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Research and Development Project Reports for FY1994

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NEDO

New Energy and Industrial Technology Development Organization

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**RESEARCH AND DEVELOPMENT
PROJECT REPORTS
FOR
FY1994**

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OVERVIEW
OF
NEW ENERGY PROJECTS

Overview
of
New Energy Projects

Developing new energy sources is one of the main pillars of Japanese energy policy. The New Energy and Industrial Technology Development Organization (NEDO) was established in 1980 to coordinate these national efforts. It provides support to and conducts studies concerning the development of oil-alternative new energy technologies. Reviewing all projects at timely junctures with public and private sector cooperation, NEDO has steadily produced exceptional results from its operations.

Since the two oil crises, Japan's primary energy supply structure has been gradually accommodating the introduction of oil-alternative energy sources such as nuclear energy and natural gas, along with energy-saving measures. With energy prices now at relatively low levels, the energy situation is fairly stable. On the other hand, energy demand in volume terms, though slowing in growth recently, is on a steady rise, reflecting the comfortable, affluent life that comes with the maturation of economic society.

The trend of energy supply and demand on the international market is also relatively stable. But the international energy structure, which centers on petroleum, remains fragile. Population increases, advancing industrialization, and improving standards of living, particularly in developing countries, are expected to lift energy demand significantly in the years ahead. There is mounting concern, therefore, that energy utilization will face restraints in the form of limited resource availability.

In addition, environmental issues, such as global warming, have become serious dilemmas as they severely affect not only world energy supply, which depends greatly on fossil fuels such as oil, coal and natural gas, but also international society and the world economy overall.

Energy and environmental problems must be tackled using measures taken from a global perspective. What is needed is accelerated development, introduction, and promotion of environmentally-benign energy utilization technologies and transfer of those technologies to developing countries. A step in this direction was made when a legal framework was created through a series of changes made in the spring of 1993, including enactment of the Law Concerning Improvement of Related Laws for Enhancement of the Energy Supply and Demand Structure. As a result, subsidy programs related to the introduction of energy conservation technology and oil-alternative energy sources, reinforcement of energy-conservation technology development activities, and activities to demonstrate the effectiveness of oil-alternative energy sources were added to NEDO's responsibilities.

NEDO is pressing ahead with the further development of new energy sources and the introduction and diffusion of new energy technologies.

1. Outline of Technological Development Projects

(1) Solar energy utilization technology development

Solar energy is both clean and abundant, and great expectations are being placed on the widespread utilization of this energy source. With the aim of realizing the practical use of solar energy utilization technologies, NEDO is carrying out the following development:

- Photovoltaic power generation, in which solar energy is directly converted into electric energy using solar cells.
- Solar thermal systems that capture solar energy with collectors as heat and utilize it as a heat source.

At present, in order to develop technology for putting photovoltaic power generation systems to practical use, work is under way to develop solar cells as well as photovoltaic power generation systems. At the same time, manufacturing equipment for solar cell compound semiconductors is under development, and joint international demonstration work is being promoted on photovoltaic power generation systems. As for the development of solar thermal systems for industrial and other uses, research and development is being conducted on chemical energy conversion technology, high-performance insulation materials, high-efficiency solar heating and cooling technology, and light modulating materials.

(2) Development of geothermal energy utilization technology

Japan, located in the Pacific Rim volcanic zone, is blessed with massive reserves of geothermal energy resources, and work is now being carried out to develop technologies for promoting geothermal energy utilization. Under development are exploration techniques for fracture-type reservoirs and survey techniques for deep-seated geothermal resources, both of which will be used in a confirmation study of the effectiveness of prospecting techniques for deep geothermal resources. Also being developed are technologies for using hot water resources for power generation, including power generation technology for making effective use of hot water resources which are estimated to exist in massive quantities but up to now have been untapped. There is also hot dry rock power generation technology, which entails the creation of an artificial geothermal reservoir in high-temperature, low-permeability rock mass and then extracting heat from the artificial reservoir. Drilling and production technologies necessary for exploiting deep geothermal resources are also under development.

(3) Development of coal energy utilization technologies

As its resources are both widely dispersed and abundant, coal is an attractive energy source. However, coal needs to be made more environmentally friendly and easier to use if it is to be more extensively utilized. For these reasons, NEDO is carrying out the development of coal conversion technologies, that is, liquefaction and gasification technologies.

To develop coal liquefaction technology, the basic and detailed designs of a NEDOL process 150 t/d pilot plant were completed for bituminous coal liquefaction, and the plant is now under construction.

To develop coal gasification technology, all research results obtained for hydrogen production from coal using a 20 t/d pilot plant were assembled, and the research program was brought to a conclusion. Also, to develop an entrained flow coal gasification combined cycle power generation pilot plant, research is under way using a pilot plant with a 200 t/d capacity.

To develop environmentally-friendly technology and ensure that it takes hold as a widely-used practical system, a project is under way to develop next-generation technology for coal utilization and promote clean coal technology. Furthermore, an international coal utilization project is being implemented to promote overseas dissemination of coal utilization technology which decreases the load on the environment.

(4) Development of fuel and energy storage technologies

Given the energy situation of Japan, a country poor in fossil fuel resources, technological development is of extreme importance in promoting energy-saving efforts on a long-term basis. NEDO is therefore carrying out the development of fuel cell power generation technology, which is expected to achieve power generation efficiency and fuel diversification, advanced battery electric energy storage systems, to contribute to load leveling, and ceramic gas turbines, to improve thermal efficiency, reduce pollutant emissions, and offer multi-fuel capability. Also under way are efforts to develop superconducting generators which have improved power system efficiency and stability, prepare the infrastructure for popularizing electric vehicles (EVs) by developing an EV charging system which taps nighttime electric power, to develop wide-area energy utilization network system techniques for waste heat recovery, long-distance heat transport and multiple-function heat supply, and conduct research and development of technologies for reducing emissions of carbon dioxide and other pollutants by making effective use of surplus energy.

