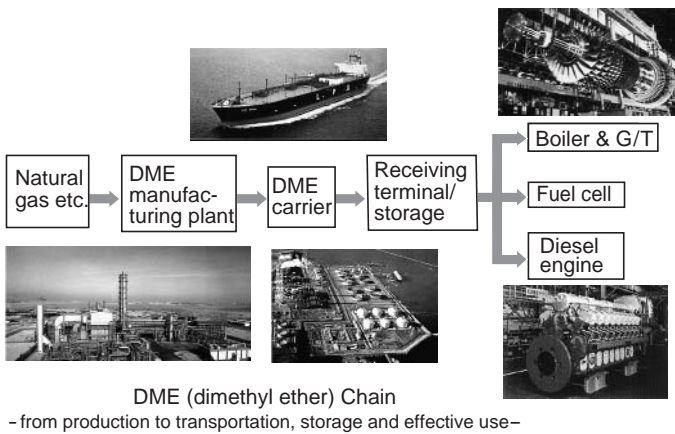


World Trend of Energy Resource and Prevention of Global Warming, and Related Development of Technologies in Mitsubishi Heavy Industries, Ltd.

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DME (dimethyl ether) Chain
- from production to transportation, storage and effective use -

1. Introduction

Mitsubishi Heavy Industries, Ltd. (MHI) considers the problems of energy and global warming as the most important global problems in the twenty-first century, and is making an effort to be a leader in these fields through business activities with a view to contributing to society. Described below are the research and development programs of MHI in these fields.

2. Awareness of energy and global environmental problems

2.1 Past awareness

As for energy problems, in collaboration with industrial, governmental and academic circles MHI has promoted development of alternative energy sources to substitute for petroleum and of energy-saving machines in compliance with the government policy of reducing the dependency on petroleum after the so-called "2nd oil crisis". Such development programs are to continue indefinitely.

As for global environmental problems, MHI has developed technologies to prevent emissions of SOx, NOx and soot in order to cope with atmospheric pollution, a by-product of the postwar high-growth period. MHI has also made efforts to deal with the problem of dioxin, and is determined to keep improving in accordance with the future trends in the regulation of contaminants.

2.2 Present awareness

The recent problems of primary energy and global warming and the new trends in energy deregulation entangle with one another to bring about changes in all fields of business related to energy and the environment and are at the very foundation of economic activity. The development and commercialization of technologies corresponding to such trends and changes are critical (Fig. 1).

3. Trends in primary energy (Fossil Fuel)

3.1 Estimation of demand for primary energy

The "Long-term Outlook of Global Demand and Sup-

ply of Primary Energy" (published in 2001) by Energy Information Administration of U.S. Department of Energy (DOE) puts the energy demand and supply for 1990 through 2020 in the levels given below.

- (1) The demand and supply for primary energy will increase by 55%.
- (2) The demand and supply of petroleum will cover the greater part of the primary energy sources, with the level expected to increase by 50% (particularly 100% in Asia) in 2020 and the dependency on the Middle East is to increase from 28% to 44%.

Note: In the case of Japan, the dependency on petroleum in terms of primary energy source (for fiscal year 1999) was 52%, with the dependency on the Middle East being 86%.

- (3) Among fossil fuels, natural gas, due to less emission of CO₂, will overtake coal in demand and supply and keep on expanding, with coal still remaining the third major energy source next only to petroleum and natural gas because of its stable supply (Fig. 2).

3.2 Natural gas with abundant supply

3.2.1 Primary energy resources

According to a survey made by the Institute of Applied Energy (IAE), the minable years obtained by dividing the confirmed minable reserves by the annual production is estimated to be 45 years for petroleum, 65 years for natural gas and 231 years for coal, with the confirmed minable reserves of petroleum being unevenly distributed to the Middle East, comprising two-thirds of the entire reserves

