JAERI-M
86-165

THE STUDY ON THE ROLE OF VERY HIGH TEMPERATURE REACTOR AND NUCLEAR PROCESS HEAT UTILIZATION IN FUTURE ENERGY SYSTEMS
— IMPACT ANALYSIS OF FUTURE ENERGY TECHNOLOGIES ON LONG-TERM ENERGY SUPPLY-DEMAND, NATIONAL ECONOMY, AND ENVIRONMENT —

November 1 9 8 6

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編集兼発行　日本原子力研究所
印　　刷　㈱高野高速印刷

The Study on the Role of Very High Temperature Reactor and Nuclear Process Heat Utilization in Future Energy Systems

- Impact Analysis of Future Energy Technologies on Long-Term Energy Supply-Demand, National Economy, and Environment -

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(Received October 14 , 1986)

This report describes the analytical results being made in the study on the role of Very High Temperature Reactor and nuclear process heat utilization in future energy system, which is aimed at zero emission. In the former part of the report, the modeling of the reference energy system, main characteristics of energy technologies, and scenario indicators as well as system behavioral objectives for optimization are explained. In the latter part, analytical results such as the time-period variation of overall energy utilization efficiency, energy supply/demand structure in long-terms, energy contribution and economic competition of new energy technologies, environmental effluents released through verious energy activities, impacts to and from national economy, and some sensitivity analyses, are reviewed.

Keywords: VHTR Reactor, Nuclear Process Heat, Heat Utilization, Future Energy System, System Analysis

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This report, being prepared for distribution to participants at the Integrated Energy System Consortium Meeting held in Sweden on September 1-4, 1986, is the third progress report of the cooperative research program between Japan Atomic Energy Research Institute and the Massachusetts Institute of Technology.

将来のエネルギーシステムにおける高温ガス炉と核熱利用の役割に関する研究
（将来エネルギー技術の長期エネルギー需給，国民経済，環境への影響分析）

日本原子力研究所動力炉開発・安全性研究管理部
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（1986年10月14日受理）

本報告書は，環境無排出を目ざす将来のエネルギーシステムにおいて高温ガス炉と高温核熱の役割の研究でなされた解析結果を詳述している。報告書の前半では，基準エネルギーシステムのモデル化，エネルギー技術の特性，シナリオ記述指標，及びシステム最適化の為の行動目的が説明されている。後半では，エネルギー利用効率の時間変化，長期間にわたるエネルギーの需要・供給構造，新エネルギー技術によるエネルギー寄与及び経済性競合，種々のエネルギー活動から生じる環境排出量，国民経済へ，及びからの影響，若干の感度解析，の分析結果がレビューされている。

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1. Introduction

The study on "The Role of Very High Temperature Reactor and Nuclear Process Heat Utilization" in future energy systems, which is aimed at zero emission, was initiated in October 1984, responding to the proposal from the Massachusetts Institute of Technology, who began "The Integrated Energy System Study" as an international cooperative research work.

Since late 1960s when the research work on nuclear steel-making began, some of industrial groups and national research institutes, such as the Japan Atomic Energy Research Institute (JAERI), have been recognizing nuclear heat utilization as one of the important research subjects in our long-term energy development, and JAERI has been undertaking the R&D role of a Very High Temperature Reactor (VHTR). Reflecting this, the MIT's proposal was soon accepted within us, and it is stimulating us now.

We have consciousnesses for some problems in the coming nuclear energy development:

(1) The thermal efficiency of present nuclear power plants, most of which are LWRs, is about 33%, which indicates us the fact that roughly two-third of fission energy is thrown away. Is it a right way to continue this situation in our expanding nuclear power programme in future years?

(2) Nuclear energy can be utilized not only for electric power generation but also as process heat sources. Standing on this fact we should explore the fields of its application. One such application is the utilization for a co-generation system, through which the improvement of plant thermal efficiency could be attained.

(3) Unit capacity of present nuclear power plant is still going to a larger size in order to seek a scale merit. However, the coming plants, whether they are installed as replaced ones or for additional capacities, are not necessarily of a large capacity. The reason why such observation can be made is that the growth rate of electric power demand will be gradually saturating with time on one hand even though it retains a high figure at present, and in place of electricity the demand for direct heat utilization will be emerging because the rational heat utilization will gain its advantage on the other hand, and for both purposes a small and medium capacity of power plant can gain more system adaptability than the larger one.

(4) As increasing number of nuclear power plant and as raising the demand of its construction near to demand area, those nuclear power plants as having a higher degree of inherently safe characterisitics will be asked.

(5) In responding the the needs presented by above (3) and

(4), it may deserve to investigate the possibility of system modularization of plant. When this can be realized, it brings us the following advantages, i.e. the application of quality control becomes much easier through increasing factory production share of equipments and appliances, and proceeding in this way the plant system can gain high degree of quality assurance, and such modularized plant may fit flexibly in with any demand level and protects excessive investment.

When we stand on those consciousnesses, how does the utilization of high temperature nuclear heat take advantages in our future energy system? To study this, we set up the following five tasks: (i) the scenario generation for socio-economic development in future years, (ii)modeling a reference energy system and a long-term energy demand-supply projection, (iii)impact analysis of the future energy system on national economy and environment, (iv)evaluation of technical and economical competition of the associated energy technologies,(v)finding the optimal path for deploying high-temperature nuclear heat utilization in the future energy system.

At the IES meeting held in Washington, D.C. in October 1984, we reported our whole work plan(1), including our research object, studying procedure, and the working schedule. At the Vienna Meeting (in April 1985), we explained our analytical method, a reference energy system and energy technologies associated with it and the data items for their characterizations, and a preliminary result of scenario runs(2). At the Taipei meeting (in January 1986), we reviewed the energy-economy-environment related activities(3) of Japan, which cover over the time periods from the year our national economy recovered to the pre-war level to the year it entered into the reduced economy. Also, we reported the results of our scenario frame presenting the possible region of the socio-economy development till the year 2030, which were analysed by the long-term macro-econometric model LTMEMO, and reported the possible ranges of long-term energy supply and demand, which were analyzed by the energy SD model ENERGYSD(4). Moreover, we reported the results of technology assessment(5) on the UT-3 technology which is used for hydrogen production by high-temperature nuclear heat.

This time, we will present our study activities being made since the last meeting. These are the structural analyses on long-term energy supply-demand and its impact analysis both on national economy and on environment. The analyses are made with the MARKAL-I/O(Translog) programme, which is one of the computer programmes constituting the Integrated Energy-Economy-Environment Model System. In the accompanying papers, we will explain the result of the technology assessment on steam reformer(6), which is operated by high-temperature helium, and also we will report the surveyed results(7) of the Japanese research and development activities on high-efficiency gas turbine technologies.

2. Modeling of Energy System and Technologies

2.1 Reference Energy System

We have set up a reference energy system to study analytically the role of the Very High Temperature Reactor and its heat utilization system in the long-term evolution of our energy system. The reference energy system involves all major energy sources, transformation technologies, demand devices, and energy carriers existing now or possibly in future. Its basic structure is shown in Fig.2-1. The figure represents all possible flows of energy carriers and associated energy technologies between primary supply and final consumption.

The reference energy system can be divided into energy supply, transformation, and utilization systems. The energy supply system consists of import and domestic production of primary energy. The imported energy includes, in addition to conventional fossil energy carriers, the liquids from coal. While, as for the domestic production, geothermal, solar, and other renewable energy sources are considered in addition to conventional fossil, nuclear, and hydropower.

The transformation system consists of technologies to generate electricity, to produce heat of low, medium, and high temperature, and to produce energy carriers other than electricity and heat. The electricity is now generated by fossil-fired plants, hydroelectric plants, and LWR plants. The new technologies in this category are the advanced coal electric, the advanced nuclear electric (The ATR, the HTGR, the FBR, the helium gas-turbine), the renewable electric such as geothermal, solar photovoltaic, the combined cycle using CO gas-turbine, the fuel cells, and others. The technology to produce low temperature heat involves gas and geothermal heating, cogeneration by coal and nuclear, and cogeneration using high efficiency gas-turbines.

The VHTR and its heat utilization system are integrated horizontally to the conversion system of coal and natural gas to produce hydrogen, carbon monoxide, reducing gas in addition to medium and high temperature process heat. The technologies involved are methane steam reforming, thermochemical hydrogen production, high temperature electrolysis, thermochemical pipeline, and CO2-utilization processes such as thermochemical splitting, methane reforming, methanol synthesis.

Coal gasification and liquefaction will have special importance among other technologies in the transformation system. The coal gasification is managed to produce various synthetic fuels by introducing hydro-gasification and steam gasification processes in combination with synthesis and separation processes. While the liquefaction system is based on the overseas production of heavy liquids and light liquids, surface transportation, and domestic refinery. The domestic production of light liquids by the indirect liquefaction process is also considered.

The most secondary energy carriers produced above pass through transmission and/or delivery technologies before they are utilized in the utilization system. The energy loss and cost associated with transmission and/or delivery of energy carriers are considered here including of electricity and low temperature heat.

The energy utilization system consists of, as shown in Fig.2-1, 35 demand sectors and 164 demand devices to offer energy services to these demand sectors. Each demand sector forms an independent energy market, where several demand devices using different energy carriers compete. The useful energy demand is specified for each demand sector in terms of annual quantity and its seasonal and diurnal distribution so as to ensure the enough capacity of technologies in both transformation and utilization systems.

The demand devices in industry are classified into motors, furnaces, and boilers. The differences in costs and efficiencies are considered among devices of a same category according to its fuels. The residential and commercial sector has several demand devices at each demand categories of space heating, water heating, air conditioning, and one at lighting and appliances. In the transportation sector, several technologies of different fuels are considered at each transportation mode of railway, automobile, truck, bus, air, and ship.

2.2 Characteristics of Main Technologies

The characteristic data on each energy technology involved in the reference energy system have been established in advance to the structural analysis of energy systems. The main characteristic data on representative technologies are listed in Table 2-1. The input and output energy carriers of these technologies are indicated in Fig.2-1.

The characteristic data listed consist of technical performance data, cost data, and emission data. Among technical performance data, the availability indicates the upper limit of annual availability. The values can be given, however, at each of six time divisions in a year for electricity generation technologies. The efficiency is a ratio of total input to total output of energy based on gross heating values.

The all cost data are expressed in terms of 1980 US dollars. The operation and maintenance cost is divided into fixed and variable components which are charged proportionally to installed capacity and activity, respectively. Here the installed capacity and activity of non-electricity generation technologies are, as a general rule, defined based on the quantity of input energy. The environmental emission generally depends on degree of control. The values given in this table are those at 1980. The emission data for the analysis have been set to decrease steadily toward to the year 2020 reflecting the progress of control technologies.

The specific features of the technologies listed in Table 2-1 are briefed in the following. The electricity generation technologies E01, E13, and E82 are of conventional fossil-fired type. The low BTU gasification combined cycle technology is adopted for E06. E21 and E26 are the LWR and the FBR electric power plant, respectively. E31 is a conventional hydroelectric plant. Geothermal electric generation can be implemented by using hot water, hot dry rock, and also by employing a binary cycle. The characteristic data of E32 are those for plants using hot water. The solar photovoltaic electricity generation, E4B, is a decentralized source of electricity. The investment cost is assumed to decrease over the long-term based on progresses in fabrication technologies of photo cells. E81 is a conventional gas turbine, while E9A is a direct cycle helium gas turbine, an application technology of high temperature nuclear heat. E9C is a combined cycle power plant using a CO gas turbine of high efficiency.

As for non-electricity generation technologies, coal gasification, coal liquefaction, high temperature heat utilization technologies are mainly listed in Table 2-1. S01 is a coal hydro-gasification technology to produce SNG by using hydrogen and oxygen provided from outside. The unreacted char from hydro-gasification reactors is ordinary re-gasified in the same plant site. However the gasification of char is treated here as an independent technology S02. S03, a coal steam gasification technology using oxygen provided from outside, produces medium calory synthetic gas with a H2/CO ratio 0.83. S0E and S0F are coal hydro-liquefaction technologies. The former produces light liquids, while the latter heavy liquids. SOF is an indirect liquefaction technology employing a Fischer-Tropsch process.

The technologies S91-S9M are those for high temperature heat utilization and for synthetic fuel production. S91 is a steam reforming technology of methane. The syngas produced here is separated by a cryogenic separation process S9C to derive CO and hydrogen. S93 and S94 are methane reforming and synthesis technologies, respectively. The coupling of these technologies forms a so-called thermochemical pipeline to transport heat in the long distance in terms of chemical binding energy. S95 produces CO and oxygen from CO2 by using high temperature nuclear heat. Here the thermochemical process using CeO2-Na3PO4 is assumed for CO2 decomposition, though it is in a laboratory stage. S97 is a thermochemical hydrogen production employing the UT-3 process, details of which were introduced at the Taipei meeting of the IES consortium. S98 is a technology to produce reducing gas of hydrogen rich from coal. Here high temperature nuclear heat is utilized to produce hydrogen and steam for gasification. S9D and S9E are a high temperature electrolysis and an air separation, respectively. The both technologies utilize nuclear heat either directly or indirectly.

The part of CO and hydrogen produced by coal gasification and/or high temperature heat utilization technologies is converted into liquid fuels in the downstream of the energy system. S9K produces methanol from CO and hydrogen. Methanol can be also produced from CO2 and hydrogen(S9L). The methanol produce here can be either consumed in the final demand sector or utilized to synthesize gasoline by a technology S9M employing a MTG process.

3. Boundary Conditions and Behavioral Objects

The main subject of the study is to clarify the long-term role of the Japanese IES composed of VHTR and nuclear heat utilization technologies through analyzing competitivity, substitutability, and complementability of technologies in total energy systems with MARKAL-I/O(Translog) model. For this purposes, boundary conditions of MARKAL calculations have been prepared exogenously as energy-economy scenarios generated by dynamic analysis. We have also chosen an objective function which represents the behavioral principles of the future energy system in Japan, and formed calculation cases of sensitivity analysis.

3.1 Economic Evolution and Energy Demand Scenarios

The long-term economic evolution of Japan had been prospected and analyzed by Long Term Macro Econometric Model(LTMEMO)(8). The projection of energy supply/demand situations in Japan until 2030 were forecasted by Energy SD Model(ENERGYSD) through such parameters as GNP elasticities, energy price elasticities, and effects of energy supply/demand ratio, etc.(9). These results of analysis and energy-economy scenarios were reported at former IES meeting in Taipei(4).

The structural analysis by MARKAL-I/O are done within these energy-economy scenarios as boundary conditions. As one of these exogenous input data for MARKAL, useful energy demand until the year 2020 from 1980 are derived based on the projection of final energy demand obtained from the results of the macro energy supply/demand analysis by ENERGYSD, utilizing the assumption of average efficiency of demand devices.

Elasticities of GNE against useful energy demand from the year 1980 until 2020 are 0.92 in the high case and 0.94 in the low case. Among main energy-economy indices of these scenarios between the year 1980 and 2020, average growth rates of GNE, projection values of final energy demand and useful energy demand are shown in the Table 3-1.

3.2 Price Scenarios of Primary Energies and Supply Constrains

Japan is owing a large part of the primary energy to the import from the abroad, therefore, the projection of import prices of primary energies are one of important assumptions for strategic analysis of total energy systems. In the analysis of the ENERGYSD model, prices of primary energies are once set as initial values, however, these are obtained as endogenous values after adjusting the realized GNP and the competition of energy carriers in the model.

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The difference between exogenous price data and endogenous price results in the analysis of the scenario generation has not become so large that these data are used for the MARKAL input data. As far as the value between the year 1985 and 2000 are concerned, they are modified by the recent tendency in the price of crude oil. These price scenarios of main primary energy are shown in Fig.3-1. Uranium price is 72.09 \$/kgU3O8 at the year 1985, and is prospected to take constant value until the year 1990, and grows 1.0% per year after the 1990.

It is not possible for Japan to ask for primary energy without any restriction in future, because Japan depends its energy resources on the import. While, setting values of upper or lower constrains have strong effects to results of analysis, because MARKAL is a LP model. Therefore, we should set suitable constrains for the amount of main primary energy supply through examining the amount of world energy resources and their allocation, historical records of the import, energy policies of the government, and macro energy-economy scenario regions described in the former section. For example, imports of crude oil are bounded under 10 EJ/year at the year 2020, while, steam coal and coking coal are bounded under 4.2 EJ/year and 3.6 EJ/year respectively. The amount of imports of heavy distilled oil is bounded under 0.6 EJ/year.

3.3 Behavioral Objects of the Energy Systems

At the beginning of this study project, we had established behavioral principles of the energy systems and reported them at the IES meeting held at IIASA in April 1985. For all analysis relative to study subjects written in the chapter 1, we had chosen following five principles: 1) effective utilization of energy, 2) aiming at zero emission, 3) conveniency, 4) stable supply, and 5) economy.

While, the structural analyses on the long-term role of Japanese IES are carried out through MARKAL-I/O(Translog) calculations of capacities and activities of technologies, mutual substitutions of energy carriers, and costs and marginal prices of energy carriers and technology activities, cost-security tradeoff, and sensitivity analysis under the setting of various objective functions. Therefore, in this structural analysis, we aimed to study along with the behavioral principles from 1), 2) and 5) points of view, and calculate from following view points: i) to minimize the cumulated discount cost of total energy system, ii) to minimize cumulated amount of such fossil fuel imports as crude oil and LNG, and iii) to evaluate the amount of environmental effluents under the case i) and ii).