(5) Development of hydrogen, alcohol and biomass technologies

Regarding the development of technologies for utilizing hydrogen, alcohol and biomass as energy sources, great expectations are being placed on practically applying them as soon as possible. These expectations are based not only from the viewpoint of promoting their use as oil-alternative energy sources and making effective use of untapped energy resources, but also from the perspective of protecting the global environment.

To these ends, NEDO has the following activities in progress: hydrogen utilization technology development under an international clean energy system development program; alcohol utilization technology development under a liquid fuel conversion development program and demonstration tests for converting thermal power plant fuel from oil to methanol; and biomass utilization technology development under a high-efficiency waste power generation technology development program, a survey on the technology to evaluate the impact of high-efficiency waste power generation on the environment, a high-efficiency methane gas production technology development program, and a research cooperation arrangement for a simple industrial waste water purification system.

Also under way is a project to develop an integrated recycling system for solid waste using cryogenic energy, a program aimed at promoting the recycling of, and energy recovery from, waste household electrical appliances using cryogenic energy of LNG.

(6) Development of other oil-alternative energy technologies

In order to put a large-scale wind energy conversion system into practical use, work is now progressing to develop a 500 kW class wind energy conversion system and control technology for a collective-type wind power generation system.

2. Overview of Resource Development Projects

(1) Development of geothermal resources

To promote the development of geothermal resources, NEDO is conducting geothermal development promotion surveys in promising geothermal energy areas which have not yet been accessed by private-sector efforts. Also being developed are small- to medium-scale binary cycle geothermal power generation systems that can utilize untapped low- and medium-temperature hydrothermal resources.

(2) Development of coal resources

To secure stable supplies of coal for Japan, NEDO is conducting, at the host country's request, geological and other surveys in countries where it is difficult for private companies to conduct business. NEDO is also engaged in the study and development of high-precision coal resource prospecting techniques in Japan and overseas. Moreover, to promote overseas coal development by Japanese companies, NEDO provides subsidies to help cover the cost of performing feasibility studies for the development of overseas coal resources, funds needed to prospect for resources, and liability guarantees to allow the companies to obtain the necessary capital for development.

3. Collection of Information

To promote the development and introduction of oil-alternative energy sources, NEDO is collecting and analyzing information collected both in Japan and overseas and is also conducting studies using that information. In addition, NEDO is engaging in publicity activities aimed at deepening the general public's understanding and awareness of oil-alternative energy, and training programs for technicians involved in the development and importation of overseas coal.

In Europe and North America, as the electricity business becomes more deregulated, positive policies are being implemented to introduce new energy forms. These countries have subsidy systems to strongly promote the introduction of new energy research and development, though the systems differ in the way they are practiced. Similarly, NEDO is engaged in information collection with the aim of promoting the introduction of new energy in Japan.

4. Promotion of International Cooperation

With respect to the supply of energy, global environmental issues are becoming a significant concern, adding to the old problem of resource limitations. In particular, it is feared that the emission of carbon dioxide, considered the principal cause of global warming, will act as a major drag on the use of oil and other fossil fuels. New energy development is crucial not only as an alternative to oil, but also as a means of addressing environmental issues. But with population increases and advances in industrialization in developing countries, energy consumption is expected to increase rapidly in the years ahead. Under such circumstances, there are limits as to what one country can do alone. New energy development calls for international cooperation.

Ever since it was established, NEDO has been promoting the enhancement of new energy development efficiency and technology transfer to developing countries. At the same time, to ensure energy security for the nation through international cooperation in energy matters, as well as to address global environmental problems, NEDO has been actively participating in international joint research and development and information exchange programs related to multilateral and bilateral new energy development efforts led by the International Energy Agency (IEA). With a set of legal framework changes effected in the spring of 1993, meanwhile, a number of international energy promotion activities were added to NEDO's purview of operations. These activities are international coal utilization projects (clean coal technology (CCT) model projects, etc.) and activities to rationalize international energy use — both international operations related to promoting overseas the introduction of energy-saving and oil-alternative energy technologies.

In the field of multilateral cooperation, NEDO carried out a total of 16 IEA-led agreement projects in fiscal 1994, including projects for fluidized bed combustion (FBC) technology, motor vehicle alternative fuel research and development implementation, and greenhouse gas-related technology research and development implementation.

In the field of bilateral cooperation, NEDO has conducted international joint demonstration studies with the goal of actively promoting the introduction of new energy sources in ASEAN and other developing countries which have large potential reserves of new energy resources. Activities carried out in fiscal 1994 included international joint demonstration studies on photovoltaic power generation systems in Thailand and other countries, on high-efficiency low-grade oil burners in Thailand, and on raw material preheaters for electric furnaces in the steelmaking process in Indonesia, as well as international joint technology development for solar energy utilization systems in Indonesia and research cooperation regarding simple-design purification systems for industrial wastes in Indonesia.

As for international energy promotion activities, NEDO has been conducting model projects involving technology transfer related to energy-saving and clean coal technologies in countries such as China and Indonesia. In fiscal 1994, NEDO carried out nine energy conservation model projects in four countries and clean coal technology model projects based on four themes and involving 10 units in four countries.