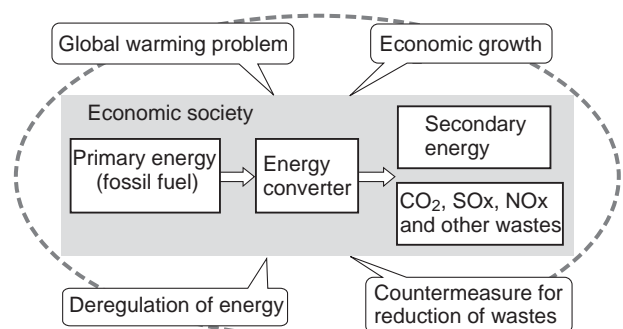


Fig. 1 Outline of energy and global environmental problems

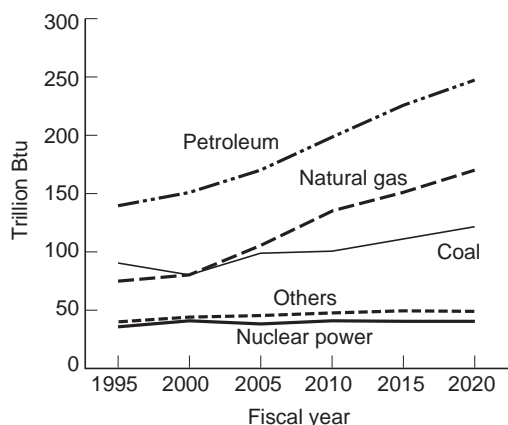


Fig. 2 Outlook of long-term global primary energy demand and supply⁽¹⁾

of the world. As for the natural gas reserves, 40% lie in the former Union of Soviet Socialist Republics (U.S.S.R.) and 30% in the Middle East (Table 1).

Further, according to a U.S. geological survey (2000), the ultimate minable reserves of petroleum that is technically and economically possible for human beings to dig out is 3 trillion barrels (1 barrel = approx. 160 liter), with nearly half of the resources to be consumed by 2030. The ultimate minable reserves of natural gas, on the other hand, is estimated in terms of petroleum to be 2 trillion and 600 billion barrels, with the quantity so far consumed being no more than a scanty dozen percent, thus an adequate quantity still remains.

3.2.2 Prediction of primary energy supply

Despite the minable years of petroleum estimated to be 45 years, the supply of petroleum will fall down below the demand level in and around 2015, according to the prediction made by International Energy Organ, OECD (Organization for Economic Corporation and Development) and major oil companies, pushing the oil price to a drastic high level. This time where the supply falls below the demand level is called a "Roll Over Point" (Fig. 3). With the various fossil fuels reaching the roll over point, new alternative energy sources competing price-wise with such fuels will appear, bringing further changes in the demand and supply of these fuels.

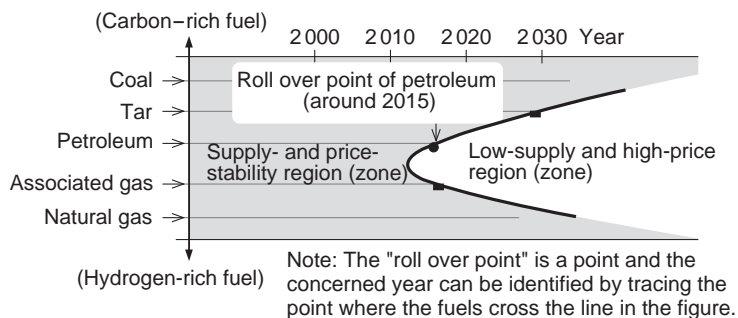


Fig. 3 Roll Over Points of various fossil fuels

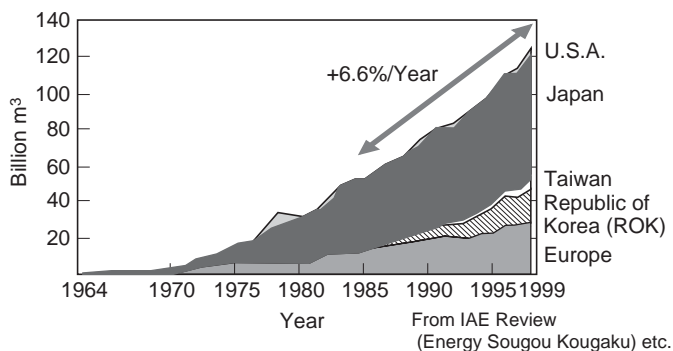


Fig. 4 Transition of LNG import (country-wise)⁽³⁾

3.2.3 Expansion of demand for natural gas

In addition to its abundant reserve power, natural gas is a clean fuel with high hydrogen content and free from sulfur, nitrogen and ash content, and it is expected that demand for natural gas will expand in the future as a countermeasure against air pollution and global warming.