As the objective function, MARKAL has the matrix optimizer composed from price and security functions. In a simple case, it is possible for user to optimize the price function (case name is P), and also possible to optimize the security function (case name is S). In a more complex case, it is possible for user to minimize the security function subject to the price function being constrained to the value of the price function in the P case (PS case) or to minimize the price function subject to the security function obtained from the S case (SP case). Moreover, it is possible to generate the function of the intermediate point on the curve between case PS and SP (QP case)(10).

In this report, we analyze the results of 15 calculation cases. Contents of these calculation are 8 cases composed from P and QP case in high and low demand scenario (HD and LD case) multiplied by high and low price scenario (HP and LP case), plus 2 cases in which amounts of environmental effluents are calculated in LD/HP-P case and in LD/HP-QP case.

Remaining 5 cases are composed of 4 ultra-high demand scenario cases (UHD case) multiplied by high and low price scenario (HP and LP case) in which demand scenarios are set in ultra-high values beyond the scenario region, and of 1 case where supply constrains in steam-coal are taken off from the UHD/HP-QP case.

4. Review of Analytical Results

4.1 Overall Energy Utilization Efficiency

Improvement of energy utilization efficiency is one of the most important subjects we are confronted with in our future energy system. The attainment of it contributes not only to primary energy resource saving but to lower environmental impacts.

There are two indicators to measure the degree of it, i.e. the first one being the ratio $\eta 1$ of an aggregated useful energy demand to an aggregated primary energy supply, and the second one the ratio $\eta 2$ of an aggregated final energy demand to the aggregated primary energy supply. While the overall efficiency of the total energy system can be measured by $\eta 1$, $\eta 2$ indicates the efficiency of energy conversion sector. The ratio $\eta 1/\eta 2$ shows the efficiency of end use sector.

The efficiency $\eta 2$ is gradually decreasing from 0.73 in 1980 to the range 0.69-0.59 in 2020 as shown in Fig.4.1-1. Such decrease is due to the growth of electric power demand along which the electric power generating efficiency is not always improving on one hand, and due to fuel switching mostly from crude oil to coal both in liquefied fuel production sector and in synthetic gas production sector, where their conversion efficiencies are decreasing when such fuel switching happens on the other hand.

The above results indicate us the necessity that in electric power generating sector not only the improvement of efficiency in electricity generation and of its transmission-distribution system but the rational use of ejected heat should be pursued, for instance, through introducing electricity-heat co-generation, and in the synthetic fuel production and its in the P case (PS case) or to minimize the price function subject to the security function obtained from the S case (SP case). Moreover, it is possible to generate the function of the intermediate point on the curve between case PS and SP (QP case)(10).

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The behavior of $\eta 1/\eta 2$ originates from various effects, i.e. structural change of production mix in industrial sectors, the changes in life style and transportation mode, the technology innovation of end-use devices and the improvement of their characteristics, for instance, improvement in fuel utilization efficiency, the changes of input-fuel mix, etc.. As shown in Fig.4.1-1, the end-use sector is improving its energy utilization efficiency through electrification, direct-heat utilization, improvement of end-use technologies.

4.2 Energy Supply/Demand Structure

The primary energy resources usable for us are broadly categorized in crude oil, coal, natural gas, nuclear fuel, and renewable energy such as solar, hydro, geothermal energy. Those energy resources have a variety of technical and economical aspects depending on their resource availabilities, usabalities, cost, impacts to environment, geopolitic advantages, etc..

For such country as Japan where the primary energy resources are scarce but their demands are high, the procurement of those becomes a really vital problem. Therefore, it is quite natural for her to follow on such guiding principle, when she will select the primary energy resources, as the best fuel mix policy characterized by low price, stable supply, and resource diversification. For the secondary energy selection concerned, low price, utilization conveniency, and cleanliness are claimed as a guiding principles.

Based on the above considerations, we will examine our scenario runs. Then we can find the following fact that the primary energy supply, as shown in Fig.4.2-1, will be gradually shifting to higher share of coal,nuclear,renewable energy sources owing to the increasing price of oil and natural gas. Especially in electric power generating sector, the demand of oil and gas will sharply decline. In place of those, both nuclear and coal are increasing, and especially for the former they will share more than 50% as shown in Fig.4.2-2 - 4.2-3 of total generating electricity in next century.

For the secondary energy configuration concerned, both electricity and low temperature heat, of which the latter comes mostly from solar heating, expand steadily their shares reflecting conveniency and cleanliness. One example of our scenario runs is shown in Fig.4.2-4. Even though oil and gas supply are declining sharply, the role of fluidized fuel as secondary energy carrier does not fall. The gap between supply and demand of it will be filled by the synthetic gas and/or liquids, which are produced by gasification and/or liquefaction technologies being an existing or a new one.

More high electrification will be taken place in the industrial sector than at the present level, as shown in Fig.4.2-5. This is due to the structural changes of this sector, i.e. the weight of production activity being shifted from primary material production to fabricated goods production such as machineries and fine chemicals, as well as service production. In residential and commercial sector, also, both electrification and direct heat utilization will be accelerated (Fig.4.2-6). The main source of the latter is solar energy. Gaseous fuel will keep the present level of demand, but liquid fuel share will be certainly declining. As for transportation sector concerned (Fig.4.2-7), more electrification will also be proceeding through penetrating electric car, and methanol and hydrogen can also be utilized in case of high fossil fuel price scenario (Fig.4.2-8).

Especially concerning on high temperature nuclear heat, the reference energy system installs the following technologies: (1) electric power generation by gas-turbine and/or steam-turbine technology, (2) reducing gas production by the CCL process and its utilization to iron-steel making, (3) hydrogen production by methane-steam reforming (4) medium temperature heat transport by chemical heat pipeline, (5) hydrogen production by thermo-chemical splitting process(the UT-3), (6) hydrogen production by high-temperature electrolysis, (7) CO2 reforming process by high temperature heat, and (8) high temperature gas cooled reactor(HTGR) as well as very high temperature gas-cooled reactor(VHTR). In most of scenario runs, we could recognize the introduction of HTGRs and VHTRs accompanying turbine technologies, steam reformer, and UT-3 process. Energy contribution by these technologies is emerging from around 2010 and in year 2020 it will take about 2.6% of total primary energy supply as shown in Fig.4.2-9.

4.3 Contribution of New Energy Technologies

In this section the results are discussed on implementation of energy technologies, especially of new technologies behind the structural changes of the energy system. The focus of the analysis is placed in the following three points, i.e. by which technologies future trend of electrification are supported, which technologies can contribute to promote the transition from scarce and expensive oil and natural gas to low grade carbon sources such as coal, and which utilization technologies will be preferred for high temperature nuclear heat in the light of diversification of primary energy sources and zero-emission to the environment. The results in the low demand and high price scenarios are briefed below.

The installed capacities of individual electricity generation technologies from 1980 to 2020 are shown in Fig.4.3-1 - 4.3-3. Nuclear energy takes a central role in future, and the LWR shares most of its capacity until the year 2020. Though the contribution is still small, the HTGR and the FBR have enough competitivity at this time period. Among technologies for other base-load and middle-load electricity generation, geothermal and advanced coal-fired electric make a considerable contribution. The both technologies have in near future sufficient economic performances in comparison with conventional fossil technologies. The natural gas CC is also an important technology as a next generation to the existing gas-fired electric.

As for the technologies for peak-load, the pumped storage continues to take a major role under the support of gas turbines and a battery storage. Renewable technologies, such as solar photovoltaic and wave, have possibility of having marketability after around 2000 depending on the future prices of fossil fuels. The cogeneration technologies using fossil fuels as well as the LWR cogeneration have enough possibility to compete with dedicated technologies to electricity and to low temperature heat. The cogeneration will become a promising technology, when necessary conditions in the demand side is arranged.

The key technologies in the transition from oil and natural gas to coal are coal liquefaction and gasification. Among coal liquefaction technologies, heavy liquids production at oversea plants is most promising. It is implemented from the year 2010 in the standard case, and from 1995 in the case giving a premium to the prices of oil and natural gas. The light liquids production and the domestic F-T liquefaction are introduced at later dates. The coal steam-gasification and hydro-gasification technologies are introduced at the year 2010 or 2020 depending on the relative prices between coal and oil (or natural gas). As for the steam gasification technology to produce medium calory gas, the availability of cheap oxygen is considered as a significant condition to get competitivity in earlier dates.

The VHTR is introduced to its upper limit from the year 2010 in every case. This result indicates sufficient marketability of high temperature nuclear heat in comparison with conventional fossil heat sources in future years. The utilization of the high temperature nuclear heat is made flexibly depending on the relative prices between coal and oil (or natural gas). In the case of small price differences the high temperature nuclear heat is utilized mainly for reducing gas production and its heating for iron and steel making, while it is utilized mainly by the thermochemical hydrogen production and methane reforming technologies in the case with larger price differences. The hydrogen produced in the latter case is used in coal hydro-gasification and methanol synthesis to produce substitutes of natural gas and oil, respectively. The CO gas also produced in methane reforming is directed to the CO gas-turbine CC and to the methanol synthesis process.

4.4 Cost Components and Marginal Price

According to the past energy statistics the energy technologies utilizing fossil fuels have in general lower capital costs and higher fuel costs, while nuclear technologies higher capital costs and lower fuel costs. When we investigate a cost configuration in electric power technologies and non-electric power technologies we can find such characteristics as higher capital cost in the former and higher fuel cost in the latter. And the total cost of the former is in general high compared with the latter. Such a tendency is well shown in the cost components of major energy technologies presented in Table 2-1.

In our future energy system, primary energy sources will shift from oil to coal and nuclear with further electrification and synthetic fuel uses. Therefore our future energy system will be more capital intensive than today. By taking the LD/HP-QP scenario as an example, we show the cost configuration of the energy conversion sector in Fig.4.4-1 - 3. The above features are well shown in the figure. The total annual cost of the energy conversion sector accounts for about 5.9% of GDP in 2000 and 6.1% in 2020. To reduce this share, the efforts should be made to reduce the capital cost and O&M cost of such new technologies as coal gasification and liquefaction, high temperature nuclear heat production and utilization, and renewable energy use.

The selection of fuels in the demand sector and also in a part of the conversion sector is determined based on their cost. The relative competitivity of energy carriers are reflected on their marginal costs (shadow prices). In Table 4.4-1 we show the marginal costs of major energy carriers at each step of the conversion process in the result of the LD/HP-QP scenario. It can be said from this table that the high temperature nuclear heat can well compete with other energy carriers after 2010s and offer the economic advantages in applications for electricity generation, hydrogen production, and so on.

4.5 Environmental Effluents

We calculate the amounts of environmental effluents from activities of the total energy systems which are optimized in case P and QP with low energy demand and high price scenario (LD/HP-P,QP case). Accounting values of environmental effluents are SOX, NOX and CO2 from the conversion sector, the process sector and the end-use sector. The amounts of SOX and NOX are counted for in equivalent value with SO2 and NO2, respectively.

Fig.4.5-1 shows the change in the total amounts of effluents and it's composition by each sector. The amounts of input energy for each sector are also shown in table form. In the figure of SOX and NOX, the composition of DMD is larger than that in the figure of CO2. It is caused by the effective removal rates of SOX and NOX emission in the end-use sector, which are setting lower than those in the conversion and the process sectors.

As for the amount of SOX effluents, it increases until the year 2000 and decreases to the present level in case P, while, it maintains almost present level until the year 2000 and decreases to the half value of the present level in case QP. The difference between the amount in case P and in case QP caused prominently by the end-use sector. The reasons why these results are obtained are seen as follows; 1) large amounts of heavy oil are used by the industrial sector in middle term range in case P, however, 2) the utilization of heavy oil is reduced in case QP, and 3) instead of this, consumer gas, kerosene, and solar heat which are low-effluent fuels are increasing, and 4) the utilization of electricity is also increased in the residential and commercial sectors.

As far as the amount of NOX effluents is concerned, it decreased to the half value of the present level over the years from 1980 to 2020, and has not such large difference as that in SOX effluents. These results may be caused from the fact that NOX emission do not depend strongly on the difference in the kind of energy carriers. The increasing amount of effluents from the process sector from the year 2010 in case QP is caused by the implementation of coal gasification technologies. However, these amounts of the increase are canceled out in the total by the decrease in the effluents from the end-use sector. That is to say in another words, the implementation of technologies which produce and/or use synthetic fuels can give good effects to the atmosphere from environmental view points.

As for the CO2 effluents, we did not consider CO2 removal this time, so the almost all carbon included in the fossil fuels input to the system is released to the atmosphere as the form of CO2. The change in the total amount has a tendency like as the SOX effluents, and has a peak at the year 2000. In the conversion sector, the amount of CO2 effluents maintains almost present level until the year 2020 in spite of the big growth in the electric power generation, it caused by the contribution of the nuclear technologies. In addition, we can see in case QP a reduction by the renewable technologies and a rise at 2020 by the implementation of the advanced coal fired electric power plant.

4.6 Impacts to and from National Economy

We showed in the previous report (3) that the economic value of all energy production is accounted for about 10% of the GDP, and for total production including inter-industrial transaction it shares about 4.5%. If we inspect those figures from view point of input base, again we can find the followings: the percentage ratio of economic value of input fuel to total factor input is about 8% as industrial average, 65% as energy conversion sector average, 10% as energy intensive industry average. For the household sector this ratio is about 3%. More detail are shown in Table 4.6-1

The above numerals might give us the understanding that the economic value of energy activities has rather small portion of national economy, that is, equivalent to around 10% economy. However, such understanding can only be formed if we limit energy activities within direct activities. If we include indirect activities, the economic value share of energy activity becomes larger than 10%.

To show this, let us consider an example of nuclear power generation. Electric power can never be generated even if we procure natural uranium. For generating electricity, we need to make a design and to construct a nuclear power station, and to prepare fuel assemblies which are processed at the front end processes including U3O8 to UF6 conversion, uranium enrichment, fuel fabrication, and to load the fabricated fuel into the reactor core, and after burnup the spent fuel assemblies are refueled by new ones and they are stored in a cooling pond, and if necessary they will be reprocessed. In addition to those activities, radioactive wastes, generated both in nuclear power station and in nuclear fuel cycle facilities should be processed and treated. Only by admitting those activities, which are all considered to be a secondary demand, electricity can be produced as a value added commodity. As those reasons the secondary demands should be included to evaluate the economic value of energy.

The numerals of item C in Table 4.6-1 reflect the above considerations. In the table, we show two different indicators, the first one being the economic value share of energy activities measured as production base and the second one being the share measured as input base. We are now proceeding the analysis to investigate how these indices will change with time by using the MARKAL-I/O(Translog) model.

We have great interest in the influence the rest of economy sector brings to the energy sector. How much does the capital cost of energy facility change when the price of goods and services of the rest of economy sector varies? How to operation and maintenance cost, and fuel related cost,too? One example, analyzed by MARKAL-I/O(Translog) model, is shown in Table 4.6-2. Reflecting the price increases of oil and gas, nuclear energy sector is also influenced with them. However, as being this sector so like to machinery and other less energy intensive industries, the impact is rather weak.

4.7 Sensitivity Analysis

1) Cost-Security Trade-off

We have made a few calculations for cost-security trade-off analysis. Calculations have been done in combination cases of high/low/ultra-high scenario for useful energy demand and of high/low scenarios for import fuel prices against two types of objective functions; the first is a discounted system cost, and the second is a weighted linear combination of a discounted system cost and a security. Where, indices of the security are cumulative values composed from import crude oil, import oil products, and import LNG.

The cost-security trade-off relationships from calculation results are shown in Fig.4.7-1. From this figure, the security value in high demand case is higher than that in low demand case. This means that unsubstitutable oil demands exists more in high demand scenario than in low demand. From elasticity point of view, these curves indicate similar characteristics not only in price elasticities, but also in demand elasticities. This means that scenario regions in demand and price are not too large nor too small, and rather conservative for the analysis on structural changes of the energy systems. In other words, this proves that macro energy-economy scenarios could be generated within suitable bands including the structural change in future. From the comparison of the slope of these trade-off curves between high demand and low demand, the slope of the high demand is sharper than that of the low demand, this means that we cannot be free from the problems of oil import even in the year 2020, if we wish high growth in future economy.

Main indices of these trade-off analysis are shown in Table 4.7-1. In this table, ultra-high case means one sample case outside the scenario region in demand values, and should be regarded as additional information. As shown in this table, the amounts of domestic fossil primary energy are fixed reflecting governmental policies. The amount of nuclear is almost constant both in high and low price scenarios, however, it shows a little change in each demand scenario. It is noted that the amount of nuclear decrease a little in security case at high demand and increases a little at low demand case in transition from cost to security. Other tendencies of the results are similar as those of obtained at the past analyses on total energy systems, for example, imports of liquid and gaseous fuels are decreasing and compensated by the increase in import of solid fuel and in renewable energies in accordance with increasing weight of the securities in the objective function.