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CHAPTER 1

DEVELOPMENT
OF
TECHNOLOGIES FOR
SOLAR ENERGY UTILIZATION

DEVELOPMENT
OF
TECHNOLOGIES FOR
SOLAR ENERGY UTILIZATION

Contents

I

Development
of
Photovoltaic Power Generation Systems for Practical Use

Photovoltaic power generation systems have remarkable advantages such as utilizing clean natural energy, permitting installation at power consumption sites, and dispensing with power transmission cables. In order to accelerate the development and practical application of photovoltaic (PV) systems, cheaper and more efficient solar cells will be developed and, at the same time, technological development will be promoted with a view to furthering the sophistication and cost reduction of system technology and peripheral equipment.

1. Development of Technology for Thin-Substrate Polycrystalline Solar Cells for Practical Use

1.1 Development of Manufacturing Technologies for Low-Cost Substrates

1.1.1 Development of Silicon Manufacturing Technology for Solar Cells

(1) Objectives and Work Program

(Objectives for FY1996)

Refining cost: ¥2/g, at an annual output of 500MW

(Work Program)

Necessary studies will be made to establish elemental technologies required for the manufacture of SOG-Si by metallurgically refining commercially available high-purity metallic silicon (about 99.5% pure) by the following process as elemental technologies for mass production.

(a) Techniques for dephosphorization of silicon

The research results of last year led to the conclusion that the EB melting method was appropriate as a technique for dephosphorization. This year, further studies will be made on the technique of dephosphorization by EB dissolution based on the findings of last year and, on the basis of the resultant findings, the dephosphorization section of the EB dissolution apparatus of a 20kg scale, which can be continuous from the solidification refining process, will be designed and produced.

High metallic silicon — Dephosphorization — Rough refining — Decarbonization/deboronization — Final refining

(b) Solidification refining techniques

Last year, solidification refining techniques were studied with an apparatus of a 20kg scale. This year, the solidification refining techniques using the 20kg-scale apparatus will be perfected and, on the basis of the resultant findings, the use of water-cooled copper molds will be studied with a view to reducing the cost of the process of removing metallic impurities.

(c) Techniques for simultaneous decarbonization and deboronization

Last year, a technique to remove boron to the target concentration (0.1ppmw) by adding water vapor was developed using a small-scale (0.6kg) plasma melting apparatus, and an apparatus of a 20kg scale was designed and fabricated.

This year, attempts will be made, using the 20kg-scale apparatus fabricated last year, to develop a technique to remove boron to the target concentration. Furthermore, preliminary experiments will be carried out to remodel the apparatus so as to develop a technique to remove boron in silicon while continuously supplying silicon.

(d) Trial production of SOG-Si

The initial schedule will be brought forward, and the trial production of SOG-Si for quality evaluation will be attempted by combining the elemental technologies now under development. The conversion efficiency of the resultant product in solar cells under the NEDO project will be assessed, and the quality of the SOG-Si produced for trial will be evaluated on the basis of the measured efficiency.

(2) Summary for FY1994

(a) Techniques for dephosphorization of silicon

Regarding techniques for dephosphorization of silicon, dephosphorization to 0.1ppmw was attained by using the electron beam (EB) melting method. The conditions under which phosphorus in silicon can be reduced while metallic silicon is continuously supplied were identified, and further study gave prospects for dephosphorization to a concentration of 0.1ppmw.

In addition, an EB melting apparatus of a 20kg scale which can be made continuous with the solidification refining process was designed and produced.

(b) Solidification refining techniques

Concerning techniques for solidification refining, with a view to cost saving, the use of water-cooled copper molds in a small apparatus of a 2kg scale was considered. As a result, prospects were gained for the development of techniques for dephosphorization and dispensation with the crucible in the solidification rough refining process.

It was found that, in the distribution of the Fe concentration in silicon in the direction of ingot height when the solidification rate was 0.8mm/min, solidification refining took place to within 70% of the full ingot height.

Regarding finish refining techniques, the release agent and other elements were studied, and the development of elemental technologies with the 20kg-scale apparatus was thereby completed.

(c) Techniques for simultaneous decarbonization and deboronization

Concerning deboronization techniques, the boron concentration was successfully reduced to the target level (0.1ppmw) by applying the water vapor-adding process using the 20kg-scale plasma melting apparatus fabricated last year. Furthermore, in order to develop techniques for removing boron in silicon while continuously supplying and melting silicon, preliminary experiments were carried out to remodel the apparatus.

(d) Trial production of SOG-Si

SOG-Si for quality evaluation was produced on a trial basis by combining the elemental technologies now under development, and its conversion efficiency in solar cells (50 x 50mm) under the NEDO project was assessed.

As a result, a satisfactory efficiency of 14.1% (comparable to the efficiency when semiconductor silicon was used) was achieved, to demonstrate that SOF-Si can be prepared by the technique to metallurgically refine metallic silicon now being developed.

The conversion efficiency of solar cells fabricated by the efficiency improving process (developed by Sharp Corporation under commission by NEDO) was even higher, at 15.9%.

(3) Future Tasks

On the basis of the results of the developmental work so far accomplished, the following aspects have to be studied from now on.

(a) Development of elemental technologies (for assessing the state of removal, accelerating the treatment, and improving the yield of silicon among others) for mass removal of phosphorus and boron in silicon with the 20kg-scale apparatus

(b) Designing and fabrication of a 20kg-scale rough refining apparatus using water-cooled copper molds, and experiments with this apparatus

(c) Development of silicon washing techniques in various stages of the process

(d) Cost reduction through the development of a crucible-free semicontinuous process

(e) Identification of and consideration of problems involved in scaling up the apparatus

(f) Investigation of the quality of start material silicon having low impurity concentrations.