Currently 80% of the world output of the natural gas is transported from producing areas to consuming countries through pipe lines and 20% as liquid natural gas (LNG). The world import of LNG has been expanding since 1985 at an average annual growth rate of 6.6%, amounting to 120 billion m³ as of 1999. A country surrounded by the sea, Japan has been importing a great deal of LNG, accounting for about two thirds of the world import of LNG (Fig. 4).

Turning natural gas into fluid like LNG to transport using a tanker enables supply from different regions of the world, ensuring high energy security and contribut-

Table 1 Status of energy resources and reserves⁽²⁾

		Petroleum	Natural gas	Coal
Confirmed minable reserves (R)		1 trillion and 7.5 billion barrels	141 trillion m ³	1 trillion and 31.6 billion ton
Region-wise status	North America	2.7%	4.9%	24.2%
	South and Central America	12.8%	5.2%	1.1%
	Western Europe	1.5%	3.8%	7.3%
	Middle East	65.5%	32.0%	-
	Asia and Australia	4.4%	7.0%	30.9%
	Africa	7.3%	6.9%	6.0%
	Former Soviet Union and Eastern Europe	5.9%	40.2%	30.6%
Annual output (P)		61.44 million barrels/day	2.18 trillion m ³	4.47 billion ton
Minaible years (R/P)		45 years	65 years	231 years

■ : Area with top reserves

From IAE Review (Energy Sougou Kougaku, October 1998)

ing to price reduction through the principle of competition. On the other hand, there are some hurdles (problems) given below that must be cleared for the use of natural gas in Japan.

- Reduction in utilization cost and stabilization of natural gas (reduction in LNG import cost and domestic distribution cost)
- Consolidation of domestic infrastructure such as pipe line, LNG satellite system, etc. (There are 21 LNG receiving terminals in Japan, while the consolidation of supply (distribution) infrastructure from these terminals is a future problem.)
- Promotion of new utility form (such as using natural gas as a liquid fuel substitute to gasoline, not as a primary energy source.)

3.3 Natural gas reformed liquid fuel

After the roll over point of petroleum (in and around 2015), the liquid fuels obtained from modified natural gas (such as synthetic kerosene/light oil, dimethyl ether [DME], methanol [MeOH], etc.) (**Table 2**) that still has sufficient reserves will make up for the shortage of petroleum supply and start expanding their use. The time will then come when natural gas will be in short supply. However, after the roll over point of natural gas (in and around 2030), liquid fuels with coal as the raw material are expected to spread.

In order to turn natural gas into liquid fuel, it is necessary to add water vapor (steam) and oxygen to the natural gas to make a mixed gas mainly of hydrogen and carbon monoxide before synthesizing the mixed gas into liquid fuel with properties almost equivalent to kerosene/light oil by using catalyzer, etc. The liquid fuel thus obtained has the

sulfur, nitrogen, ash content, etc. eliminated during the process of production, making it a clean fuel.

There are some restrictions such as the need of a large-scale gas field with a huge quantity of natural gas containing less CO₂ for LNG production, but since such restrictions are fewer in the production of modified liquid fuel, it is possible to make use of the low-priced natural gas from medium and small size oil fields not suitable for LNG production.

4. Trend in countermeasures against global warming

4.1 Target for controlling emission of greenhouse gasses

The supply and demand of primary energy both in Japan and abroad will undergo a drastic change depending on the trend of the Framework Convention on Climate Change aimed at the prevention of global warming.

Bills on international law related to the implementation of the Kyoto protocol were adopted (and agreement was reached on the working rules) in the Seventh Conference of the Parties to the U.N. Framework Convention on Climate Change (COP7) held in Marrakech, Morocco on October 29, 2001 through November 9, 2001.

The adoption almost led to the effectuation of the International Framework Convention based on the Kyoto protocol. As a country that ratified the agreement, Japan bears an obligation to reduce the emission of greenhouse gas between 2008 and 2012 annually by an average of 6% against the level of emission in 1990. Japan aims at keeping the CO₂ emission level produced by the primary and secondary energy sources to the level of 1990 (**Table 3**). However, the CO₂ emission level produced

Table 2 Outline and features of natural gas reformed liquid fuels

Example of natural gas reformed liquid fuel	Merit	Demerit	Handling	Boiling point °C
Synthetic kerosene/light oil (GTL)	Needs less modification of machines currently in use	Likely to be interlocked with petroleum price	Treated in the same way as kerosene/light oil	70 to 180 Approximately
Dimethyl ether (DME)	Excellent ignition, inflammability and environmental features	Needs modification of machines in use, low lubricity	Pressurized liquefaction for transportation and storage	-24.8
Methanol (MeOH)	Liquefaction possible at room temperature and normal pressure	Toxic and low calorie	Treated in the same way as the existing kerosene/light oil	64.5
LNG	Established for power generation and use as city gas	Needs cryogenic machines and difficult for inland transportation	Liquefied at extremely low temperature for transportation and storage	-161.5

Note: LNG is returned to gas whereas natural gas reformed liquid fuel is used in the form of liquid.

