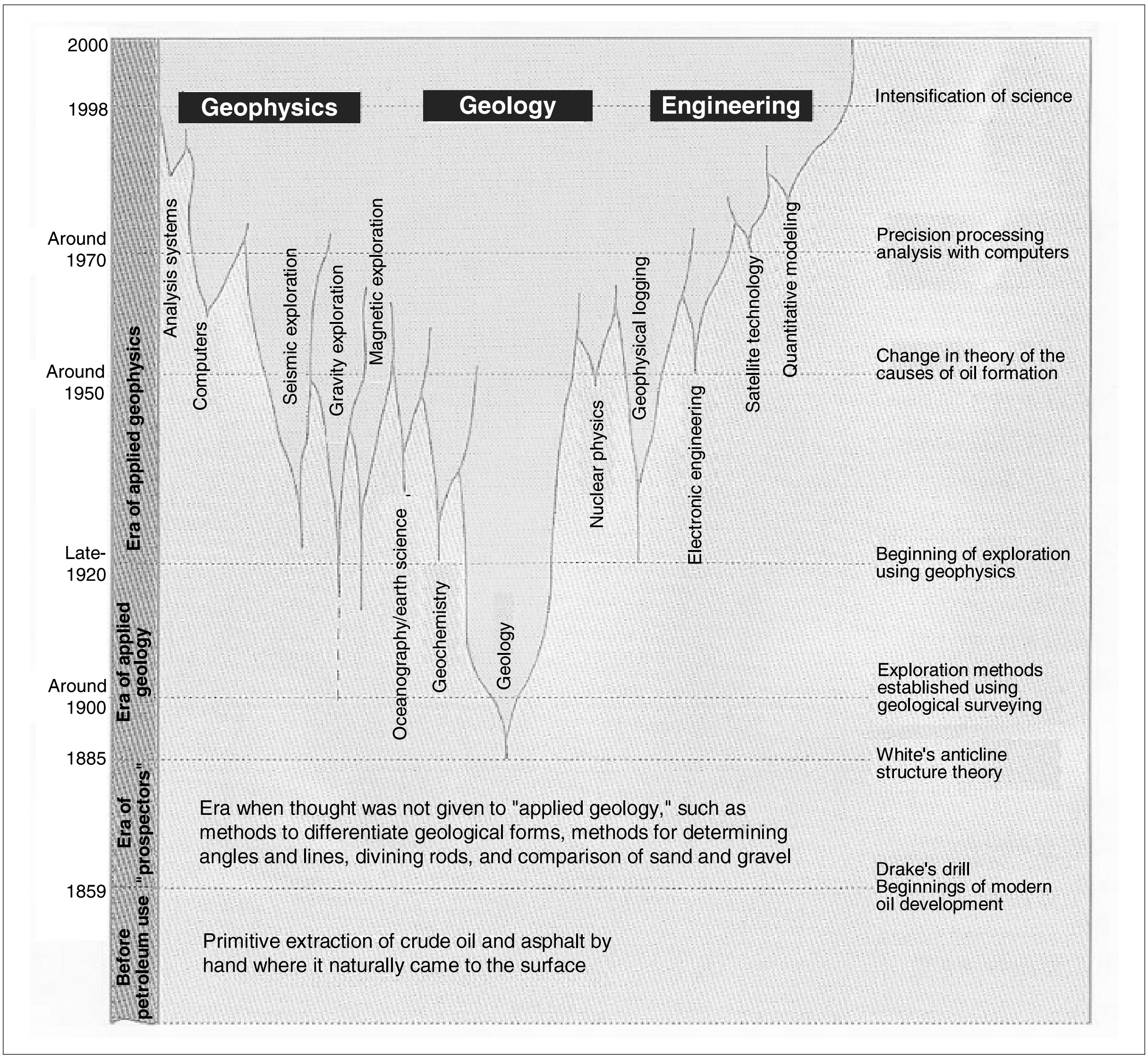
Figure 4 shows the development of mineral exploration technology. Based on geology and other sciences, mineral exploration technology began in the early 20th century. Since about 1930, geophysics has been used to survey subsurface structures. Recent advances in computer performance, the accumulation of vast amounts of data, and the use of analysis systems and quantitative modeling simulations have enabled the precise description of geological conditions and oil reservoirs, enabling the projection of future resource production.