1.1.2 Development of Solar Cell Substrate Manufacturing Technology

(1) Electromagnetic Casting Process

(a) Objectives and work program

(Objectives for FY1996)

Manufacturing cost:	¥45/W at a module efficiency of 15% and an annual output of 100MW (basic process)
Ingot size:	35cm square
Lifetime:	No less than 20μsec
Casting rate:	2.0mm/min

(Work Program)

Whereas this project is to study a casting method for low-cost production of silicon ingots by melting and solidifying granular silicon material or substandard material consisting of crushed silicon lumps, the following aspects will be specifically taken up this year.

(i) Study to establish conditions for steady production of ingots with a 220mm square electromagnetic casting furnace

(ii) Study to raise the casting rate and improve the quality of crystals

(iii) Designing and production of the power source, coils and crucible system for a 350mm square electromagnetic casting furnace by using electromagnetic field simulation

(iv) Output tests and aluminum melting tests using the power source, coils and crucible for the 350mm square electromagnetic casting furnace

(b) Summary for FY1994

(i) Electromagnetic casting techniques for 220mm square furnace

This year, acceleration of the casting rate and development of steady casting techniques were attempted with the existing 220mm square electromagnetic casting furnace (Furnace No. 3), and the casting rate was successfully raised further from last year's 2.5mm/min to 3.0mm/min, resulting in the realization of continuous steady casting under the given conditions. It was also confirmed that there was no deterioration of the crystal quality results from the acceleration.

The EMC method is superior to the conventional casting method in the continuity of melting, solidification and cooling. In the EMC method, silicon is electromagnetically melted in a water-cooled copper crucible, and fine grains of silicon material are charged from above the molten bath.

As the molten bath is held floating on the side by the electromagnetic force during the charging, there are few paths for impurities to enter the molten bath.

The maximum casting rate achieved last year was 2.5mm/min, but this year steady casting was realized at a higher rate of up to 3.0m/min. The cast volume per hour at that rate was about 20kg.

The quality of crystals was evaluated in terms of conversion efficiency n in the cell fabrication process for in-house evaluation, diffusion length L, and C and O measurement by FT-IR.

Crystalline substrates were sampled from several ingots produced with the 220mm square electromagnetic casting furnace, and the correlation between the diffusion length and the conversion efficiency was investigated.

The casting rate was 2.0mm/min in every case. Fixing the casting rate at only one level made it possible to clearly reveal the L-η correlation. Whereas the change in L-η correlation with the casting rate presumably derives from a difference in the shape of the solid-liquid interface according to the casting rate and the consequent difference in temperature hysteresis, which delicately varies the crystal quality distribution in the horizontal cross sections of ingots, details are yet to be studied.

In the $L \leq 50\mu m$ range, the L-η correlation was evident on every cell fabrication line, but it was obscure on some cell fabrication lines in the $L \geq 50\mu m$ range. This point also has to be studied further.

Regarding the relationship between the carbon concentration in electromagnetically cast crystals and the cell conversion efficiency, whereas the solid solution limit of carbon in Si is about 3.5×10^{17} atoms/cc, the cell conversion efficiency is observed to decline at a lower carbon concentration than this level. Carbon may have a pinning effect on the propagation of crystal defects of Si during the casting process. Incidentally, the carbon concentration in the crystals produced with the conventional teeming type furnace is about 3.5×10^{17} atoms. While the EMC method is characterized by low susceptibility to the infiltration of impurities, as the presence of impurities contributing to the improvement of product quality has been suggested, the possibility of the need for doping with impurities cannot be totally excluded.

These findings about the correlation gives useful guidelines for the improvement of crystal quality in the future.

(ii) 350mm square electromagnetic casting furnace

a. Analysis of oscillator circuit constants of power source system

The oscillator circuit constants needed for the designing of the No. 4 electromagnetic casting furnace were analyzed. Whereas a 305mm square electromagnetic casting furnace was planned, the analysis was applied to a round model equivalent in cross-sectional area on account of the constraint of the number of elements. The impedance of the circuit system was about 0.1Ω. It was also confirmed that the molten bath could be maintained in an adequate shape for melting the raw material.

The optimal number and length of slits, which are main structural factors of a water-cooled copper crucible, were figured out by analysis, and used as design guidelines. The efficiency of melting was represented by the eddy-current loss (calorific value) of the molten bath part.

The melting efficiency changing with the number of slits reached the optimal level at 60 slits. Regarding the variation in melting efficiency with the slit length, the longer the slits, the higher the efficiency, but the inclination tended to become easier at about 600mm. The slit length was set to 530mm partly in view of the handling ease in experiments.

b. Testing of power source, coil and crucible systems for 350mm square electromagnetic casting furnace

In a graphite heat generation experiment using a 350mm square water-cooled copper crucible having a 1,000kw high-frequency power source, it was confirmed that sufficient heat for initial melting of silicon could be obtained. In an aluminum block melting test, the shape of the molten bath, induced heat generation and the oscillation of the molten bath, among other factors, were observed, and the researchers were convinced that no problem would arise even when silicon was melted.

(c) Future tasks

In order to further advance this research project eventually to make solar batteries available for practical use, the following aspects of casting technology should be emphatically studied.