2) Effects by the Change of Constrains

Since the optimization by MARKAL is made using many external constrains, we tried to analyze the change of the result under different constrains. Among various constrains, the most important one is the availability of primary energy supply, therefore, we tried to compare the results of calculation cases with and without a constrains on amounts of imported steam-coal in UHD/HP-QP scenario. The cost-security trade-off curve of this special case is shown in Fig.4.7-2, and the QP point of (UHD/HP) case has moved to the QP* point, if the constrain of steam-coal import is taken off. That is to say, if our country can import steam-coal without limit, oil and LNG will be substituted by coal sufficiently and the security value can be reduced to the point QP*. Moreover, increases in the total cost from QP to QP* is not so large as that of the total cost from low price case to high price case.

At first glance of this figure, one can easily imagine that the same pattern of change in the substitution of primary energy has occurred in both movements from P to QP and from QP to QP*. However, if we can notice in detailed examination of the results that different phenomena in the substitution has occurred in both cases. At the year 2020, oil and oil products are reduced by about 40% in the case from P to QP, while, they are reduced by about 15% in the case from QP to QP*. Natural gas is reduced by about 84% in the case from QP to QP* against about 22% reduction in the case from QP to QP*. On the contrary, steam-coal is increased by about 63% in the case from QP to QP* against about 17% increase in the case from P to QP. That is to say, LNG is substituted by coal in the case from QP to QP*, while oil is substituted by coal in the case from P to QP.

Coal utilization in the case from P to QP* is increased by 12 times in the amount of coal gasification, 2 times in power generation, 8 times in direct use, and no change in liquefaction and coke oven. That is to stay, coal utilization for gasification made large increase and such IES technologies as CO shift conversion, CO methanol synthesis, etc. has been introduced rapidly.

While examining the results from point of constrains bound in implementation of new energy technologies, we found that the amount of coal liquefaction(F-T), COM, coal gasification, coal advanced power, LWR, LWR-cogeneration, ATR, HTGR, marine reactor, geothermal, hydoroelectric, geothermal cogeneration and helium gas turbine technology are introduced to their upper limits. In the final demand sector, heat pump and truck and bus using hydrogen and electricity are introduced to their upper limits. These technologies seem to have large competitivities in future energy systems even at present cost level.

5. Remaining Tasks

We have finished now completely the first and the second task and almost finished the third and the fourth task described in chapter 1. What is left at present is to accomplish the fourth and the fifth task from now on.

More strictly speaking, we finished 1, 2, and 3 of study procedures in Fig.5-1 which has been shown in our paper at vienna meeting, and left the procedure 4 . The object of procedure 4 is to study on each technologies of Japanese IES (VHTR and nuclear heat utilization system) by detail technical assessments, and to intend to extract R&D subjects left in each technologies if possible.

If some technologies reveal their prominent usefulness in these assessments, we would like to examine whether or not these technologies could be industrialized commercially in future through detail cost analysis and financial simulation study by the cost model and the financial model.

As far as the benefit of the technology is concerned, we will analyze its social and economic effects on local societies by the simulation model RILOSEP (Regional Impacts on Local Societies by Energy Plant). On the other hand, we will analyze cost/benefit characteristics of energy technologies through the value-flow analysis by the MARKAL model.

As far as the risk analysis of energy technologies are contrary, steam-coal is increased by about 63% in the case from QP to QP* against about 17% increase in the case from P to QP. That is to say, LNG is substituted by coal in the case from QP to QP*, while oil is substituted by coal in the case from P to QP.

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As far as the risk analysis of energy technologies are concerned, we decide to postpone the goal and now come back to the basic studies of methodologies because of the delay in model developments.

As far as VHTR technologies are concerned, we projects technical assessments beyond the task force in Fig. 5-1 from view points of the small and medium power reactors for the purpose of extracting the R&D subjects. That is to say, we are now scheduling to do a series of technical assessments for the purpose of extracting value criteria not only from supply sides but also from demand sides: e.g. safety (inherent safety), economy (cost, life-time, O&M), constructions (QC, QA, factory fabrication), standards and criteria (reactor grade, non reactor grade), resources (fuel cycle, materials), adaptabilities for energy demand (forms, load following, activities), investments (modularization), efficiencies (co-generation, utilization system), public acceptance (benefit/risk, environment impacts), fuel selection (uranium/thorium), etc..

While, the study on the interaction problem between environment and energy system would not be accomplished at this time, because the environmental problem includes broad subjects and we have not yet succeeded in preparing sufficient data on protection technologies and on the situation of present utilization for these technologies. Results of the analysis presented here are only the amounts of air effluents of total energy systems, however, we continue these studies. For the purpose of accomplishing the study on the zero emission energy system and the role of VHTR and nuclear heat utilization in it, we are carrying out the cost-effluent trade-off analysis.

If we could obtain useful results in both assessments studies and environmental studies, we would like to report at foreseeable IES meetings.

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Table 2-1 Main characteristics of representative technologies

Technology		Technical Data			Cost Data			Emission Data at 1980		
		Lifetime (Year)	Availability (%)	Efficiency (%)	Inv. Cost $/*1	Fix. Cost $/*1/Yr	Var. Cost $/GJ	SOx $10^6 Nm^3/PJ$	NOx $10^6 Nm^3/PJ$	CO_2 $10^3 t/PJ$
Conversion Technology										
E01	Conv. Coal-Fired	20	70	35.2	901.6	38.0	0.51	0.026	0.054	248.9
E06	Adv. Coal-Fired	20	70	44.0 ~ 48.0	919.6	40.0	0.80	0.013	0.027	199.1
E13	Oil-Fired	20	70	39.1	522.9	22.4	0.16	0.046	0.017	184.7
E82	Gas-Fired	20	70	40.0	522.9	22.4	*3	0.005	0.010	126.5
E21	LWR	30	70	33.7	1422.	81.6	0.67	—	—	—
E26	LMFBR	30	70	40.3	1849.	106.0	*3	—	—	—
E31	Hydroelectric	50	45	—	2378.2	83.3	*3	—	—	—
E32	Geo-electric	20	80	—	1812.	72.0	0.08	(H_2S) 0.669	—	—
E4B	Solar Photovol.	20	50	—	3056.2 ~ 1439.6	2.3	*3	—	—	—
E81	Conv. Gas Turbine	20	5	30.5	327.7	10.0	0.76	0.005	0.017	—
E9A	He Gas Turbine	30	70	43.0	299.1	14.8	0.38	—	—	—
E9C	CO Gas C.C	30	80	60.0	688.	40.5	0.18	—	—	0.3
Process Technology										
S01	Coal Hydrogas.	20	90	88.8	3.19	0.14	0.06	0.000	0.010	0.2
S02	Char Steam-gas	20	90	91.9	5.54	0.29	0.14	0.001	0.018	28.7
S03	Coal Steam-gas	20	90	86.6	6.58	0.41	0.12	0.001	0.018	24.6
S0E	Coal Liq. (Light)	20	90	65.0	35.57 ~ 23.72	1.18 ~ 0.59	0.37 ~ 0.19	*4	*4	*4
S0F	Coal Liq. (F-T)	20	90	63.0	16.40	0.55	0.17	0.005	0.019	30.7
S0G	Coal Liq. (Heavy)	20	90	70.3	28.90 ~ 19.26	0.91 ~ 0.46	0.29 ~ 0.15	*4	*4	*4
S91	Steam Reform.	20	90	97.0	1.77	0.08	0.04	—	—	—
S93 ~ S94	Thermochem. Pipeline	20	90	88.6	7.61	0.50	0.18	—	—	—
S95	CO_2 Splitting	20	90	24.1	9.35	0.28	0.20	—	—	—
S97	Thermochem. H_2	20	90	*2 100	1.51	0.11	0.06	—	—	—
S98	Coal to Red. Gas	20	90	70.9	3.09	0.32	0.07	0.008	0.046	40.4
S9C	CO-H_2 Sep.	20	90	90.3	3.62	0.17	0.32	—	—	—
S9D	H.T. Electrolysis	20	90	96.9	12.03	0.64	1.16	—	—	—
S9E	Air Separation	20	90	—	89.61	23.06	0.21	—	—	—
S9K	Methanol Syn.	20	90	94.6	1.43	0.08	0.03	—	—	—
S9M	Gasoline Syn.	20	90	82.9	2.95	0.20	0.09	—	—	—

*1. capacity unit of technologies
i.e. kW for conversion technologies
GJ/y for other technologies
*2. assumed full use of recovery heat
*3 included in fixed cost
*4 assumed to site abroad

Table 3-1. Main indices of energy-economy scenarios

Item / Case / year	10 years Average Growth Rate of GNE		Final Energy Demand Scenarios PJ / year		Usefull Energy Demand Scenarios PJ / year	
	Low *	High *	Low *	High *	Low	High
1980	2.7	3.4	10880		5544	
1990	2.4	2.9	11640	12035	6495	6690
2000	1.3	2.0	13400	13640	7970	8288
2010	1.0	1.5	14000	15000	8637	9357
2020			14650	16325	9304	10426

* High and Low case correspond to α and β case in the analysis of scenario generation.

Table 4.4-1 Fuel dual activity in LD/HP-QP scenario case

($/GJ)

	Primary Supply			Conversion sector			End Used Sector			
	1985	2000	2020	1985	2000	2020		1985	2000	2020
Steam Coal	1.54	3.38	3.92				S	13.09	14.93	15.47
							L	4.97	12.44	15.47
Coaking Coal	2.34	2.89	4.29				S	4.24	11.70	9.16
							L	4.24	4.96	7.70
Crude Oil	4.35	5.33	9.28							
Heavy Dist. Oil				4.35	5.32	8.88		4.69	5.65	9.22
Kerosene				5.33	6.04	9.84	S	6.25	12.24	13.39
							L	5.33	6.37	10.30
Gasoline				5.87	7.13	8.45		9.77	11.03	12.35
Methanol				10.31 (in 1990)	12.39	11.84		11.22 (in 1990)	12.57	12.35
Coal Liquids (RN)				4.35 (in 1990)	5.46	8.88				
(MIX)				3.73 (in 1990)	5.36	9.34				
LNG	4.34	4.88	8.81				S	4.85	11.96	10.53
Consumer Gas				4.85	5.46	9.42	L	11.36	6.57	15.92
Hydrogen				8.93 (in 1990)	11.00	9.89		8.98 (in 1990)	11.62	14.34
Reducing Gas					7.21 (in 2010)	6.41			11.51 (in 2010)	10.71
Low Temp. Heat								5.00	6.44	4.84
Process steam				5.02	4.81	4.79				
High. Temp. Heat					3.98 (in 2005)	4.53				
Electricity								12.90	14.64	12.39

Table 4.6-1 Ratio of economic value of input energy to factor input

sector \ Calendar year		1980
(1)	AGRICULTURE FORESTRY AND FISHERY	3.5
(2)	OTHER MINING	6.3
(3)	FOOD	1.6
(4)	FIBER	2.2
(5)	PULP AND PAPER	6.5
(6)	CHEMICAL PRODUCTS	13.5
(7)	NON-MATALLIC MINERAL PRODUCTS	11.3
(8)	IRON AND STEEL	12.5
(9)	NON-FERROUS METAL PRODUCTS	10.6
(10)	METAL PRODUCTS	4.6
(11)	GENERAL MACHINERY	1.5
(12)	ELECTRIC MACHINERY	2.1
(13)	TRANSPORT EQUIPMENT	1.4
(14)	PRECISION INSTRUMENT	1.4
(15)	OTHER INDUSTRIAL PRODUCTS	2.0
(16)	BUILDING CONSTRUCTION	1.8
(17)	WATER SUPPLY	5.7
(18)	WHOLESALE AND RETAIL TRADE	1.6
(19)	FINANCIAL AND INSURANCE SERVICES	0.7
(20)	REAL ESTATE DEALING	0.2
(21)	TRANSPORT	22.3
(22)	COMMUNICATION	0.9
(23)	SERVICES	3.0
(24)	COAL	52.5
(25)	CRUDE PETROLEUM AND NATURAL GAS	73.0
(26)	ELECTRIC POWER SUPPLY	39.0
(27)	GAS SUPPLY	37.6
(28)	INDEPENDENT ELECTRIC SUPPLY	65.4
ENERGY SHARE IN FACTOR INPUT		
(A)	SECTOR(1 - 28) AVERAGE	8.3
(B)	ENERGY SECTOR AVERAGE	64.8
(C)	DIRECT & INDIRECT AVERAGE*	10.7
(D)	HOUSEHOLD SECTOR	3.0
ENERGY SHARE IN PRODUCTION		
(E)	IN TOTAL PRODUCTION	4.5
(F)	IN GDP	10.0

*[(INPUT FROM ENERGY SECTOR)+(FACTOR INPUT EXCLUDING ENERGY INPUT OF ENERGY SECTOR(24 - 28))]/TOTAL FACTOR INPUT

Table 4.6-2 Evolution of technology costs in real term under structural changes in economy

	E01	E13	E21	E25	S28	S03	S0F
Investment Cost ($/kWe, $/(GJ/yr))							
1980	1246.	747.	1978.		6.60		
85	1185.	669.	1870.		6.18		
90	1185.	633.	1864.		6.05	9.42	
95	1219.	622.	1916.		6.10	10.16	20.81
2000	1281.	628.	2013.		6.28	11.06	21.26
05	1363.	648.	2143.		6.55	12.09	22.01
10	1456.	676.	2293.	2284.	6.89	13.18	22.93
15	1545.	704.	2437.	2423.	7.20	14.18	23.78
Fixed O&M Cost ($/kWe/yr, $/(GJ/yr)/yr)							
1980	51.2	30.4	110.6		0.348		
85	53.2	31.6	114.9		0.362		
90	56.6	33.7	122.4		0.385	0.596	
95	60.9	36.2	131.8		0.413	0.642	0.798
2000	65.8	39.2	142.5		0.445	0.690	0.843
05	71.1	42.4	154.0		0.481	0.740	0.889
10	76.5	45.6	165.6	140.7	0.517	0.788	0.933
15	80.9	48.2	175.3	148.9	0.549	0.824	0.962
Variable O&M Cost ($/GJ)							
1980	0.723	0.232	0.939		0.017		
85	0.779	0.250	1.013		0.018		
90	0.848	0.272	1.103		0.020	0.169	
95	0.925	0.297	1.204		0.022	0.179	0.268
2000	1.007	0.323	1.311		0.024	0.189	0.282
05	1.092	0.350	1.422		0.026	0.198	0.296
10	1.173	0.376	1.528	1.130	0.028	0.206	0.308
15	1.238	0.398	1.614	1.193	0.030	0.211	0.313

E01 : Conv. Coal-Fired Electric
E13 : Oil-Fired Electric
E21 : LWR Electric
E25 : HTGR Electric
S28 : Oil Refinery
S03 : Coal Steam Gasification
S0F : Coal F-T Liquefaction

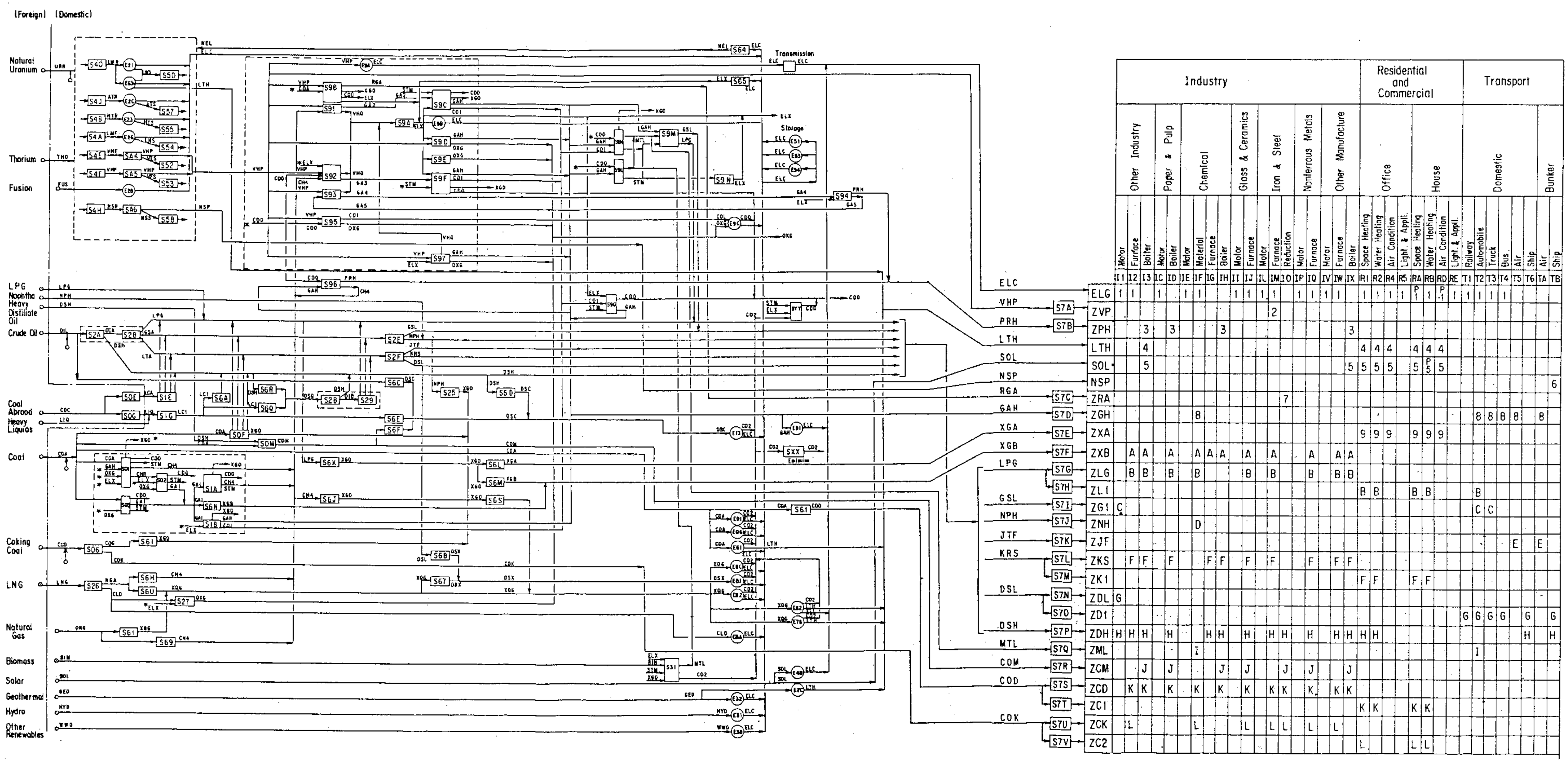
Table 4.7-1. Main indices of the results in trade-off analysis