As for seismic exploration, which was touched on in 2-1 above, closely linking the locations of epicenters and receivers and measuring multiple reflected waves with different phases allows three-dimensional imaging of geological formations. Precision measurement enables the estimation of gas reservoirs with large differences in density sandwiched between other geological formations.

3-2 Advanced drilling technology

With regard to deep drilling to extract resources from deep underground, in 1985 the former Soviet Union reached a depth of 12,000 m in the Arctic. Currently, deep drilling technology is being developed with the goal of reaching 15,000 m.

Figure 4 : History of mineral exploration technology



Source: Reference [3] (p. 9)

To avoid surface obstacles or to extract resources from oil reservoirs spreading horizontally from vertical wells, inclined wells and long horizontal wells are in development and being used. Multilateral well systems combining one vertical well with multiple horizontal wells are already in use, increasing the economic viability of resource extraction.

This kind of drilling requires accurate drilling control to precisely determine the underground position. Therefore, MWD (measurement while drilling) that obtains bottom hole data at the point of drilling and feeds it back to surface control systems is now in use. Positioning using satellite data, quick collection of drill head data, control programs, automatic control of databases that need to be compared and other developments are constantly evolving.

Furthermore, in addition to obtaining bit load, torque, and other drilling parameters at the drilling point, systems that use sensors to obtain data on geological conditions (such as specific resistance and gamma-ray absorption) and send them to the surface have been developed, enabling the application of the so-called LWD (logging while drilling) method that simultaneously performs drilling and logging.

Improving the transmission speed of large amounts of data is another area of development. Advances are also being made in the development of mud pulse, mud siren, and pipe transmission methods and systems that use mud as a medium.

3-3 Advances in oil reservoir evaluation technology

The acquisition, analysis, and interpretation of data on liquid pressure and movement from rock, oil, gas, and stratum water obtained from wells can be combined with information from geological exploration, well building, logging, and oil reservoirs to create quantitative models of oilfield shapes and conditions. Predictive simulations have also been created, and these are being developed as a method for assessing oil reservoirs at the point of drilling. The flow of liquid within oil reservoirs can also be modeled, and outside forces (e.g. changes in flow when water or carbon dioxide is injected from the surface) can also be simulated. This is expected to improve recovery rates.

Samples obtained from oil reservoirs are being used for measuring physical properties deep underground to estimate the physical properties of deep oil reservoirs. When these analyses are collected from multiple wells on a site, they can be used to create a detailed image of geological and oil reservoirs in an area.

In the process of production work, repeated three-dimensional seismic exploration and oil reservoir evaluation that tracks changes over time allows so-called four-dimensional monitoring and simulation. Extending this over time may yield remarkable improvements in the accuracy of predicting oil reservoir productivity and reserves.

3-4 Pursuing the limits of development

The limits of resource development are reaching towards the Earth's mantle, at ocean depths exceeding 2,000 m, and expanding mining areas in the Arctic. Not only must exploration and development be started under harsh natural conditions, but production and transport must also be continued. Protection of the environment in such cases is also an important issue. Complete technical development for exploration, development, and production technologies suited to the natural environment together with appropriate materials and systems will be needed.

3-5 Enhanced oil recovery (EOR) technology

The amount of oil that can be recovered through natural pressure or pumping (primary recovery volume) is usually 20-30 percent of the resources in an oil reservoir. In order to continue recovery beyond that point, water (steam) and gas may be injected, raising pressure in the oil reservoir. This secondary recovery raises the rate of recovery to 30-40 percent. In addition, insertion of steam and surfactants to lower oil viscosity, injection of carbon dioxide to separate oil from rock, and dilution with chemicals or solvents can raise the recovery rate to 40-60 percent. Experiments are also underway to raise the rate by growing microorganisms in oil reservoirs to depolymerize oil into lighter components or to perform underground gasification reactions.

Improvements in such recovery methods are a major reason that recoverable reserves are now increasing.

Over time, production is accompanied by changes in oil components. Production can also be reduced or halted by obstacles in geological formations. Technologies using water pressure or explosives to remove such geological obstacles are being developed. In complex geological formations containing faults, oil reservoirs are broken up, so such technologies will be an important means of improving recovery rates.