(i) Improvement of the quality of crystals produced with the 200mm square electromagnetic casting furnace (by remodelling it to provide a heat insulating structure which can freely control the ambient temperature of ingots

(ii) Elucidation of the relationship between the concentrations of impurities and the quality of electromagnetically cast crystals

(iii) Study on the body structure of a 350mm square electromagnetic casting furnace, and designing and production of the furnace on that basis

(iv) Analysis of the temperature distribution and stress distribution in ingots with a view to producing larger electromagnetic casting furnaces

(2) Continuous Casting Method

(a) Objectives and work program

(Objectives for FY1996)

Manufacturing cost: ¥45/W at a module efficiency of 15% and an annual output of 100MW (substrate process)
Oxygen concentration: No more than 10ppma
Carbon concentration: No more than 5ppma
Diffusion length: No less than 150μm

(Work Program)

Using the silicon melting section fabricated in the preceding year, ingots of many different sizes including the 9-piece size and 16-piece size will be fabricated, and comparatively evaluated in terms of crystal quality and solar cell performance to find the most suitable size for mass production. In addition, a cooling section to be connected to the melting/injecting section will be fabricated for use in cooling the molds while being driven and in checking the effect of vibration on crystal growth.

(b) Summary for FY1994

(i) Fabrication of ingots of 16-piece size

Using the silicon melting/injecting section produced the previous year, a 16-piece ingot (430mm x 430mm x 400mmh) was fabricated by a batch process (molten silicon dripping). The ingot weighed 170kg. Compared with the 9-piece ingot previously fabricated, the 16-piece ingot retained a greater calorific value in relative terms and, at the same dripping rate as before, it was more difficult for the heat to radiate from the bottom of the ingot. Therefore, the 16-piece ingot was produced without insulation on its sides. Fine stripes were witnessed on the side faces, attributable to the intermittent supply of raw material silicon.

(ii) Oxygen and carbon concentrations of wafer

After the 16-piece ingot was machined and sliced, its oxygen and carbon concentrations were measured. The target concentrations, 10ppma or less for oxygen and 5 ppma or less for carbon, were substantially achieved. Yet, a greater carbon concentration was observed in the upper part of the ingot, which indicates room for further improvement.

(iii) Resistivity

The resistivity distribution in the boron-doped 16-piece ingot was substantially within the planned range of 1 to 2Ω•cm, though there was some unevenness.

(iv) Cell conversion efficiency and ingot height yield

Cells 100 x 100mm^2, 350μm in thickness, were fabricated for evaluation. Although the cell conversion efficiency was observed to be lower in the upper central part of the ingot, the overall efficiency stability in the vertical direction was generally satisfactory. It seems that the cell conversion efficiency in the upper central part of the ingot can be improved by adjusting the thermal gradient during the ingot fabrication process.

(v) Crystal growing section

The crystal growing section, fabricated in fiscal 1994, was connected to the melting/injecting section, and it was confirmed that the mold into which silicon was injected could be automatically driven from the injecting section to the growing section with no problem. Nor was found any vibration problem during the shift.

(c) Future tasks

From now on, while reproducing the manufacturing conditions, which have been identified through the batch process, in the crystal growing section, ingots will be produced while driving the mold in a state close to a continuous process. However, since no empty mold can be supplied with only the melting/injecting section and the crystal growing section, only one ingot can be fabricated. In view of this limitation, a preheating section will be produced in fiscal 1995 to enable ingots to be produced consecutively.

The yield and the cell efficiency distribution of the produced ingot will be checked, and the relevance of manufacturing conditions to these aspects will be studied, so that ingots of higher quality can be produced.

1.2 Development of Elemental Technologies for Cost Reduction of Polycrystalline Cells and Modules

1.2.1 Large-Area Cells

(1) Objectives and Work Program

(Objectives for FY1996)

Manufacturing cost: ¥210/W at a module efficiency of 15% and an annual output of 100MW

Elemental technologies needed for the production of high-efficiency low-cost solar cells will be developed, using 15cm square, 200μm thick large-area substrates.

(Work Program)

(a) Study on elemental technologies to reduce the cost of junction formation

For the formation of junctions on the light-receiving side, attempts will be made to optimize the dispersing conditions, and the possibility of increasing the throughput will be studied by using an in-line type apparatus. Regarding the formation of junctions on the back side, a method of formation which is compatible with thin substrates will be studied.

(b) Study on elemental technologies to reduce the cost of fine electrode pattern

With an eye to reducing the cost while achieving high efficiency, study will be made on mass production technology for the fabrication of a stable fine electrode pattern by a printing process using paste.

(c) Study on elemental technologies to reduce the cost of a low-reflection structure

With a view to reducing losses due to surface reflection, cost reduction of the low-surface reflection structure will be studied by applying a dry etching process.

(d) Study on elemental technologies to

reduce the cost of passivation

Elemental technologies for low-cost passivation will be studied.

(e) Study on module manufacturing technology

Investigation will be made on module structures, materials and other factors which would contribute to high-efficiency low-cost manufacturing.

(2) Summary for FY1994

(a) Study on elemental technologies to reduce the cost of junction formation

In order to form junctions on the light-receiving side at a high throughput, attempts were made to optimize the conditions of formation and to develop an apparatus. A junction is formed by inserting a substrate set in a jig into the furnace, subjecting it to dispersion and drive-in, and taking it out. An attempt was made to shorten the time taken to complete this junction formation step by raising the drive-in temperature.