Scenario			Total System Cost($10^{12}$$)	Security (EJ)	Primary Energy Cumulative Value (EJ)						
Demand	Price	Object F.			Total**	Import			Domestic		
						LIQ	SOL	GAS	NUC*	FOS.	REN
High	High	P	2.503	382.1	907.6	322.3	229.9	70.1	482.0	36.8	86.0
		QP	2.553	316.7	910.9	277.7	275.1	56.5	475.7	36.8	100.5
	Low	P	2.382	455.7	879.4	387.3	138.2	85.8	481.9	36.8	69.0
		QP	2.454	320.7	910.6	280.3	274.1	58.1	476.3	36.8	97.1
Low	High	P	2.391	373.2	853.0	312.4	224.5	65.1	404.5	36.8	76.8
		QP	2.428	317.6	856.2	274.3	255.1	59.0	397.5	36.8	92.0
	Low	P	2.276	443.2	827.3	385.1	137.9	72.5	404.3	36.8	57.8
		QP	2.339	318.8	855.9	274.6	255.3	60.2	398.1	36.8	90.3
Reference (Ultra-high)	High	P	2.814	451.5	1003.8	379.8	251.6	85.0	482.0	36.8	88.2
		QP	2.857	397.8	995.8	308.4	277.0	96.4	475.7	36.8	102.2
	Low	P	2.674	492.9	987.6	409.2	198.2	104.4	482.4	36.8	76.9
		QP	2.73	399.7	999.8	326.7	277.1	93.6	476.3	36.8	101.5

* unit of nuclear is 10^3 ton

** nuclear are counted for by fossile equivalent

Fig.2-1 Detail flow diagram of the reference energy system



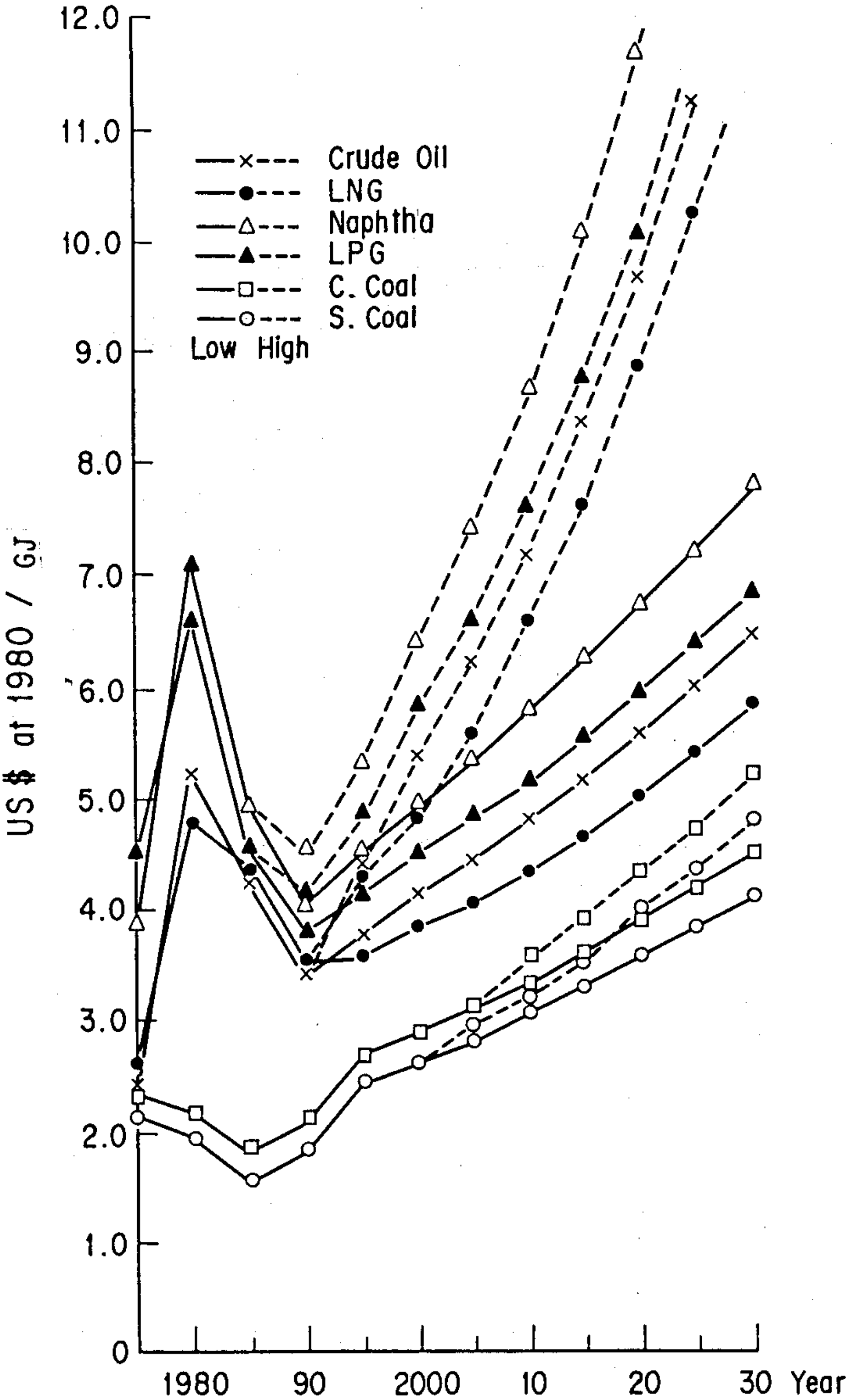
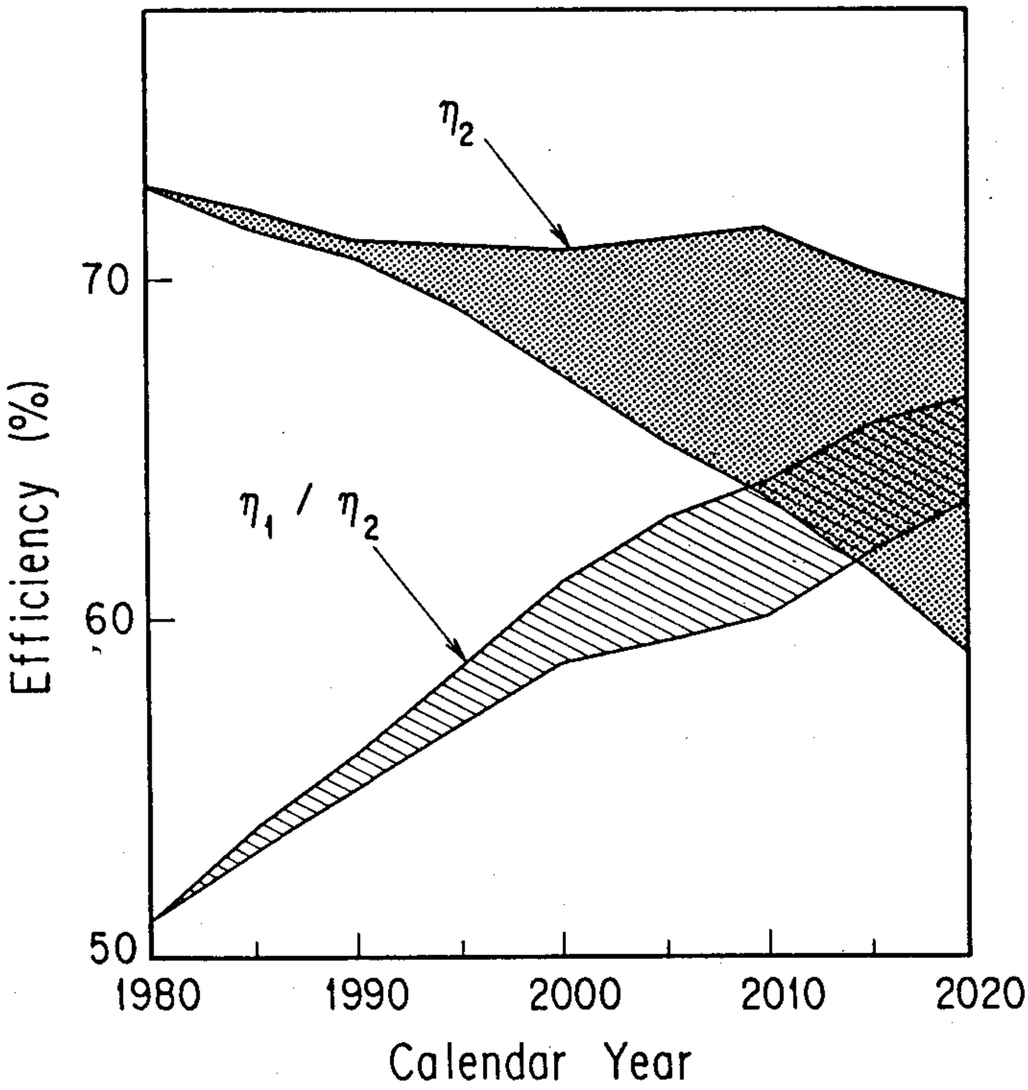


Fig.3-1. Price scenarios of main primary energies

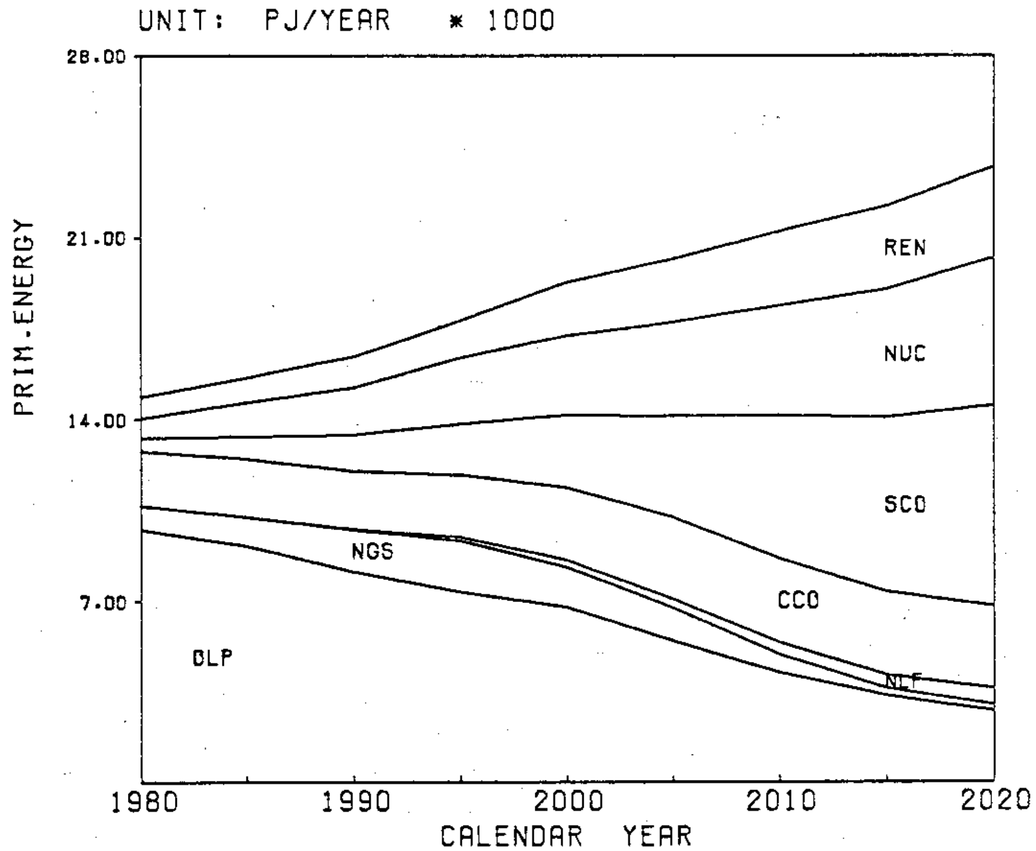


η_2 , η_1/η_2: energy utilization efficiency for conversion sector, end-use sector respectively

Each area is constructed from the union of the results of the scenario run LD-LP/P&QP, LD-HP/P&QP, HD-LP/P&QP, HD-HP/P&QP

Fig.4.1-1 Energy utilization efficiencies of conversion sector and end-use sector

YEAR	1980	1985	1990	1995	2000	2005	2010	2015	2020
OLP	9772.8	9181.9	8187.2	7375.1	6804.8	5503.8	4251.8	3371.9	2773.4
NGS	900.0	1089.4	1595.5	1984.1	1521.0	1266.7	719.5	275.1	253.0
NLF	0.0	0.0	40.0	146.0	272.0	340.0	450.0	525.0	600.0
CCO	2104.0	2234.0	2217.0	2377.0	2803.0	3196.1	3265.2	3200.9	3205.1
SCO	534.5	865.0	1399.2	1958.5	2757.7	3896.0	5496.0	6696.0	7696.0
NUC	736.1	1306.2	1811.6	2506.2	3068.1	3574.6	4194.9	4911.5	5690.4
REN	839.0	945.9	1160.9	1431.3	2019.9	2444.3	2866.8	3218.9	3474.2
TOTAL	14886.3	15621.7	16410.9	17778.3	19246.6	20161.5	21244.2	22198.8	23692.0

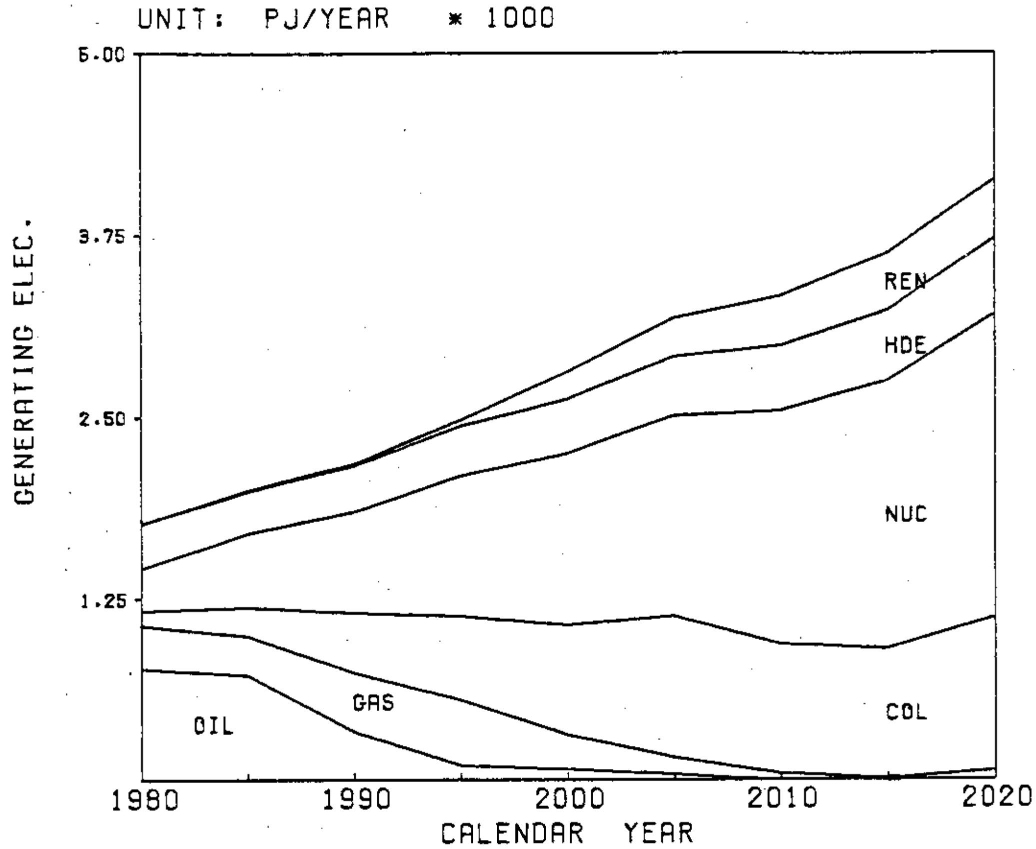


OLP = CRUDE OIL AND OIL PRODUCTS
NGS = NATURAL GAS
NLF = NEW LIQUID FUEL
CCO = COKING COAL
SCO = STEAM COAL
NUC = NUCLEAR
REN = RENEWABLE ENERGY