3-6 Noteworthy Japanese technologies

The Japan Oil, Gas and Metals National Corporation (JOGMEC) is developing the following technologies, aiming to apply and demonstrate them in domestic and overseas developments. It is working with Halliburton and Schlumberger on the commercialization of oil reservoir analysis.

(1) Imaging of subsurface structures

Accurate depiction of the complex underground geological structures of steep slopes and the faults, fissures, and salt domes that accompany them is difficult to carry out with analysis of ordinary strata exploration. However, a program combining multiple seismic exploration analysis programs to portray complex underground geological structures is being developed. This technology uses parallel processing in small workstations while linking multiple sites to analyze subsurface structures. Its effectiveness is now being verified.

(2) Logging technology

In logging technology, improved technology for analysis of core rock is expected. Observing the flow of oily water inside the rock core with an X-ray CT scanner allows analysis of the dynamic behavior of liquid in the rock. With this technology, the status of water accumulation in Middle East oilfields from improvements in extraction using the water flooding method was clarified. This in situ analysis is an important means of accurately measuring the current status of oil reservoirs. In the future, one can imagine that the technology will progress to comparisons of the chemical and physical structures of rocks and to the modeling of entire areas.

Detection of hydrogen atoms using the emission of gamma rays by hydrogen atoms irradiated with neutrons is used as means of logging to measure the characteristics of geological formations in the vicinity of well walls and liquids within them. This technology can detect water. Radioactive material had been used as the pulse neutron source, but pulse neutron sources that generate neutrons electrically have been developed as an LWD tool. Verification testing with Schlumberger for the commercialization of the technology is progressing.

(3) Drilling and drilling tools

Multistage fracturing of low-permeability lithofacies more than 5,000 m deep to release gas reservoirs, which can increase natural gas productivity six-fold and allows precise and accurate underground work, is the subject of much attention. For re-access to multilateral horizontal wells and horizontal drilling, drilling equipment (multilateral tieback and remote directional control system) with a drive system that can be controlled in any direction is being developed. Demonstrations are being conducted along with Sperry-Sun and Halliburton, and commercialization is expected.

In addition, large amounts of dense corrosive gases such as hydrogen sulfide and carbon dioxide are generated, so highly durable materials must be selected and cost reduction is necessary. This requires corroborative testing over long periods of time. Selection tests that reproduce actual conditions such as water content, temperature, pressure, are underway, and cost reductions are being pursued.

4 Resource Developments in the Near Future

Because of today's strong demand and concerns about future supplies, attention is turning to oil and natural gas in areas where extraction was considered economically or technically difficult. In some cases, development for extraction has begun, while in others preparation for the future is underway.

4-1 Technology to utilize ultraheavy crude oil

The appearance of ultraheavy crude oil, which has a small amount of distillable oil components, on international markets would appear to be feasible. Arabian heavy, Kuwait heavy, Marlim crude, Orinoco tar, and tar sand bitumen are types of ultraheavy crude oil. With the aim of raising prices in oil-producing countries, stable production and appropriate up-grading are the subjects of technical development. One of the types of ultraheavy crude oils, tar sand bitumen, is extracted along with silica through opencast mining. Oil is extracted and collected, and distilled oil is obtained from distilled residual oil through coker cracking. This oil undergoes light hydrotreating and appears on the market as synthetic crude oil. In the future, as opencast mining becomes more difficult as the depth of reserves increases, new recovery methods such as underground steam injection, partial burning, and underground gasification will need to be introduced. Meanwhile, for today's markets in developed countries, the development of high-quality refining technology is necessary. Therefore, integrated development of recovery and refining that unites upstream and downstream processing is required. This integrated development is a topic that Japan can address now and in the future. International participation has already begun, and now is probably the last chance to guide joint development with an eye to the future of oil-producing countries.

4-2 Technical development accompanying the development of small and medium gas fields

Long-distance transport of natural gas is based on pipelines and LNG transport. In both cases, massive investment is required to prepare infrastructure. Utilization of small and medium gas fields with limited production volume for other than local consumption is therefore difficult, retarding development. However, if economic means of long-distance transport can be developed, they can be commercialized. Technologies that could make this possible include:

(1) Transport utilizing storage in high-density adsorbents or methane hydrate slurry
(2) Transport after conversion from natural gas to compounds that liquefy under low pressure, such as dimethyl ether (DME) and light hydrocarbons.