Table 3 Details of "6% reduction" of greenhouse gasses in Japan⁽⁴⁾

Measure (Policy)	Petroleum	Effect
Restraint on anathermal gas emission	Elimination of CO ₂ emission from energy source	±0.0%
	Elimination of CO ₂ emission through development of innovated technology	-2.0%
	Elimination of methane nitrogen monoxide	-0.5%
	Restraint on alternative CFC emission	+2.0%
Absorption by forest	CO ₂ absorption through growth and control of forest	-3.9%
Cutdown realized overseas	Utilization of Kyoto mechanism such as trade of emission rate, etc	-1.6%
Total		-6.0%

(From "Guideline for Measures to Prevent Global Warming (March 2002)")

by the primary and secondary energy sources in 1999 has already shown an increase of 8.9% since 1990. It is, therefore, necessary to cut down on this increase rate while dealing with the increase in demand of energy due to economic growth in the future.

The Agency of Natural Resources and Energy has therefore drafted an estimate of primary energy supply for 2010 and announced the figure as the policy target (objective) aiming at the $\pm 0.0\%$ emission reduction (Table 4). The key points of the estimate draft are as follows.

- Drastic increase of nuclear power, natural gas, renewable energies (such as solar power generation, wind power generation, geothermal power generation, etc.) and new energy, effective for reducing CO₂
- Reduction in the use of petroleum in order to decrease the petroleum dependency on the Middle East
- Continuous utilization of coal while ensuring high stability in supply
- As a concrete action policy to reduce the greenhouse gas by 6%, the government of Japan decided a new "Guideline for Measures to Prevent Global Warming" on March 19, 2002.

4.2 Technologies and products required for reduction of CO₂ emission

In order to put the CO₂ emission from primary and secondary energy sources back to the level of 1990 and

to correspond to the increase of energy because of the future economic growth, new markets for CO₂ reducing technologies and products will be created (Fig. 5).

The area equivalent to the CO₂ reducing market in Fig. 5 is anticipated as the new market, with the main countermeasure technologies highly effective for CO₂ reduction in the new market being given below.

- Production, introduction and expanded utilization of fuels with less CO₂ emission (such as utilization of nuclear power, natural gas, natural gas reformed fuel and renewable energy)
- Reduction of energy consumption and higher efficiency utilization [such as high-efficiency generation, cogeneration (distributed power generation), resource circulation, etc.]
- Recovery, sequestration, utilization and trading of CO₂

4.3 Measures taken by Japanese government for reduction of CO₂ emission

In order to comply with the increasing demand for energy in addition to the need for reducing CO₂ emission while maintaining economic growth, the Japanese government is going to promote intensively the following measures (policies) in the future.

- Intensification and expansion of "Top Runner" machinery and technologies with low energy consumption

Note: 1998 revision of the Energy Conservation Law (in Japan) led to the introduction of "Top Runner system" in

Table 4 Transition and outlook of CO₂ emission from primary energies and energy sources⁽⁵⁾

Unit: Converted into crude oil; 1 million kL

Item	Fiscal year		1990		1999		2010(Target)	
	Real number	%	Real number	%	Real number	%		
Primary energy supply	526		593		Approx. 602			
Energy-wise division	Real number	%	Real number	%	Real number	%		
Petroleum	307	58.3	308	52.0	271	45		
Coal	87	16.6	103	17.4	114	19		
Natural gas	53	10.1	75	12.7	83	14		
Nuclear power	49	9.4	77	13.0	93	15		
Hydraulic power	22	4.2	21	3.6	20	3		
Geothermal power	1	0.2	1	0.2	1	0.2		
New energy, etc.	7	1.3	7	1.1	20	3		

CO₂ emission from energy source (carbon weight; 1 million ton)