Fig.4.2-1 Supply structure of primary energy in LD/HP-QP scenario case

UNIT: PJ/YEAR

YEAR	1980	1985	1990	1995	2000	2005	2010	2015	2020
STG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.1	62.1
OIL	767.6	729.1	331.6	100.2	70.4	41.4	0.0	0.0	0.0
GAS	296.5	268.6	408.1	453.4	239.2	114.0	42.9	1.3	1.3
COL	105.5	200.9	411.9	577.5	759.9	976.9	894.8	896.8	1057.6
NUC	283.4	502.9	697.6	964.9	1180.6	1374.3	1603.5	1840.1	2088.4
HDE	309.7	289.5	312.2	340.6	376.1	411.5	447.0	482.5	518.0
REN	3.5	9.9	17.3	42.5	185.0	263.0	341.0	392.4	407.9
TOTAL	1766.1	1994.8	2178.6	2479.2	2811.1	3181.1	3329.2	3621.2	4135.3

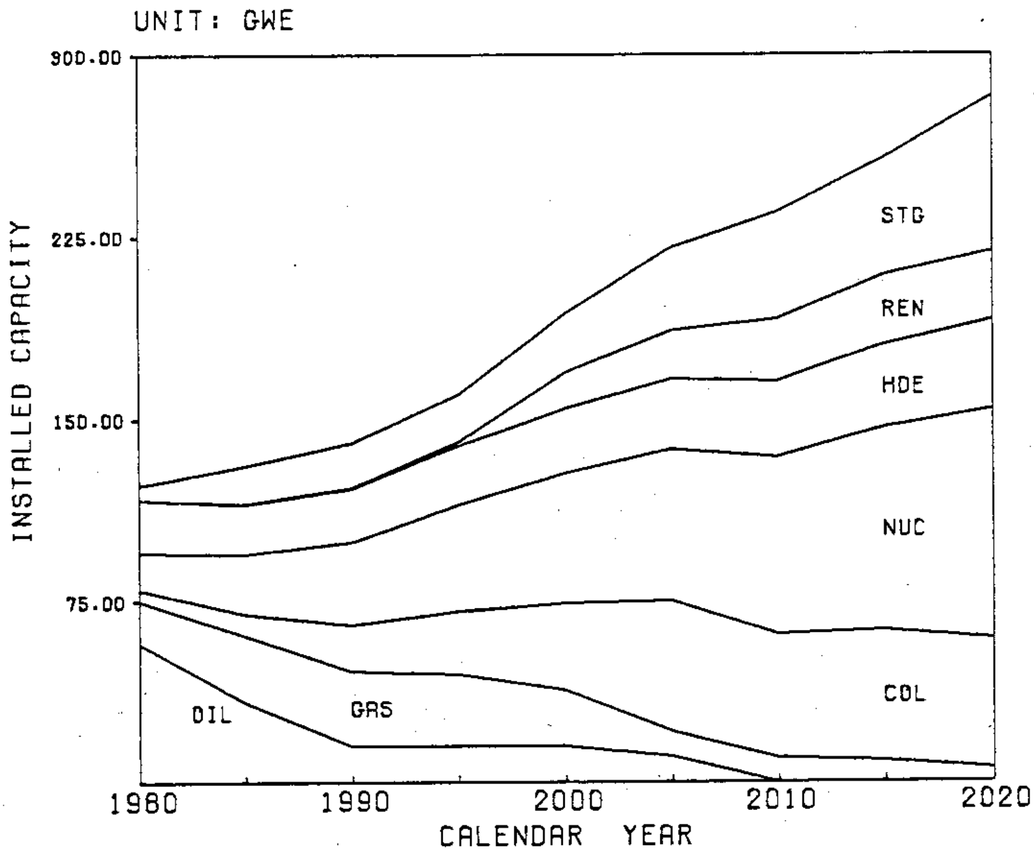


STG = ELECTRIC STORAGE POWER PLANT
OIL = OIL STEAM ELECTRIC POWER PLANT
GAS = GAS STEAM ELECTRIC POWER PLANT
COL = COAL STEAM ELECTRIC POWER PLANT
NUC = NUCLEAR ELECTRIC POWER PLANT
HDE = HYDRO ELECTRIC POWER PLANT
REN = OTHER RENEWABLE ELECTRIC POWER PLANT

Fig.4.2-2 Generating electricity of electric power plant in LD/HP-QP scenario case

UNIT: GWE

YEAR	1980	1985	1990	1995	2000	2005	2010	2015	2020
OIL	57.6	33.2	15.0	15.0	15.0	10.7	0.0	0.0	0.0
GAS	17.5	27.6	31.1	29.6	23.1	10.4	9.8	8.7	5.7
COL	4.8	9.1	19.0	26.2	36.1	54.0	51.5	54.2	53.6
NUC	14.9	24.5	34.0	43.7	53.5	62.3	72.6	83.4	94.6
HDE	21.8	20.4	22.0	24.0	26.5	29.0	31.5	34.0	36.5
REN	0.1	0.4	0.7	1.7	14.9	20.1	25.3	28.5	28.3
STG	6.0	15.5	18.0	19.5	24.2	34.0	44.0	48.2	64.0
TOTAL	122.8	130.6	139.8	159.7	193.3	220.3	234.8	256.8	282.7

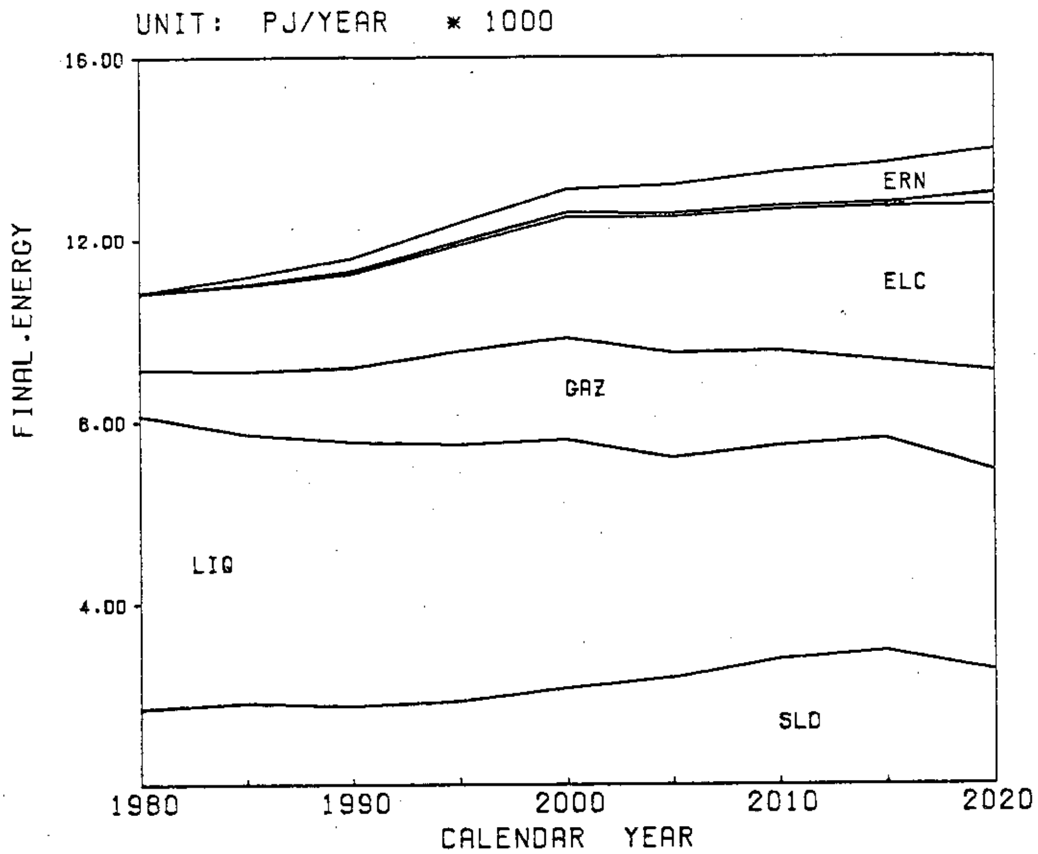


OIL = OIL STEAM ELECTRIC POWER PLANT
GAS = GAS STEAM ELECTRIC POWER PLANT
COL = COAL STEAM ELECTRIC POWER PLANT
NUC = NUCLEAR ELECTRIC POWER PLANT
HDE = HYDRO ELECTRIC POWER PLANT
REN = OTHER RENEWABLE ELECTRIC POWER PLANT
STG = ELECTRIC STORAGE POWER PLANT

Fig.4.2-3 Installed capacity of electric power plant in LD/HP-QP scenario case

UNIT: PJ/YEAR

YEAR	1980	1985	1990	1995	2000	2005	2010	2015	2020
SLD	1683.7	1795.3	1728.8	1838.8	2132.2	2365.0	2762.2	2948.6	2522.0
LIQ	6456.2	5935.1	5816.3	5652.0	5474.7	4838.3	4704.4	4675.6	4401.2
GAZ	1005.9	1392.0	1642.2	2052.3	2239.2	2300.2	2069.5	1710.1	2170.9
ELC	1659.9	1874.6	2046.8	2326.7	2640.0	2987.1	3120.4	3385.2	3663.3
LTH	0.0	27.3	71.8	94.3	104.3	87.8	86.6	89.3	239.3
HTH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	20.1
ERN	25.5	155.8	279.2	396.5	508.4	624.4	738.6	851.0	960.9
TOTAL	10831.3	11180.2	11587.1	12360.7	13098.7	13202.8	13481.7	13664.7	13977.8

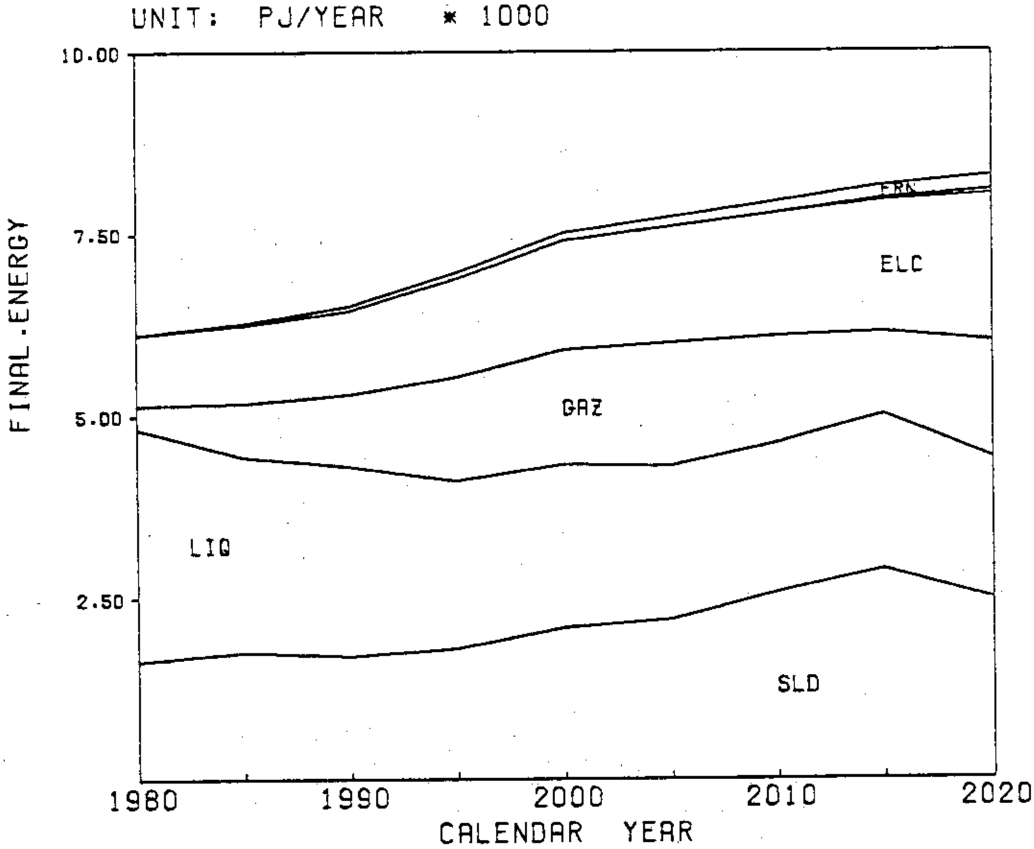


SLD = SOLID FUELS
LIQ = LIQUID FUELS
GAZ = GASEOUS FUELS
ELC = ELECTRICITY
LTH = LOW TEMPERATURE HEAT
HTH = HIGH TEMPERATURE HEAT
ERN = DECENTRALIZED SUPPLY

Fig.4.2-4 Energy type of final energy demand in LD/HP-QP scenario case

UNIT: PJ/YEAR

YEAR	1980	1985	1990	1995	2000	2005	2010	2015	2020
SLD	1630.5	1749.8	1699.3	1810.5	2088.4	2198.1	2574.8	2876.3	2486.0
LIQ	3190.0	2678.8	2595.7	2294.6	2228.2	2099.5	2031.5	2126.3	1927.4
GAZ	918.9	739.5	1001.4	1418.6	1578.7	1686.4	1469.0	1122.5	1595.5
ELC	967.2	1075.8	1147.7	1346.7	1505.6	1604.3	1701.5	1813.9	2022.6
LTH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.3	47.6
ERN	0.0	31.8	59.9	84.8	107.2	131.5	155.0	177.7	199.6
TOTAL	6106.6	6275.7	6504.0	6955.2	7508.1	7719.8	7931.9	8152.9	8278.7

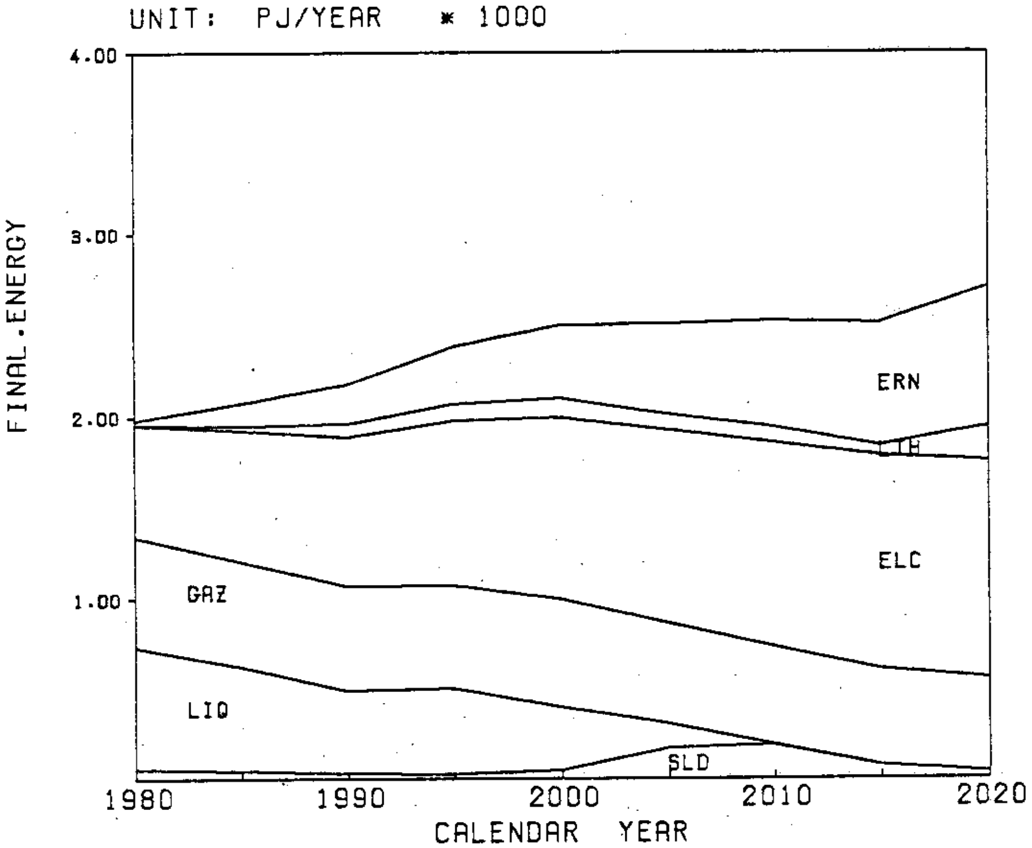


SLD = SOLID FUELS
LIQ = LIQUID FUELS
GAZ = GASEOUS FUELS
ELC = ELECTRICITY
LTH = LOW TEMPERATURE HEAT
ERN = DECENTRALIZED SUPPLY