4-3 Consideration of methane hydrate

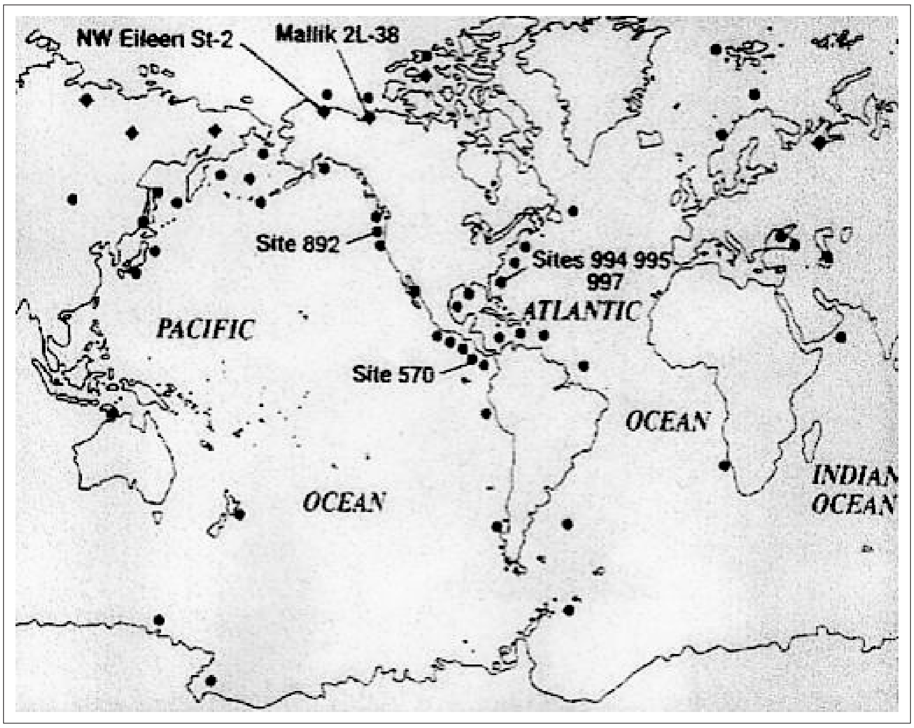
Combined with water in specific proportions, methane gas forms the sherbet-like substance methane hydrate. It is found in large quantities in geological formations under deep oceans. Because it exists in large amounts in deep oceans all over the world, including in the vicinity of Japan, it is seen as a future natural gas resource. Figure 5 shows locations around the world where the existence of undersea methane hydrate has been confirmed.

However, technology that can efficiently recover methane alone from methane hydrate without melting ice and consuming large amounts of energy to transport solid hydrate has yet to be developed. In addition, extraction of methane hydrate, which is abundant in the deep ocean and polar regions, is practically difficult. Furthermore, methane that is released into the atmosphere has an enormously large impact on the environment, so great care must be taken in its collection in order not to increase the burden on the environment. Basic research on methane hydrate should be carried out rationally from scientific and economic perspectives, without believing that it is some sort of dream resource.

5 The Status of World Resource Development and Japan's Activities

World resource development has been led by the major oil companies, ExxonMobil (USA), Shell (Netherlands/UK), BP (UK), Total (France), ConocoPhillips (USA), and Chevron (USA) and various other companies known as quasi-majors. Although recently there has been talk that investment is stagnant, mineral exploration and development costs in 2004 still reached an overwhelming $4-10 billion.