(From) "Long-Term Outlook of Energy Demand and Supply" by Sougo Shigen Energy Survey Committee (July 2001)

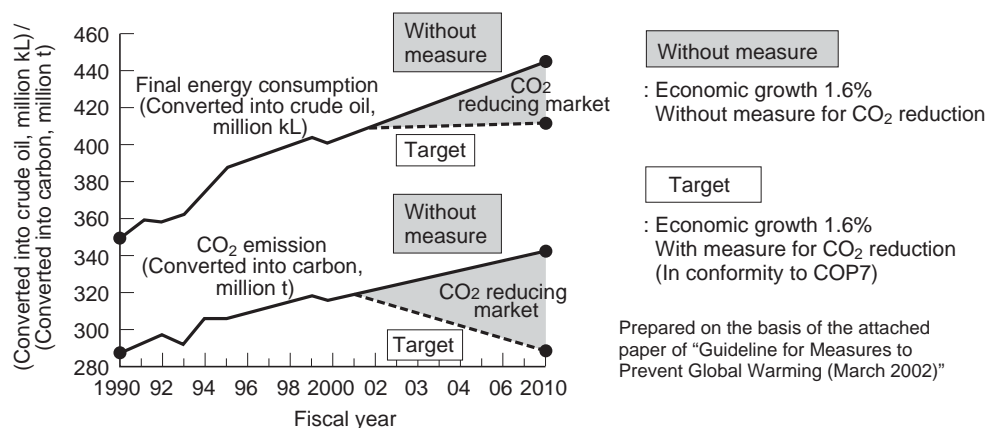


Fig. 5 Record and outlook of final energy consumption and CO₂ emission in Japan⁽⁶⁾

defining energy saving standards for home/office appliances and fuel economy standards for automobiles.

- Positive support and promotion for the extension of nuclear power generation
- Measures for new and expanded utilization of new energy and renewable energy (such as setting up the framework for the introduction, publication and trading of the utility bonds after the introduction, etc.)
- Supportive measure for fuel conversion (subsidy, regulation and taxation, etc.)
- Introduction of CO₂ emission tax and utilization of the tax revenue for reducing CO₂ emission
- Promotion of CO₂ trading through utilization of the Kyoto mechanism

5. Energy deregulation

Various regulations related to the energy business have so far contributed greatly to ensuring security in the supply and demand of energy and developing business in Japan.

However, under pressure from the recent demand for the reduction in energy prices (cost) and for the globalization of market economy and finance, the Japanese government is promoting deregulation of the energy business, bringing about mutual advance and competition in these business fields, such as the Electric Power Company starting the sales of gas and the Gas Company entering into the business of selling electric power (Table 5).

Further, the spread of distributed power generation like cogeneration has motivated the Electric Power or Gas Company to reduce the prices and has triggered the reduction of prices of various energies. Further deregulation of electric power is scheduled for 2003, with the electric power companies making efforts to comply with the forthcoming situation and eventually to reduce the cost.

Further, the energy-related business firms have begun to establish new companies as joint ventures with different business companies in accordance with the business form. On the other hand, the energy consum-

ers (users) have also started to grope for development of new business on the basis of self-owned resources (such as land, fund, energy equipment, etc.)

6. Status of the relevant technologies in MHI

As mentioned above, the primary energy, the problem of global warming and the trends in energy deregulation are inflicting mutual influence on each other and have begun to show great changes. In order to cope with these changes MHI has taken a leading role and promoted various development programs. Some examples of such programs is listed in Table 6. Some of the development programs listed in the Table are described below.

6.1 Example of correspondence to the change in primary energy

The practical example of MHI's undertaking to correspond to the change in primary energy is the general project of DME (DME Chain) from production to transportation, storage and effective use. The DME Chain program currently underway through government support includes construction of large-size DME manufacturing (production) plant abroad and transportation of the produced DME to Japan to use for boilers, gas turbines and diesel engines as the low-pollution fuel.

6.2 Example of correspondence to the global warming

The recovery and underground sequestration of CO₂ is a program involving recovery of the CO₂ discharged from coal-burning power plants, etc. at low cost before feeding to the aquifer sealed deep under the ground with rock layer for permanent sequestration. Further, the CO₂ emission credit obtained through the sequestration is about to be traded in the international market as a new business.