Fig.4.2-5 Industrial fuel mix in LD/HP-QP scenario case

UNIT: PJ/YEAR

YEAR	1980	1985	1990	1995	2000	2005	2010	2U15	2020
SLD	53.2	45.5	29.5	28.3	43.7	166.9	187.4	72.3	36.0
LIQ	678.3	578.3	462.2	473.6	351.2	139.0	2.9	0.0	0.0
GAZ	610.8	581.2	573.8	570.5	600.8	555.8	544.0	532.7	521.9
ELC	611.1	718.2	819.4	901.3	999.9	1062.8	1118.2	1178.3	1192.5
LTH	0.0	27.3	71.8	94.3	104.3	87.8	86.6	52.9	191.7
ERN	25.5	124.0	219.4	311.7	401.2	492.9	583.6	673.2	761.3
TOTAL	1978.9	2074.5	2176.1	2379.8	2501.1	2505.1	2522.7	2509.6	2703.5

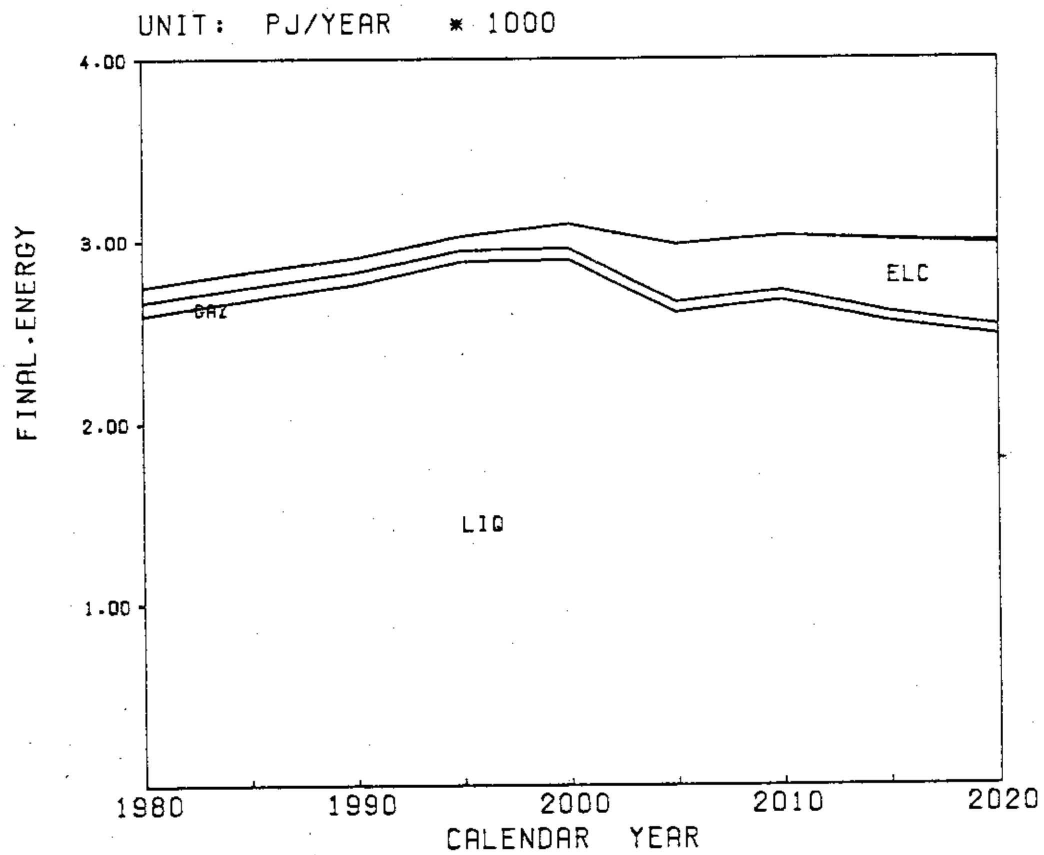


SLD = SOLID FUELS
LIQ = LIQUID FUELS
GAZ = GASEOUS FUELS
ELC = ELECTRICITY
LTH = LOW TEMPERATURE HEAT
ERN = DECENTRALIZED SUPPLY

Fig.4.2-6 Resdiential and commercial fuel mix in LD/HP-QP scenario case

UNIT: PJ/YEAR

YEAR	1980	1985	1990	1995	2000	2005	2010	2015	2020
LIQ	2587.9	2678.1	2760.4	2883.8	2895.2	2599.8	2670.0	2549.2	2473.8
GAZ	76.2	71.9	67.0	63.2	59.8	58.0	56.4	54.9	53.5
ELC	81.6	80.6	79.7	78.8	134.6	320.0	300.7	393.0	446.1
HTH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	20.1
TOTAL	2745.7	2830.0	2907.0	3025.7	3089.5	2977.9	3027.1	3002.2	2995.6

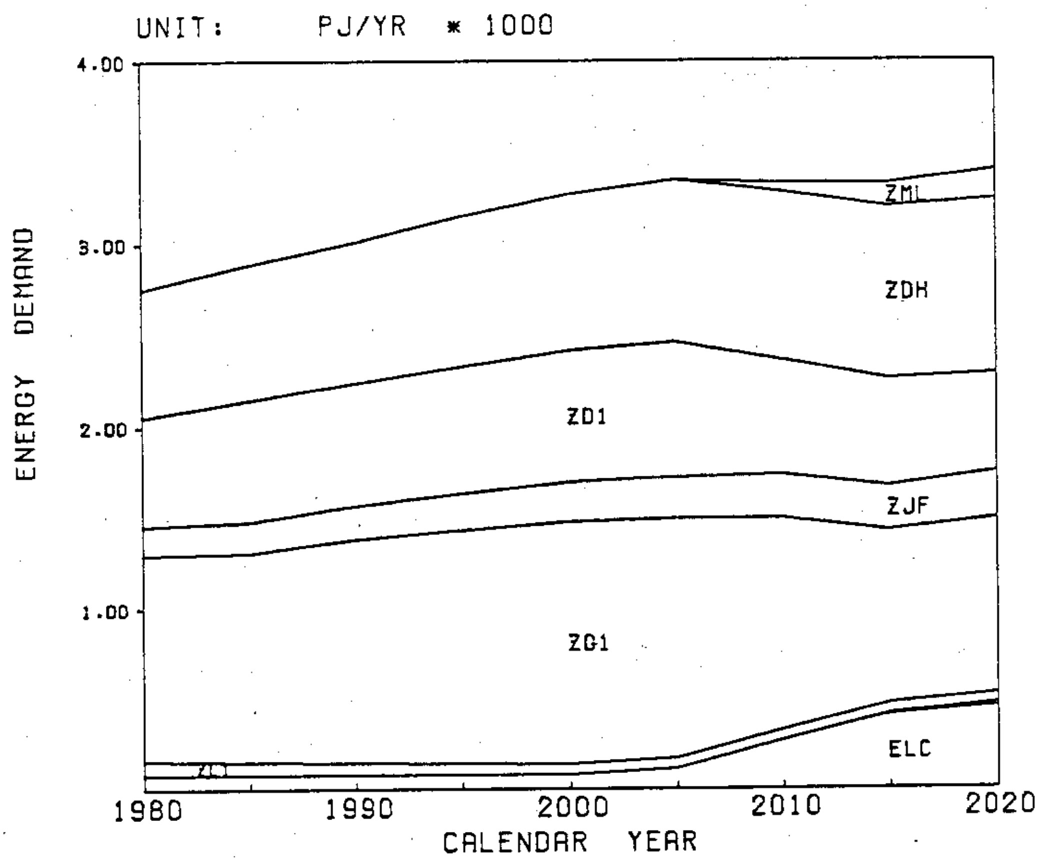


LIQ = LIQUID FUELS
GAZ = GASEOUS FUELS
ELC = ELECTRICITY
HTH = HIGH TEMPERATURE HEAT

Fig.4.2-7 Transport fuel mix in LD/HP-QP scenario case

UNIT: PJ/YR

YEAR	1980	1985	1990	1995	2000	2005	2010	2015	2020
ELC	81.6	80.6	79.7	78.8	77.8	109.5	265.9	406.6	448.1
NSP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	20.1
ZL1	76.2	71.3	67.0	63.2	59.8	58.0	56.4	54.9	53.5
ZG1	1133.3	1159.6	1227.9	1283.1	1335.7	1321.9	1168.5	952.4	965.3
ZJF	158.4	173.7	187.5	202.6	216.3	226.5	236.1	245.4	254.2
ZD1	601.8	665.6	668.9	698.7	722.2	741.2	633.9	588.2	537.7
ZDH	694.4	738.1	777.6	820.7	860.1	890.7	919.8	943.3	956.8
ZML	0.0	0.0	0.0	0.0	0.0	0.0	50.1	128.3	159.5
TOTAL	2745.7	2882.8	3008.5	3147.1	3271.9	3347.7	3330.8	3324.2	3395.3



ELC = ELECTRICITY
NSP = PROPUL.HEAT FOR SHIP
ZL1 = LIQ.PETR.GAS(S.CONS)
ZG1 = GASOLINE
ZJF = JET FUEL
ZD1 = L.DISTL.OIL (S.CONS)
ZDH = H.DISTL.OIL
ZML = METHANOL

Fig.4.2-8 Transport energy carrier in HD/LP-P scenario case

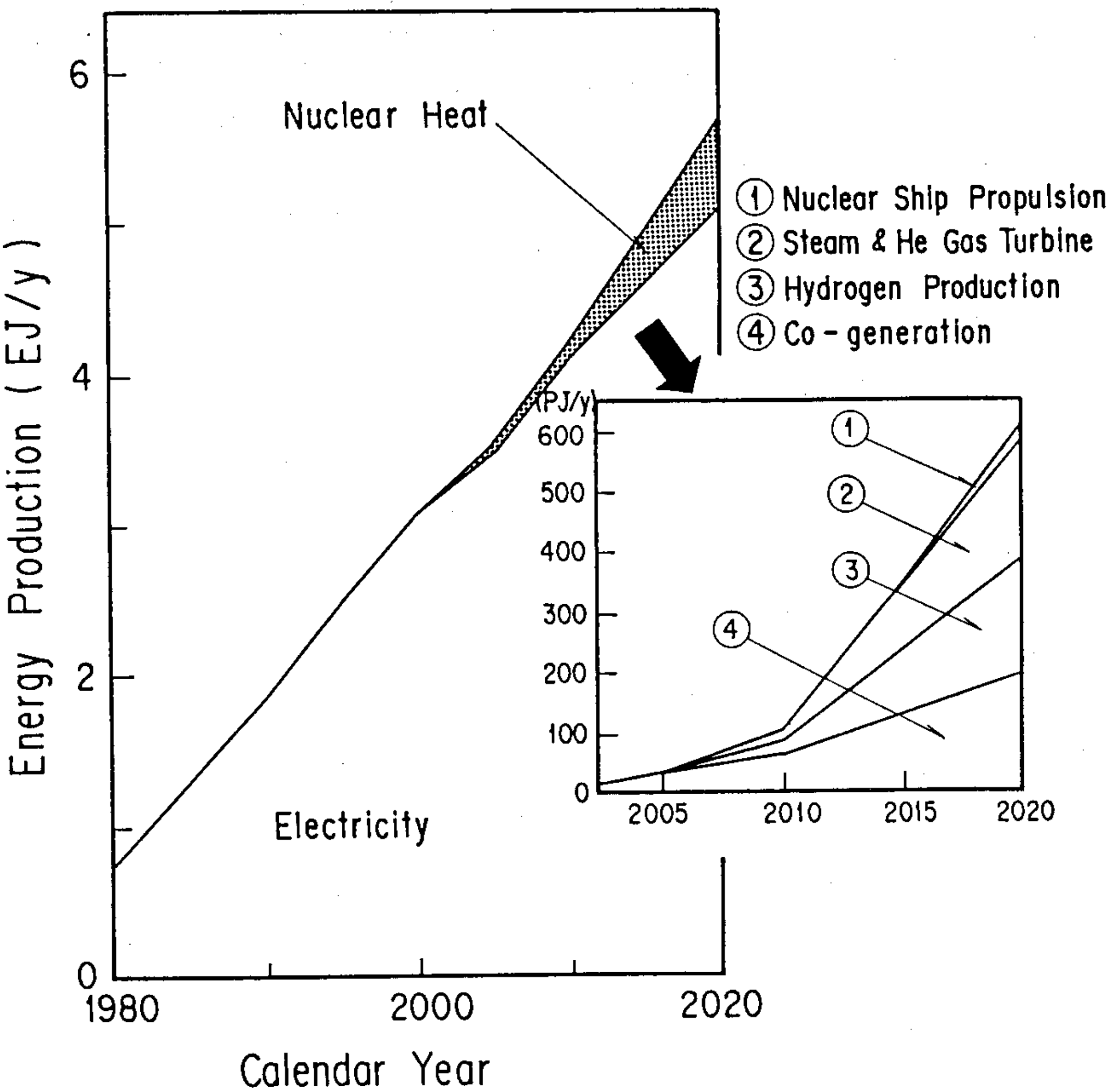


Fig.4.2-9 Low, intermediate, high temperature nuclear heat production and their utilizations in LD/HP-QP scenario case

UNIT: GWE

YEAR	1980	1985	1990	1995	2000	2005	2010	2015	2020
E01	4.8	9.1	18.4	25.6	31.3	34.6	28.9	20.7	13.4
E06	0.0	0.0	0.2	1.6	3.0	7.6	15.9	24.1	27.8
E13	57.6	34.2	16.8	16.8	16.8	11.4	0.0	0.0	0.0
E61	0.0	0.0	0.0	0.0	1.0	2.0	3.0	3.0	2.0
E81	0.1	2.7	2.7	2.7	2.6	0.0	0.0	0.0	0.0
E82	17.4	19.9	22.3	19.7	10.3	5.1	0.0	0.0	0.0
E8A	0.0	0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4
E8C	0.0	0.0	1.0	2.0	4.0	4.0	3.0	2.0	0.0
E9A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
E9B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
TOTAL	79.9	66.2	61.8	68.7	69.9	65.1	51.2	50.2	44.9

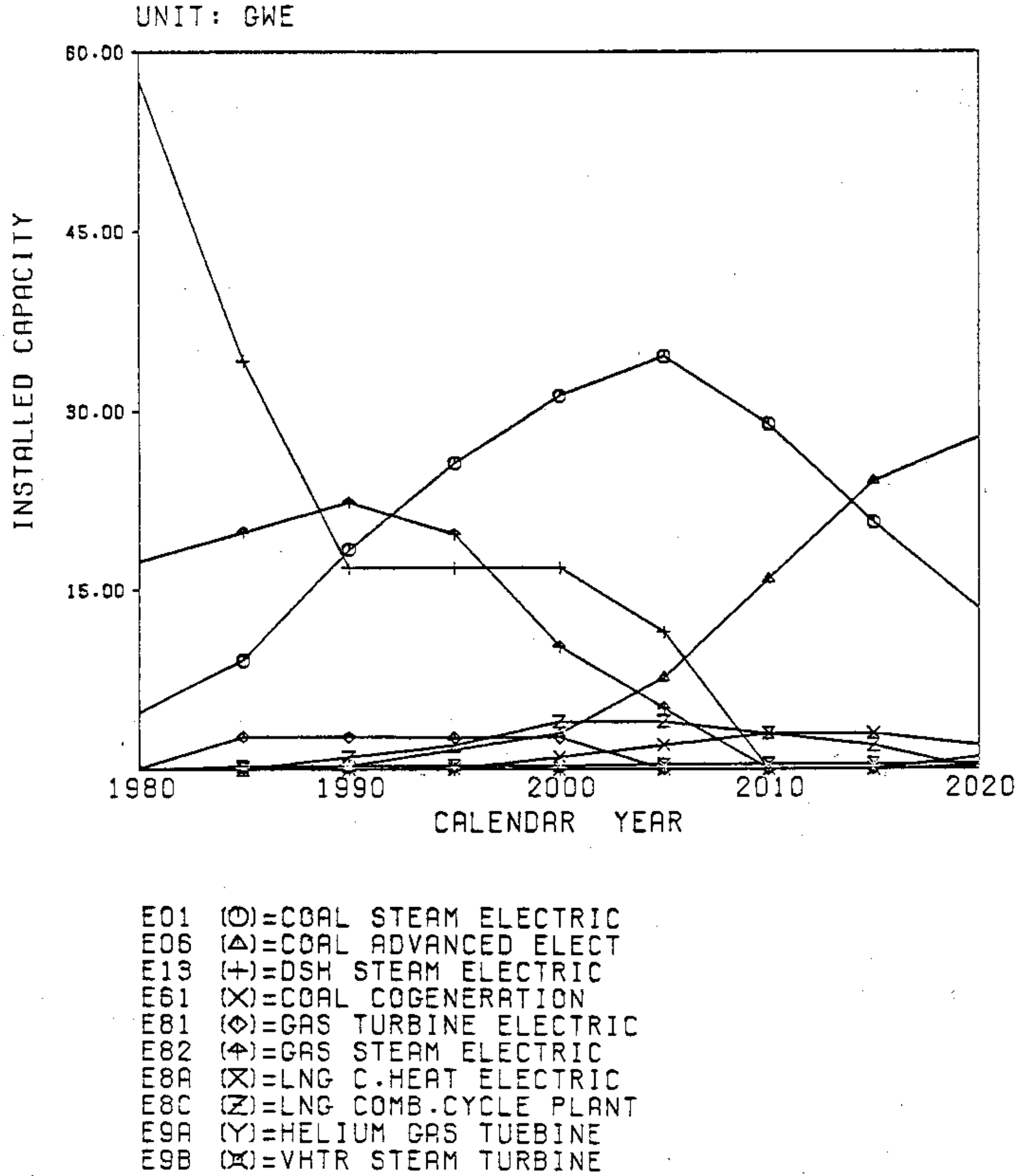


Fig.4.3-1 Installed capacity of fossil electric power plant in LD/HP-P scenario case