Figure 5 : Areas where methane hydrate exists



Source: Reference [5] (p.31) and Kvenbolden 1999

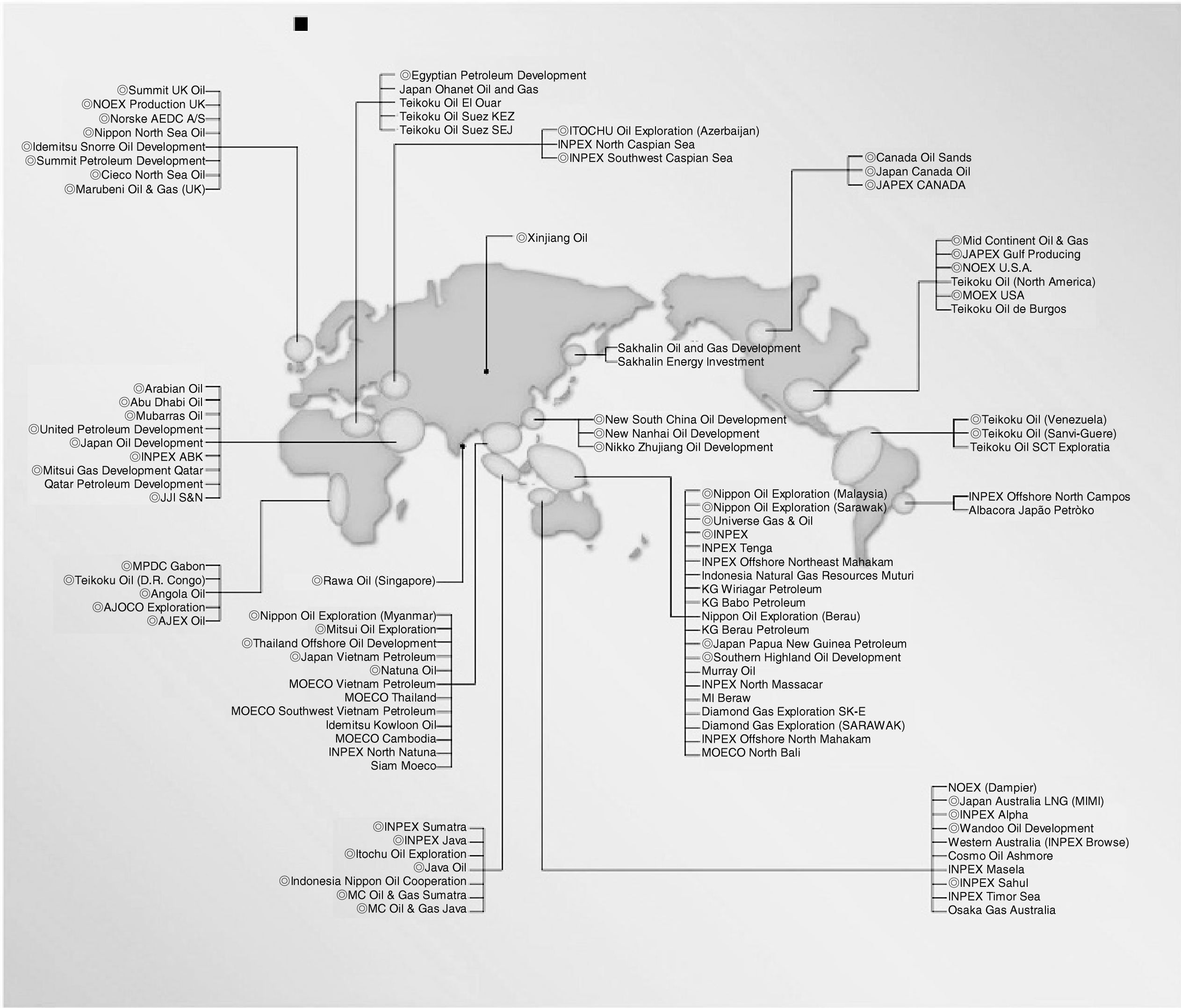
Based on the Energy Independence Plan, the USA's Department of Energy (DOE) is also working to develop upstream technologies. It has announced a policy of promoting developments at underwater depths greater than 1,500 m. At the same time, it has set aside a large amount of funding to support research that will form the basic infrastructure for development. Areas for technical development include recovery of natural gas from sandstones and coal seams, gas recovery from depths below 5,000 m, and boring with low environmental impact.

Meanwhile, China National Petroleum Corp. has invested as much as $8 billion in domestic and foreign development, taking its place among the above-mentioned majors. It is active in foreign development in the seas around Japan, in the ocean off Vietnam, and in countries such as Kazakhstan, Algeria, Nigeria, and Brazil. It is now making the transition from acquiring technologies to developing its own. In addition, two more companies, China Petroleum and Chemical Corp. and China National Offshore Oil Corp. are close behind. In 2004, the 20 major resource and environment topics of the Ministry of Science and Technology of China included deep sea oil and gas exploration and key technologies, theories of exploration of the geological conditions of gas, liquid, and coal resources and their technologies, and security technologies for ocean oil and gas resources development. This indicates the effort that the state is putting into this type of research.