Regarding the relationship between the drive-in temperature and the conversion efficiency, it was found that the processing time could be reduced by performing drive-in at 780°C after dispersion at 755°C. Further study was carried out on the dispersion step and the optimization of the drive-in temperature. While one cycle had been accomplished in 100-minute tact with the conventional dispersion furnace, it was confirmed that the total processing time could be reduced by 60% to 40 minutes. It was also confirmed that, by using an in-line type apparatus with separate dispersing and drive-in functions, the processing time could be reduced to 5.5 sec/sheet, far better than the target of 11 sec/sheet.

Concerning the formation of junctions on the back side, a gas dispersion method using BBr_3 was studied as a highly productive formation method with a high process yield and free from warping. The flow rate of N_2 in BBr_3 in an ambience of 1,000°C in dispersion temperature at an O_2 flow rate of 2l/min was varied, and a sheet resistance of 13Ω /□ was obtained at a flow rate of 15l/min. Then, a BSF structure was formed by varying the dispersion temperature between 800°C and 1,000°C, and electrical characteristics were evaluated. Investigation of the relationship between the dispersion temperature and the sheet resistance and of electrical characteristics showed that both the voltage and the amperage were higher at higher temperatures.

The voltage tends to be lower with this BSF structure than with the earlier developed BSF structure using Al paste, but its efficiency is not inferior.

(b) Study on elemental technologies to reduce the cost of fine electrode pattern

While a fine electrode pattern had been formed by photolithography or by a lifting-off method involving vapor deposition, electrode formation using Ag paste was attempted to save materials and to simplify the process.

Last year, fine electrode patternization was carried out by direct writing and printing, but a printing process using a screen was studied with an eye to achieving electrode formation at a still higher throughput. The apparatus discharges paste from a paste holder onto the screen to perform printing. At the time of printing, the squeegee section and the screen surface scarcely undergo printing, and the opening is filled with paste.

The paste is discharged onto the screen by the rotation of a roller within the unit.

The roller of the unit has functions to knead and deliver the paste, and the inside of the unit can be subjected to temperature control to keep the viscosity of the paste constant.

Fine patternization of the electrode requires optimization of the Ag paste, screen and printing apparatus among other things.

Printing was accomplished with three kinds of paste differing in viscosity and masks of different opening widths, and the paste characteristics were checked. More viscous paste was found more effective for fine patternization and increasing the film thickness.

This paste was further used for printing on a 15cm square substrate to confirm its suitability for printing. Electrodes of 90 to 100μm in width were uniformly formed all over.

(c) Study on elemental technologies to reduce the cost of a low-reflection structure

Dry etching was studied to reduce the cost of a low-reflection structure. As dry etching is little affected by the surface orientation, it offers good prospects for reduced manhours. First, a 15cm square substrate was dry-etched, and the distribution of the etched quantity within the surface was checked, resulting in the finding that the unevenness of the etched quantity was within ±10%. Furthermore, evaluation was carried out to estimate the effects of electrical characteristics, and an assessment of the open voltage distribution revealed that the unevenness within the surface was no more than ±0.75%.

Then, the damaging effect of dry etching on the substrate was investigated. It was found that there was no such effect.

(d) Study on elemental technologies to reduce the cost of passivation

Optimization of passivation technology was attempted with an oxide film. The effective carrier lifetime τeff was extended by introducing HCl before and after the oxidation. An oxide film of 150Å in thickness was formed at 800°C, and then subjected to annealing with hydrogen. This treatment resulted in the improvement of τeff, which had been about 300μsec, to 1msec (1.2msec at max.) (p-type MCZ (111), 180Ω•cm).

As passivation of a polycrystalline substrate with an oxide film tends to suppress the bulk passivation effect of the P-SiN film, the passivation effect was checked with bifacial silicon nitride solar cells (BSNSC) with a P-SiN film formed on the back side as well. The substrate used was a conventional cast product from Sumitomo Citix Co., Ltd. The result revealed that hydrogen annealing after the P-SiN film formation contributes to improvement in performance characteristics. The relationships of hydrogen annealing conditions with Jsc and Voc were compared with cells having only SiN (not hydrogen-annealed), and Voc of 622mV was obtained by hydrogen annealing at 700°C.

(e) Study regarding module manufacturing technologies

Investigation was made regarding module manufacturing technologies. In order to produce high-efficiency modules at low cost, conceivable approaches include the saving of material costs, reduction of the manhours spent in the module fabrication process, automation and enlargement of the module square measure. It is also necessary to study module structures differentiated by application, including the development of a module structure integrated with building materials. Using a polycrystalline substrate of 15.6% in average efficiency (with a standard deviation of 0.1%), it was found that even the conventional super-straight structure could give an efficiency of 15% or above.

(f) Evaluation of substrates

Three lots of cast substrates from the conventional No. 3 electrical casting furnace, built by Sumitomo Citix Co., Ltd., and SOG polycrystalline substrates produced by Kawasaki Steel Corporation were evaluated by the conventional evaluation process. Average efficiencies of 13.4% and 13.6% were achieved by Lot No. 3E-79-1 and Lot No. 3E-79-26, respectively, of the electrically cast substrates, while the average efficiency of Kawasaki Steel's SOG substrates was 13.4%. These results represent a major improvement (by 3.1% in average efficiency over the results of the previous evaluation).

Performance characteristics were evaluated of Bayer's polycrystalline substrates (German product), Sumitomo Citix's electromagnetically cast polycrystalline substrates and Daido Hokusan's DCM polycrystalline substrates, and comparison was made with the bulk passivation effect of an AR(P-SiN) film.

The result revealed that the P-SiN film has a bulk passivation effect. The lower the substrate quality, the greater that effect.