UNIT: GWE

YEAR	1980	1985	1990	1995	2000	2005	2010	2015	2020
E2C	0.2	0.2	0.2	0.8	0.8	0.8	0.6	0.6	0.6
E21	14.8	24.4	33.9	42.7	52.2	60.6	69.1	77.5	85.9
E25	0.0	0.0	0.0	0.0	0.0	0.0	0.3	1.6	3.0
E26	0.0	0.0	0.0	0.3	0.3	0.3	1.6	1.6	2.1
E63	0.0	0.0	0.0	0.0	0.2	0.6	1.0	2.0	3.0
TOTAL	14.9	24.5	34.0	43.7	53.5	62.3	72.6	83.4	94.6

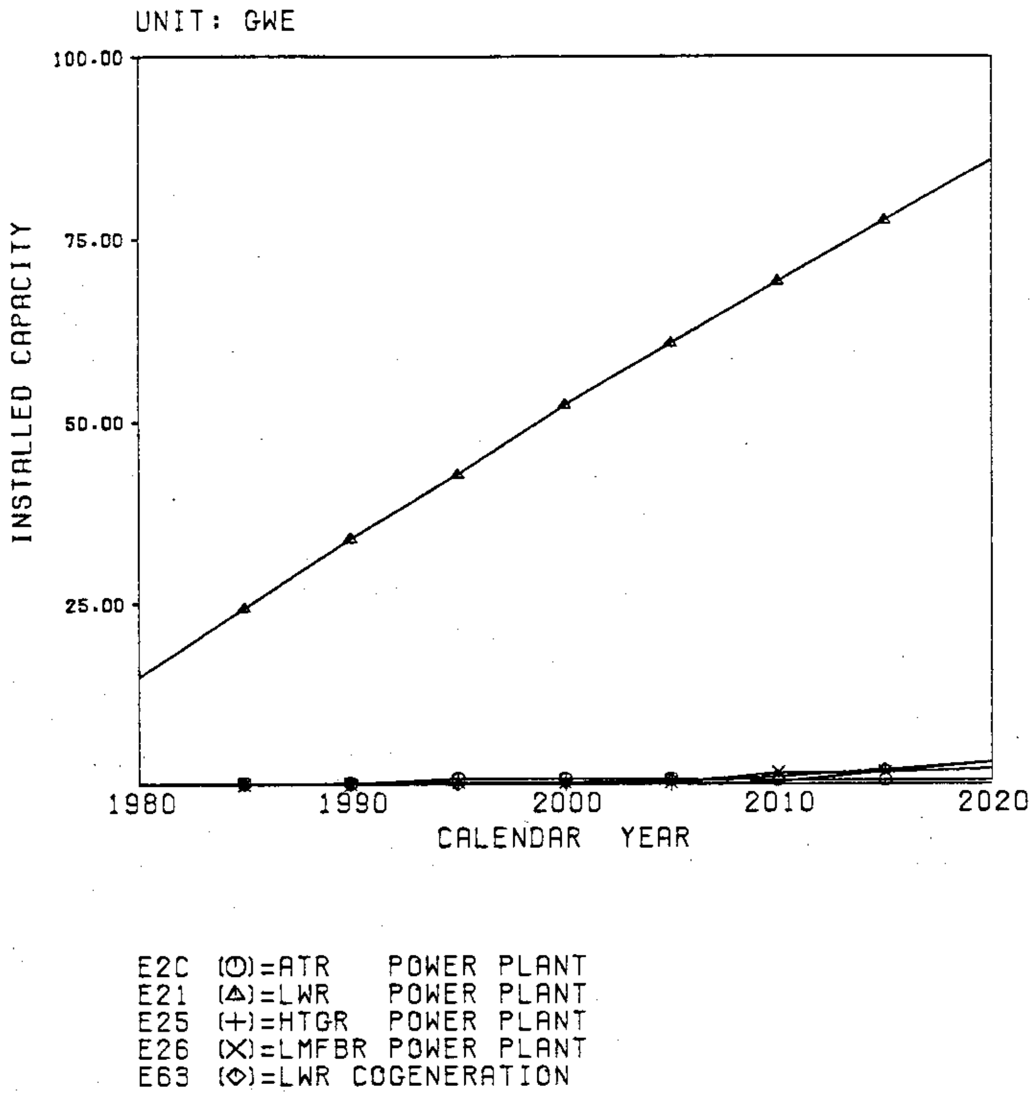
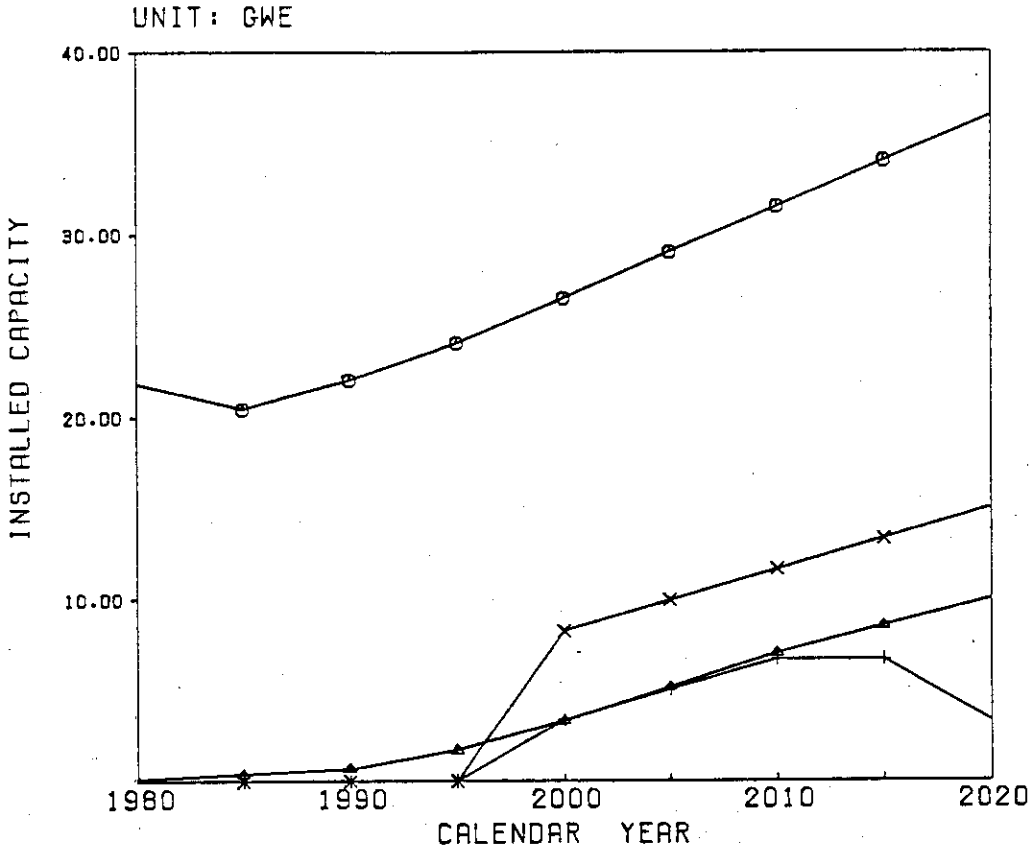


Fig.4.3-2 Installed capacity of nuclear power plant in LD/HP-QP scenario case

UNIT: GWE

YEAR	1980	1985	1990	1995	2000	2005	2010	2015	2020
E31	21.8	20.4	22.0	24.0	26.5	29.0	31.5	34.0	36.5
E32	0.1	0.4	0.7	1.7	3.3	5.1	7.0	8.5	10.0
E38	0.0	0.0	0.0	0.0	3.3	5.0	6.7	6.7	3.3
E4B	0.0	0.0	0.0	0.0	8.2	9.9	11.6	13.3	15.0
TOTAL	22.0	20.8	22.7	25.7	41.4	49.1	56.8	62.5	64.8

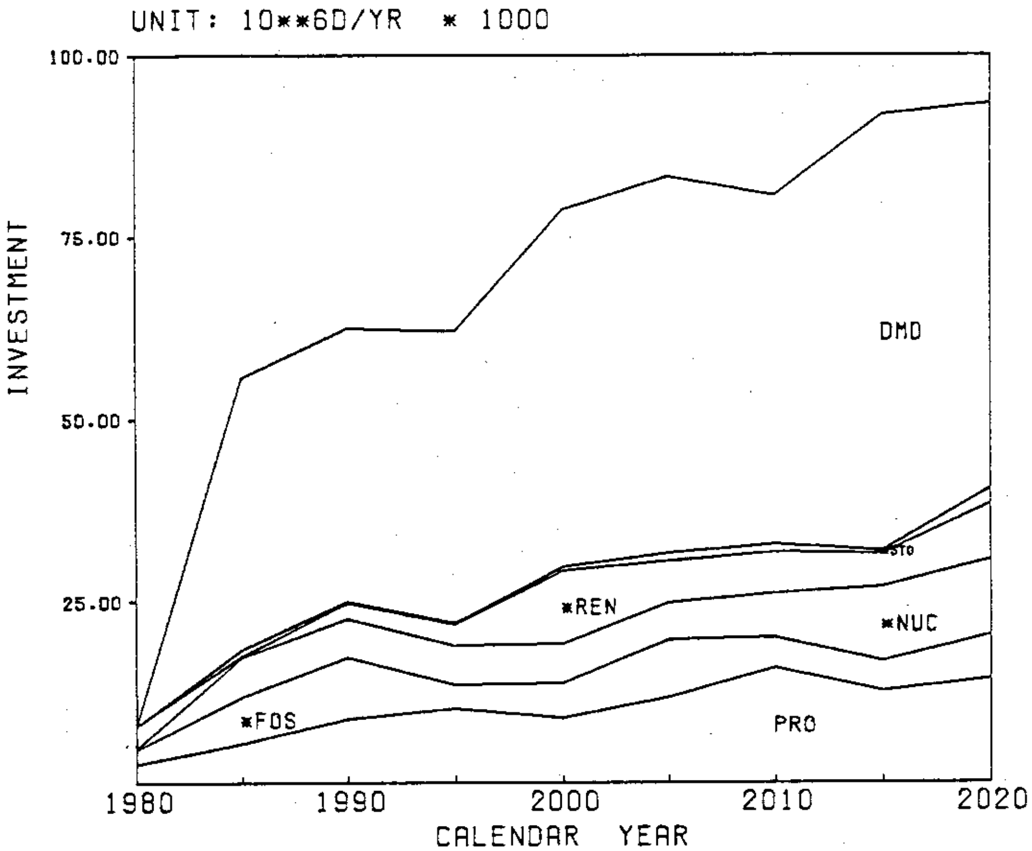


E31 (O)=HYDROELECTRIC
E32 (△)=GEOTHERMAL ELECTRIC
E38 (+)=RENEWABLE ELECTRIC
E4B (X)=SOLAR PHOTOELC (DCN)

Fig.4.3-3 Installed capacity of renewable energy power plant in LD/HP-QP scenario case

UNIT: 10**6D/YR

YEAR	1980	1985	1990	1995	2000	2005	2010	2015	2020
PRO	2587.3	5427.2	8809.1	10230.5	8970.5	11823.4	15859.7	12716.2	14388.4
*FOS	1989.2	6504.8	8467.5	3359.0	4795.5	7971.4	4244.1	4062.8	6018.4
*NUC	133.4	5330.9	5296.8	5416.5	5463.0	5046.9	6059.3	10200.1	10403.0
*REN	3126.9	275.6	2216.4	2844.4	9978.7	5659.7	5595.7	4593.7	7563.8
*STG	0.0	911.7	278.6	186.9	536.9	1100.5	1125.4	431.9	2076.0
DMD	192.1	37281.1	37367.0	40055.0	49115.6	51669.0	47770.5	59812.6	62956.3
TOTAL	7970.8	55731.2	62435.5	62092.4	78860.2	83270.9	80654.6	91817.4	93405.9

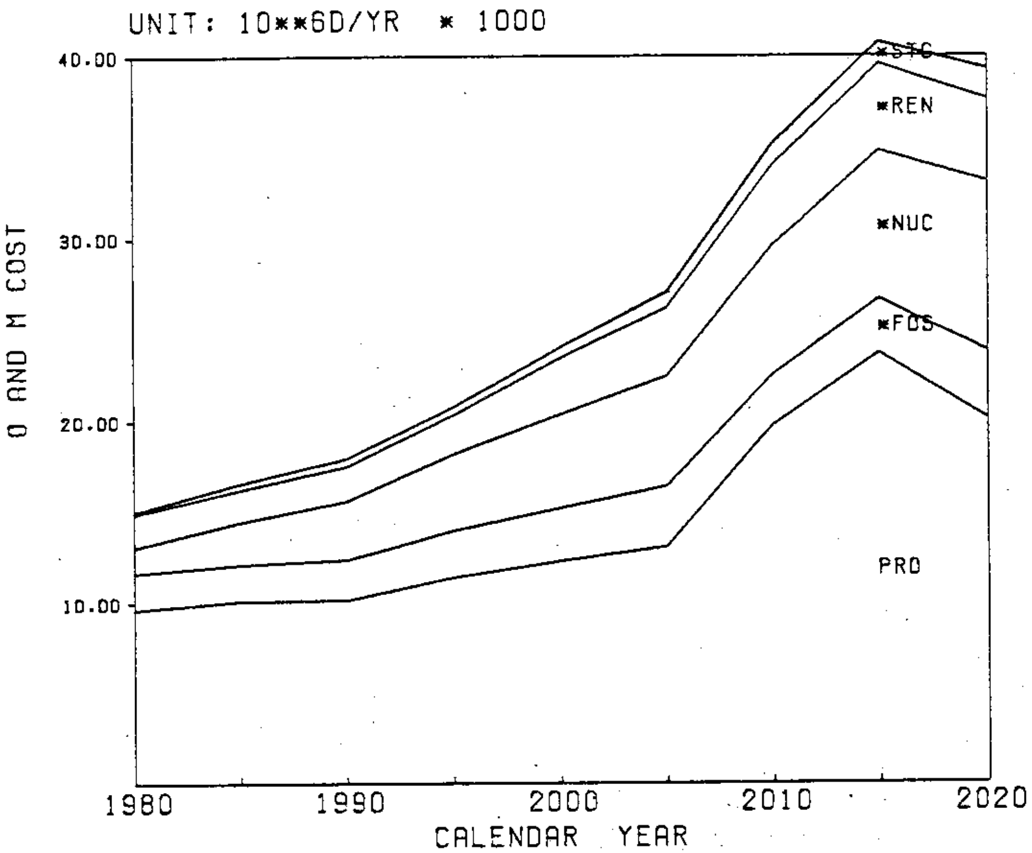


PRO = PROCESS TECHNOLOGY
*FOS = FOSSIL TECHNOLOGY
*NUC = NUCLEAR TECHNOLOGY
*REN = RENEWABLE TECHNOLOGY
*STG = STORAGE TECHNOLOGY
DMD = DEMAND DEVICE

Fig.4.4-1 Investment cost without salvage in LD/HP-QP scenario case

UNIT: 10**6D/YR

YEAR	1980	1985	1990	1995	2000	2005	2010	2015	2020
PRO	9596.8	10114.8	10151.9	11360.5	12259.7	13070.9	19692.8	23691.6	20087.7
*FOS	2042.3	1982.3	2179.1	2555.7	2899.2	3288.5	2809.2	2966.7	3699.3
*NUC	1406.6	2334.1	3238.8	4201.3	5156.9	6030.9	7069.4	8152.3	9290.8
*REN	1828.0	1744.6	1915.2	2174.1	3111.6	3762.4	4413.2	4753.5	4521.1
*STG	133.2	344.1	399.9	433.2	556.5	825.1	1099.9	1193.7	1657.0
DMD	7.2	8.5	6.9	6.9	12.8	76.1	90.5	29.4	11.0
TOTAL	15014.0	16528.4	17891.7	20731.7	23996.6	27053.8	35174.9	40787.1	39266.9



PRO = PROCESS TECHNOLOGY
*FOS = FOSSIL TECHNOLOGY
*NUC = NUCLEAR TECHNOLOGY
*REN = RENEWABLE TECHNOLOGY
*STG = STORAGE TECHNOLOGY
DMD = DEMAND DEVICE

Fig.4.4-2 Operation and maintenance cost in LD/HP-QP scenario case

UNIT: 10**6D/YR

YEAR	1980	1985	1990	1995	2000	2005	2010	2015	2020
OIL	46415.9	34198.7	27337.1	28695.2	30720.2	28165.1	27330.9	27238.2	25981.6
GAS	4024.8	4395.1	5755.5	8005.1	6671.9	6304.0	3725.6	1003.1	1034.8
COAL	5644.7	5442.7	7395.5	11795.8	16366.7	21996.4	29117.4	35632.6	42979.6
NUC	115.8	375.7	457.6	594.5	740.1	927.8	1208.8	1623.6	1313.7
TOTAL	56201.2	44412.2	40945.7	49030.6	54498.3	57393.4	61382.5	65497.4	71909.6