Along with its rapid economic growth, demand for oil and natural gas in India has skyrocketed. Indian national and municipal companies such as Oil and Natural Gas Corp., Indian Oil Corp., and Reliance Industries Ltd. are engaged in natural gas development around their own country and have obtained development rights all over the world. They are also active in oilfield development. At this time, joint ventures are the mainstay of their business, but if the example of the steel industry is followed, it will not be long before they begin to master upstream technologies and to carry out their own technical development and applications. Intense competition with China can already be predicted.

The growth of national oil companies and oil development technology companies such as Thailand PTT Public Co., Singapore's Keppel Corp., Indonesia's Bumi Resources, and Malaysia's Petronas has also been remarkable. The scale of these companies is already comparable to that of Japan's Nippon Oil Corp. and INPEX Corp., and they are accelerating their overseas activities.

Figure 6 : Major overseas oil development projects by Japanese oil development companies



Note: Those marked with a circle are in production

Source: Reference [1] (p. 28)

Brazil is South America's second-largest oil-producing country, producing more than 500 million barrels of crude oil annually. The national company Petrobras monopolizes that country's upstream sector and is carrying out deep sea development at a depth of 1,400 m off Rio de Janeiro. Average production cost is expensive at \$10-\$14/barrel, but it is said to already have development and production systems using its own technology. In 2005, Brazil became 100 percent self-sufficient in oil. It is expected to begin exporting oil and is accelerating development of upstream and downstream technologies.

Based on guidance from the national government, Japan has also used its technical expertise and large market as tools to increase its presence in the upstream sector. As shown in Figure 6, Japan has aimed to acquire crude oil from all over the world. Japan is strong in technical areas such as deep underground production technology and the application of advanced technologies, but it has a limited record as a main operator in the development of major oilfields. Its ties with the governments of oil-producing countries are not strong, so it seems to lack power in the face of the vast size of the major oil companies and the energy of emerging nations. A lack of human resources needed to fully develop Japan's strength is also a concern. Under these circumstances, the Committee for the Strategic Examination of Oil Development Technology (chair: Kazuo Fujita, Professor Emeritus, the University of Tokyo) of the Information Center for Petroleum Exploration and Production was commissioned by JOGMEC

Table 7 : Development goals for oil and gas development technology

Theme	Individual topics
1. Improved exploration success rate	(a) Integration of oil data
	(b) Advanced geological modeling
	(c) Precision geological exploration technology
	(d) Precision geophysical exploration technology
	(e) Development of methods for direct hydrocarbon detection
2. Improved recovery rates for already-discovered oilfields and gas fields	(a) Precision reservoir assessment technology
	(b) Productivity-raising technology
	(c) Recovery-improvement technology
3. Cost reduction	(a) Reduced cost of three-dimensional self-submerging exploration
	(b) Reduced drilling costs
	(c) Reduced production costs
	(d) Development of new drilling and production systems
4. Effective use of gas	(a) Reduced LNG and natural gas costs
	(b) Technology to convert gas to liquid fuel
5. Development of unconventional oil resources	(a) Oil shale development technology
	(b) Ultraheavy crude oil development technology
	(c) Methane hydride exploration development technology
	(d) Technology for optimal development of water-soluble natural gas
6. Conservation of the global environment	(a) Technology to reduce environmental impacts
	(b) Technology to assess environmental impacts
	(c) Oil spill response technology

Source: Committee for the Strategic Examination of Oil Development Technology of the Information Center for Petroleum Exploration and Production (commissioned by JOGMEC)

to establish goals for oil and gas development, as shown in Table 7. Unfortunately, to date no policies that strongly promote the achievement of these goals have been set. The authors hope that debate on the proper form of science and technology in this sector, and the industries that apply and commercialize them, will advance.

6 Proposals

In Japan, the pessimistic argument that this country can never match the American and European majors in terms of industry and technology in the upstream sector of oil and natural gas has been pervasive. In the face of the remarkable growth of emerging nations and their shift to their own technologies, some believe there is nothing to do but wring one's hands in self-deprecation. However, Japan has a national policy of being a science and technology oriented nation. In order to thrive in the first half of the 21st century, Japan must secure oil and natural gas and maintain its technological capability. For both the upstream and downstream sectors of oil and natural gas resources, Japan should vigorously develop technologies and the supporting science that it can pass on to the rest of the world. At the same time, it is essential to strengthen the industries that can lead the way. The intelligence and fortitude of the Japanese people are other keys. In addition to including oil and natural gas in a comprehensive energy policy, the authors offer the following three proposals.