(3) Future Tasks

Further efforts should be made in the following aspects so as to establish a low-cost high-efficiency module manufacturing process using a 15cm square polycrystalline silicon substrate:

(a) Study on a process compatible with thin substrates having back side junctions and a formation apparatus;

(b) Optimization of process conditions for the low-cost formation of a low-reflection structure and a passivation film;

(c) Optimization of the formation conditions for a fine electrode pattern, and

(d) Search for a low-cost module structure.

1.2.2 High-Performance Modules

(1) Objective and Work Program

(Objectives for FY1996)

Manufacturing cost: ¥210/W at a module efficiency of 15% and an annual output of 100MW

Mass production technologies will be developed for high-efficiency solar cell modules using polycrystalline substrates.

(Work Program)

(a) Development of elemental technologies for mass production

Ways to speed up the process will be emphatically studied, focusing on the surface machining of cells and the junctioning process, as part of the development of elemental technologies for a high-speed cell fabrication process.

(b) Development of new module structure

Regarding high-efficiency low-cost modules, vigorous study will be made on high-speed continuous automation focusing on cell wiring techniques, and an experiment to confirm long-term reliability will be started through environmental testing.

(2) Summary for FY1994

(a) Development of elemental technologies for mass production

Emphatic study on ways to speed up the process, focusing on the surface machining of cells and the junctioning process, was started as part of the development of elemental technologies for a high-speed cell fabrication process.

Concerning the surface machining of cells, ways to speed up groove formation, which has already achieved a high conversion efficiency, are being studied.

Regarding the junction formation, technological development attempts were launched to achieve a higher speed from a comprehensive point of view, centering on the thermal dispersion method and involving its relevance to the formation of an anti-reflection film, with the objective of establishing fundamental technologies for mass production of principal parts in the cell fabrication process.

(i) Study on speeding up surface machining

So far it has been revealed that the formation of many groves on the cell surface by machining is effective for reducing the surface reflection of polycrystalline cells. With an eye to establishing mass production technology, study was made on sandblasting and grinding with a rotating whetstone, which were considered effective for high-speed formation of fine grooves on the surface of polycrystalline silicon substrates.

In sandblasting, which is described first, grooves are formed by blasting fine whetstone grains onto the substrate with compressed air. The substrate surface was covered with a sandblast masking film (50μm thick), and given a striped pattern by photolithography.

Then, a nozzle with which to blast the grains together with compressed air was moved over the substrate surface to grind grooves on it.

The material and size of grains suitable for the grinding of silicon substrates were studied, and it was found that grooves of 120μm in pitch and 50μm in depth could be formed with alumina-based grains of 20μm or greater.

Next is described the study progress on the method using a rotating whetstone. In the previous process for the fabrication of polycrystalline high-efficiency grooved cells, grooves were formed with a dicing saw having a thin rotating blade 50mm in diameter and 100μm in thickness.

This time, with a view to multi-blading, multiple blades were formed on the 10mm thick circumference of a whetstone 200mm in diameter, and the silicon surface was directly ground with it in high-speed rotation. Fine grooves of a 70μm pitch were successfully formed for the first time.

To evaluate these two machining methods together, while sandblasting is limited in its ability to shorten the pitch and involves difficulty in precise shape control, the rotating whetstone was revealed to be subject to little friction with the whetstone and permits high-speed machining of precisely shaped grooves.

(ii) Study on acceleration of electrode formation

As a result of study in fiscal 1993 on the acceleration of the electrode formation process, which is the main part of the cell fabrication, it was found that using silver paste for high-temperature baking and raising the substrate carrying speed in the baking furnace to 2000mm/min could give as high a conversion efficiency as the process under the previous conditions.

This year, study was continued on the possibility of increasing the carrying speed in the baking furnace by using a high-speed printing/baking apparatus.

The experiment was conducted at carrying speeds of 550, 1000, 2000 and 3000mm/min in the high-speed baking furnace, and the optimal baking temperature at each speed was determined. It was found that the higher the carrying speed, the higher the optimal baking temperature. Given these optimal baking temperatures, the cell performance at each carrying space was assessed, and it was found that at least as good a performance as before could be achieved even at a very high carrying speed of 3000m/min, 7.5 times as high as the previous carrying speed.

(iii) Acceleration of junctioning and anti-reflection film formation

Study was made on a system for simultaneous formation of junctions and anti-reflection films. In the experiment, junctions and anti-reflection films were formed at the same time by thermally decomposing titanium compound and phosphorus compound gases under normal pressure and depositing the decomposition products on the silicon substrate surface, followed by heat treatment.

Concerning the cell performance, a satisfactory conversion efficiency for a first attempt was achieved, though the amperage was somewhat low.

(b) Development of a new module structure

In fiscal 1993, study was made on the reduction of reflection on the glass surface and the achievement of a high packing factor for modules.

This year, study was carried out on the optimization of the groove angle, reduction of reflection on the glass surface and simplification of the module structure, centering on the acceleration of cell wiring within modules, and an experiment was started to confirm the long-term reliability of modules through environmental testing.

(i) Optimization of cell groove angle in module structure

Whereas groove formation in polycrystalline cells significantly contributes to performance improvement, this particular study focused on the optimal groove angle on the cell surface so that the module structure could maximize its optical confinement effect. The experiment was carried out by fabricating polycrystalline cells on whose surface grooves were formed with the aforementioned dicing saw at a blade tip angle of 30° to 70°, and assessing their performance characteristics. It was found that the optimal groove angle was in the range of 40° to 55°.