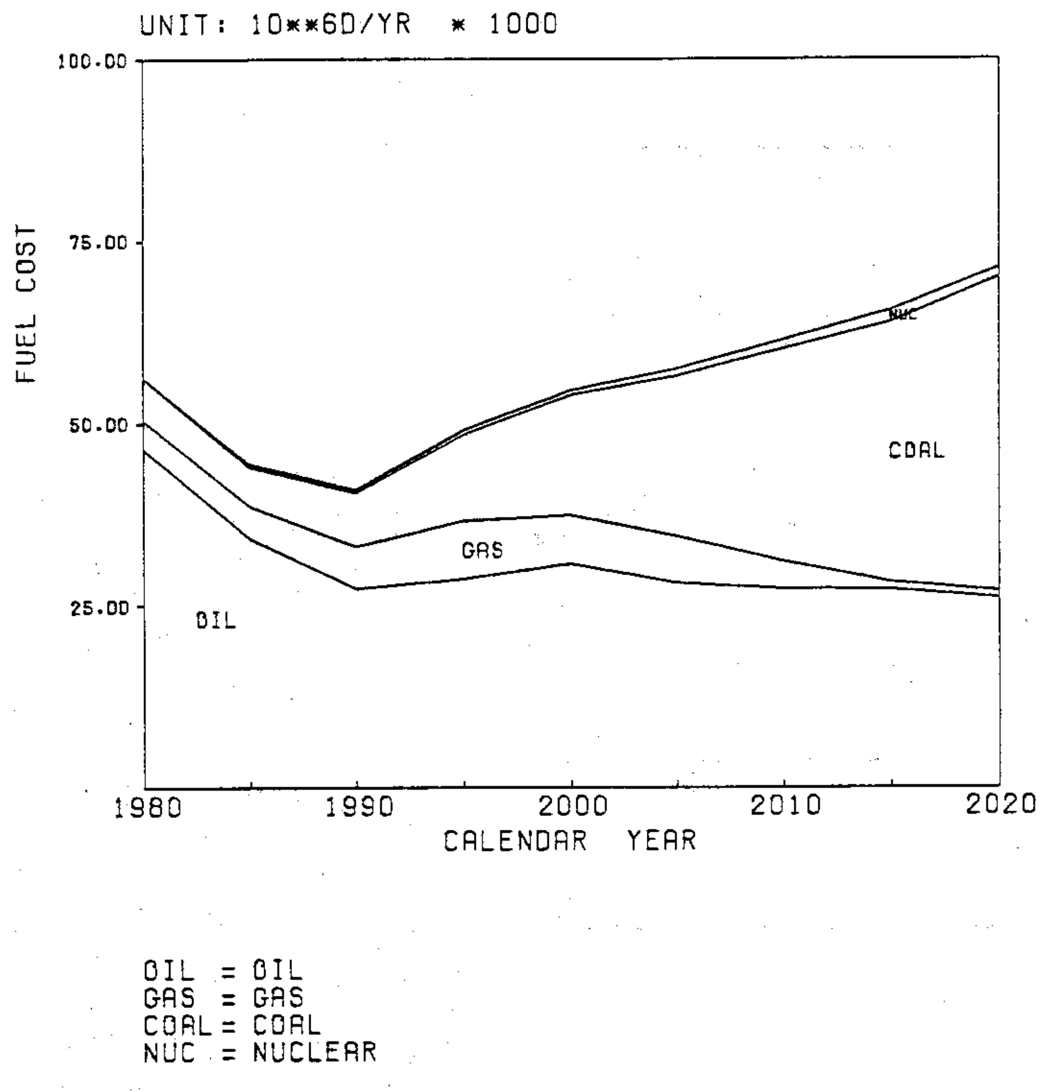
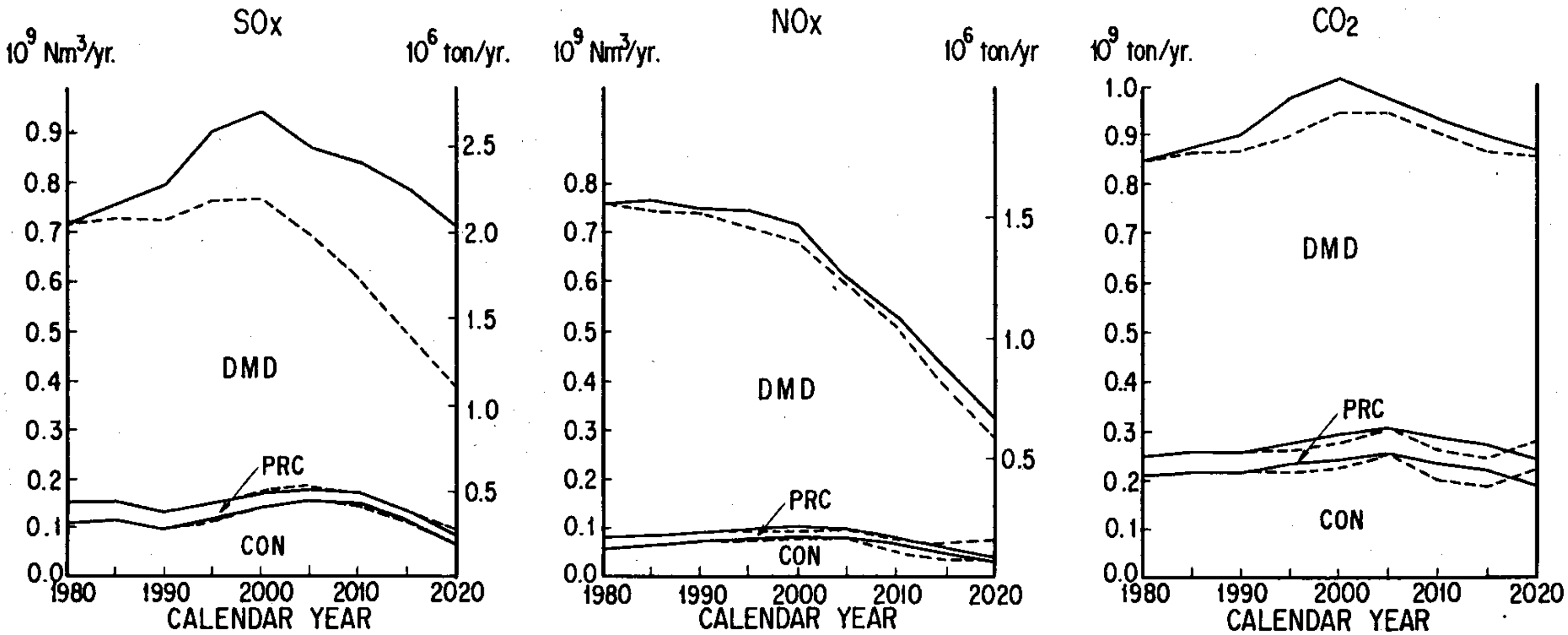


Fig.4.4-3 Fuel cost in LD/HP-QP scenario case



Input Energy for Technologies
at Low-Demand, High-Price Scenario

(EJ / yr.)

Case	Year	1980	1985	1990	1995	2000	2005	2010	2015	2020
P	CON	4.96	5.96	6.73	7.48	8.72	9.71	10.59	11.46	19.15
	PRC	14.69	13.88	14.08	14.42	14.16	13.67	16.88	17.71	18.81
	DMD	10.84	11.27	11.75	12.68	13.46	13.55	13.82	14.10	14.46
QP	CON	4.96	6.04	6.78	7.65	8.69	9.77	10.30	11.24	12.38
	PRC	14.51	14.08	14.90	15.92	16.26	15.96	18.55	20.54	22.64
	DMD	10.83	11.18	11.59	12.36	13.10	13.20	13.48	13.67	13.98

Scenario : LD/HP
Case P : ——
Case QP : ----

Fig.4.5-1 Environmental effluents in LD/HP-P,QP scenario cases

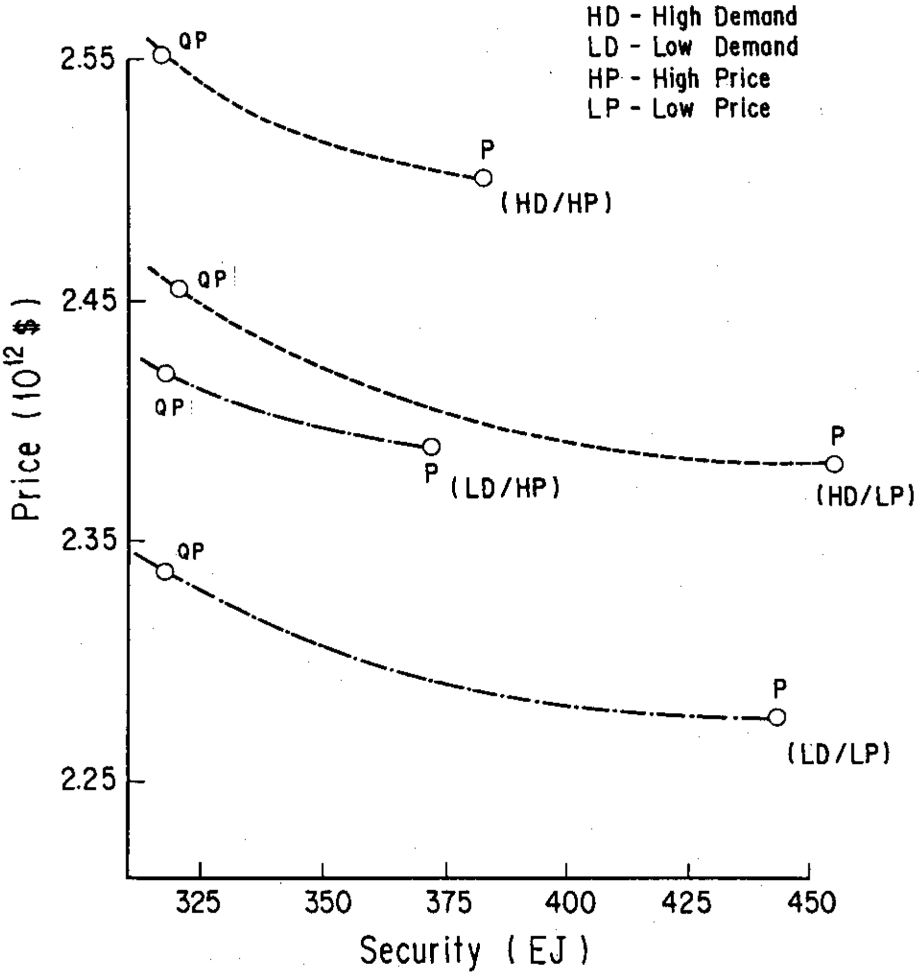


Fig.4.7-1. Estimated cost/security trade-off relationships

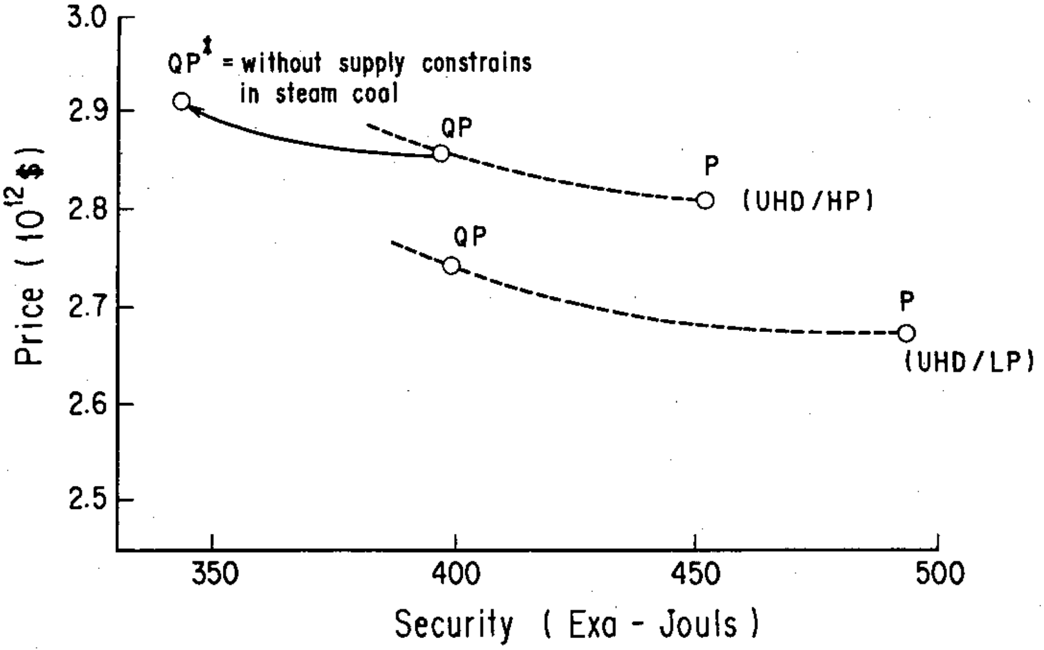


Fig.4.7-2. Cost/security trade-off with and without a constrain on the amount of imported steam-coal

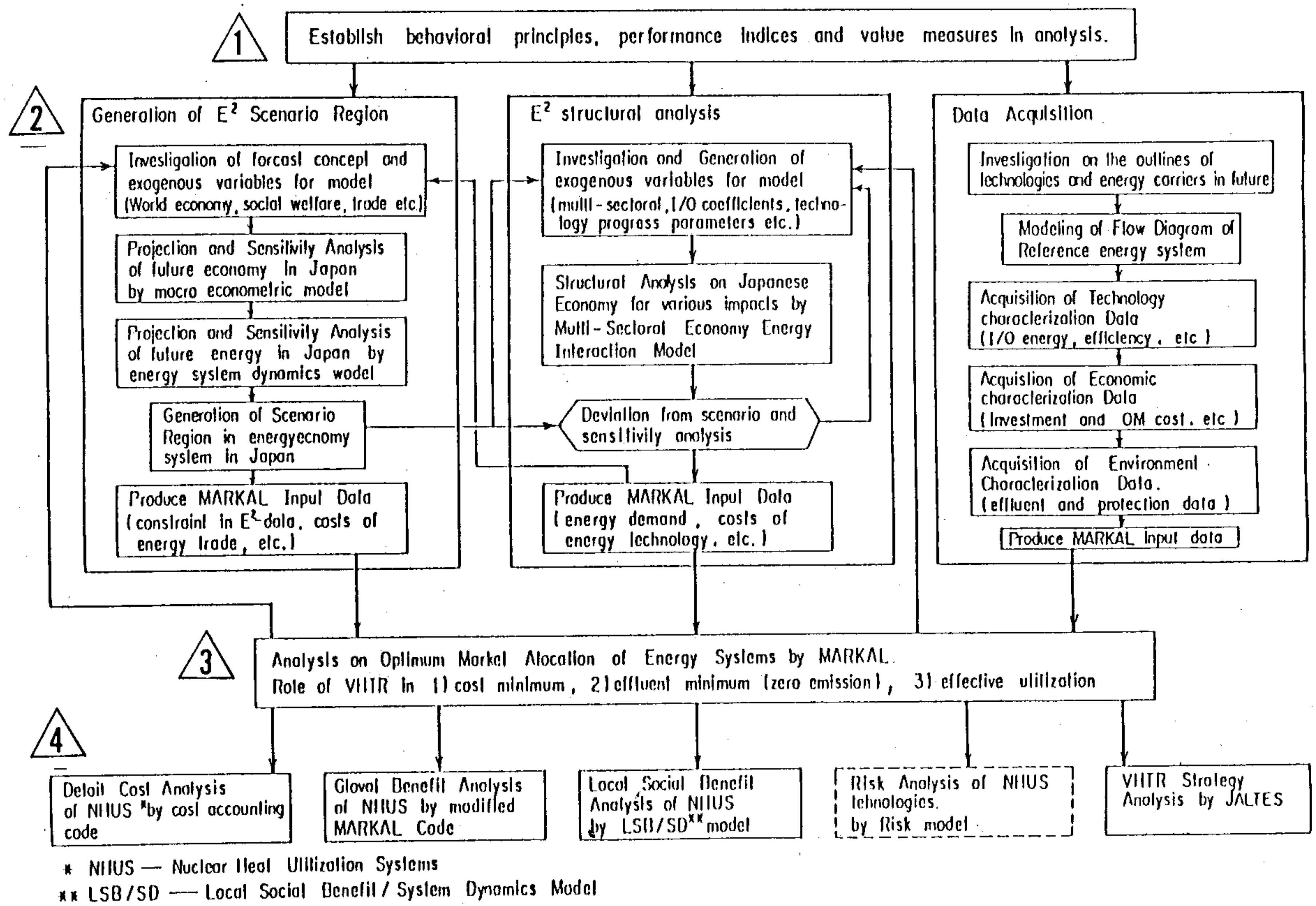


Fig.5-1 Breakdown of task procedures of the study subjects