(1) Strengthen industrial expertise

Currently, there is a trend for companies in the oil refining and production fields to form businesses on a scale large enough to integrate upstream and downstream sectors. Japanese society must recognize the importance of doing this, and assemble the capital, technology, and bargaining power to have a global impact. The national government and the people of Japan, who will be the investors, should think seriously about building a powerful oil industry infrastructure that can pass on competitive upstream technology to the world by demonstrating and applying exploration, development, and production technologies.

(2) The importance of continued progress in upstream technologies

Against the background of Japan's broad range of advanced science and technology, it is necessary to further the development of upstream technologies as an integrated science. In particular, Japan should tackle technology for deep underground and deep sea development. The development of ultraheavy crude oil should also be made a priority.

Japan should aggressively promote technical development of robots, communications, control, sensing data processing, and precise and durable machinery and materials. This could develop into remote sensing technology for oil resources.

Furthermore, geophysics, geochemistry, surface chemistry, chemical engineering related to upstream technologies should be strengthened and their active contributions to practical technology should be promoted. These new sciences must be introduced into mineral exploration, development, and production. The recently completed deep sea drilling vessel Chikyu is one of the world's best exploration vessels. It is to be hoped that the Chikyu's research into the geological structures under the deep sea around Japan can be integrated into the complete description of underground resources with research on mantle drilling, which has never been carried out before. Such information is of the highest value for our nation not to be easily released.

(3) Fostering and retaining human resources

The training of people who can be active anywhere in the world where oil and natural gas resources exist is an urgent task for Japan. In corporate and university research institutions in Japan and abroad, Japanese people who possess scientific and technical knowledge, development expertise, and business-oriented minds and who are able to converse with a range of ethnic groups are needed.

Therefore, Japanese universities and corporations should collaborate in a program in which each year about 100 creative and vital college graduates with a broad education in science and engineering will be trained as human resources with international value. The goal should be the fostering of strong-minded people who want to face international challenges and who can not only develop advanced technologies from a background of accumulated experience and accomplishments, but can also deal with ethnic conflicts and competition to acquire international rights in development work. In so doing, Japan must recognize that it will need the assistance of universities, research institutes, and corporations in various countries that have already achieved international recognition. In this field, Japan needs to abandon its self-satisfied stance of offering its favors to developing nations and be prepared to learn from the rest of the world. Preferably, it will be Japanese companies that accept these human resources, but the goal should be the fostering of people with broad visions who will be internationally active. Preparing graduate schools and research institutes that enable Japan to be a place that produces the human resources needed by the world is a task for industry as well as educational institutions and the national government.

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Glossary

*1 Confirmed reserves

Reserves confirmed by seismic exploration, logging, etc.

*2 Recoverable reserves

Reserves that can be economically recovered at a specific point in time. Recoverable reserves increase through price rises and advances in extraction methods. Recoverable reserves increase even without the discovery of new oilfields when economic changes or price rises make subsidized extraction or drilling under difficult conditions economically viable.

*3 Reserve life index

Reserve life index = Recoverable reserves / Production (annual)

*4 Halliburton

Halliburton was established in 1919 in Texas, USA. It has 85,000 employees and is active in over 100 countries. It has two main divisions, ESG, which provides oil and natural gas upstream services, engineering, and construction, and KBP, which provides oil and natural gas upstream and downstream services, engineering, and construction. It also provides advanced measurement while drilling (MWD) and logging while drilling (LWD) technology/underground imaging, production, and disaster management. It is renowned for putting out 320 oilfield fires in Kuwait during the Gulf War in 1991. (Taken from the company's web site.)

*5 Schlumberger

Schlumberger was established in 1912 in Paris, France. It specializes in electric logging. In 1940, it relocated to Texas, USA. It has 58,000 employees and is active in 80 countries. First to adopt LWD, it is renowned for wireline measurement. Its corporate arsenal consists of drilling, geophysical exploration, and logging.

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