MHI is also promoting research and development together with the Japanese government for the production of hydrogen using nuclear heat, and for transportation, storage and utilization of hydrogen as an effective utilization of nuclear power which is an indispensable countermeasure against global warming, to comply with the "hydrogen society" expected to come in the future.

Table 5 Outline of deregulation of energy in Japan

Industry	Deregulation	Expected effect
Electric Power	<ul style="list-style-type: none"> • Deregulation of wholesale supply business • Establishment of specific electric power business • Deregulation of specific supply 	<ul style="list-style-type: none"> • Price down of electric power due to entry of general enterprisers into the wholesale supply business • Promotion of introduction of cogeneration
	<ul style="list-style-type: none"> • Deregulation of retail business • Abolition of business control 	<ul style="list-style-type: none"> • Further price down due to entry of large-scale power company into retail business • Vitalization of electric power consignment
City gas	<ul style="list-style-type: none"> • Deregulation of large-scale gas rate • Deregulation of entry into large-scale gas business 	<ul style="list-style-type: none"> • Expansion of new entry into large-scale gas consumer • Vitalization of gas consignment
	<ul style="list-style-type: none"> • Expansion of large-scale deregulation limits • Notification and publication of consignment and agreement 	
LPG	<ul style="list-style-type: none"> • LPG sales business shifted from license system to registration system 	<ul style="list-style-type: none"> • Expansion of new entry into LPG sales business
Oil	<ul style="list-style-type: none"> • Deregulation of import of products related to gasoline, kerosene and light oil, etc. 	<ul style="list-style-type: none"> • Formation of domestic price levels and price systems due to competition between imported and domestic products

Table 6 Examples of intensification and expansion of energy and environment business

Field	Expanding needs	Examples of undertakings by MHI
Correspondence to changes in primary energy	· Expansion of the use of natural gas and LNG	Expansion, enhanced efficiency with emission of cleaner gas of machines such as gas heat pump, gas engine, gas turbine, etc.
	· Production and utilization of clean liquid fuel · GTL (synthetic kerosene/light oil) · DME (dimethyl ether)	Promotion of survey on trends in technical developments, correspondence to the newly established plant and development of technologies and products related to manufacture, introduction and use
	· Use of reproducible energy (elimination of petroleum consumption)	Intensification of technologies for wind power and geothermal power generation and expansion of their sales underway; promotion of the use of biomass gas and commercialization of fuel synthetic system; mass production and expanded sales of solar batteries underway
Correspondence to global warming	· Recovery and sequestration of discharged CO ₂	Reparations underway for verification test of recovery, underground and ocean sequestration of CO ₂ discharged from power plants, etc.
	· Utilization of CO ₂ emission credit trading	Trial experiments under implementation for elimination of CO ₂ emission and for trading of obtained emission credit
	· Utilization of nuclear power	Research and development on fuel cycles of innovated future furnaces including multi-purpose furnace (manufacture of hydrogen using nuclear heat), and fast-breeder reactor (FBR) underway
	· Expansion of forestation, etc. for CO ₂ absorption	Joint projects in collaboration with industrial, official and academic circles underway for improving desert environment and securing water source (in collaboration with Ministry of Education, Culture, Sports, Science and Technology, universities, Saudi Arabia, etc.)
Correspondence to deregulation	· Expansion of distributed power generation	Intensification of development on distributed generation, and intensification and expansion of sales of cogeneration underway
	· Expansion of retail business for electric power	Entry into power wholesale business for power retail enterprisers
	· Energy solution business	Comprehensive business on MHI energy and environment related machines and systems underway for diversified needs and customers

6.3 Example of correspondence to the deregulation

MHI is making efforts to supply electric power using its own power generating facilities (engine, wind power generation, etc.). As the electric power companies are establishing new energy businesses jointly with the fuel companies, etc. and promptly advancing to the energy solution business, so is MHI promoting joint development with other companies by supplying systems through combination of distributed power generating equipment such as engines, etc. and air-conditioning & refrigeration equipment.

7. Conclusion

Various research and development programs have so far been made in consideration of the energy problems as an important topic for the national security of Japan. However, with the current deregulation of energy in addition to the various restrictions imposed as the countermeasures against global warming, a number of countermeasures are getting entangled. It is therefore necessary to discern how these countermeasures will be put into practical programs in the future before taking

any steps. MHI takes it as a mission to make efforts in cultivating technical power to have a clear view of these transitions and, accordingly, to comply comprehensively with them.

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