(ii) Study on reduction of glass surface reflectance

In fiscal 1993, with an eye to improving the short-circuiting amperage in the module state, an MgF_2 layer ($n \neq 1.35$) was deposited on a colorless sheet glass surface, and a 1.7% improvement in short-circuit amperage was confirmed.

This year, study was continued on performance improvement with the MgF_2 layer, and a fluorine resin film (n≠1.34) was also taken up for study as an alternative to the MgF_2 layer. This film, which can be formed by dipping, is likely to contribute to cost reduction.

In the experiment, the MgF_2 layer was formed over a colorless tempered glass sheet. The fluorine resin film was formed by dipping. Using these glass sheets, after laminating the cells, comparison was made with the conventional module structure to assess the improvement of the short-circuit amperage.

The short-circuit amperage was improved by a maximum of 2.7% with the MgF_2 film of 1000Å in thickness.

On the other hand, the glass sheet coated with the fluorine resin film (1000Å thick) also gave a 2.9% improved short-circuit amperage, comparable to the MgF_2 layer, and was found substitutable for the MgF_2 layer.

(iii) Study on acceleration of wiring

In order to reduce the cost of modules substantially, study is needed, at the same time as the development of a module structure which would make optical confinement possible, on a structure which would also permit high-speed wiring of cells, a requirement from the viewpoint of commercial application. In this report, an overview is given of the attempts under way to develop technologies for automatic high-speed wiring.

The apparatus which was designed and produced was intended to permit high-speed wiring and connection of 100mm-square cells in series by adopting a new cell aligning mechanism, shifting system and heating arrangement.

The experiment on the series connection of cells which were consecutively supplied gave a satisfactory curvilinear factor in the series-connected state, comparable to the previously achieved factor. More detailed conditions are being studied using the newly developed apparatus with a view to realizing a major breakthrough in high-speed wiring.

(iv) Study on evaluation of raw materials

Cell (50mm square) formation was carried out using unidirectional solidified substrates (75mm square) for use in the evaluation of silicon material. The cell efficiency achieved for the evaluative process was 14.1% at the maximum (10.9% in 1993), 13.5% at the minimum and 13.9% on the average. The high-efficiency process, for which a double-layer anti-reflection film was formed on the groove surface, gave a maximum efficiency of 15.9%.

(3) Future Tasks

With a view to working out elemental technologies for mass production, the development of new basic technologies for cost reduction was attempted, including a machining system to reduce reflection on the cell surface and the simultaneous formation of junctions and anti-reflection films. Regarding the module structure, an experiment to confirm long-term reliability was started while studying the possibility of speeding up the cell wiring process.

From now on, study should be continued on the stabilization of cell performance characteristics and time saving in the formation of new junctions, and at the same time attempts should be made to accelerate surface machining and optimize the conditions for high-speed electrode formation.

Concerning the module structure, under the condition of trying to reduce the time spent on wiring, optimization with the lamination process will be attempted.

In fiscal 1996, overall optimization will be sought while coordinating various elemental technologies from cells to modules, and elemental technologies will be established to achieve a module cost target of ¥210/W and a module efficiency target of 15% (an annual output of 100MW being presupposed).

1.3 Investigation and Research on Analysis for Practical Use

(1) Objectives and Work Program

(Objectives for FY1996)

In order to support research to bring thin substrate solar cells into practical use, current technical trends will be surveyed and analyzed, and technical solutions will be studied so as to have the findings reflected in the research and development activities for the practical application of thin substrate polycrystalline solar cells.

(Work Program)

(a) Surveys on technical trends regarding practical application of manufacturing technologies for thin substrate solar cells

(i) Silicon raw material and substrate

Current status of refining techniques for metallic silicon and its casting method, thin substrate cells, crystal defects, and lifetime

(ii) Cell formation technologies

Monocrystalline cell formation technology and polycrystalline cell formation technology

(iii) Research on achievement of ultra-high efficiency

New cell structure, hetero junction, thin substrate type cell, crystal defects, lifetime, surface/interface (electrical properties of interface and hydrogen passivation), and new electrode structure

(iv) Surveys on technical trends in scholastic societies, etc.

(v) Surveys on industrial trends

(vi) Future technical tasks

(vii) Surveys through invitation of lecturers

(b) Technical research on practical application of thin substrate type solar cell manufacturing technology

For efficient development of manufacturing technologies for thin substrate type solar cells, their technical problems will be analyzed, and solutions sought.

(2) Summary for FY1994

(a) Surveys on technical trends regarding practical application of thin substrate type polycrystalline solar cells

(i) Survey on silicon raw material and substrate

a. Silicon raw material

Combination of electronic beam (EB) melting and ingot fabrication results in evaporative removal of C, P, Ca and Al by EB melting and removal of Fe and Ti by solidifying segregation during ingot fabrication. In plasma melting, addition of hydrogen to plasma generating gas increases the energy efficiency.

For the dephosphorization technique adopted by NEDO, a hearth type refining technique involving the continuous supply of metallic silicon is being studied, and the techniques for the removal of carbon and boron use a non-shift type plasma apparatus to add water vapor for melting.

b. Techniques for substrate fabrication

i. Casting method

A molten silicon dropping method (DCM) is being developed as a basic technique for continuous casting, and DCM not only is more advantageous for unidirectional solidification but also excels in cell conversion efficiency. The maximum cell conversion efficiency and the maximum dispersion length by this method were 15.5% and 210μm, respectively.

For 9-piece ingots, a maximum cell conversion efficiency of 14.3% was achieved, and a yield of 80% or more was attained for cells of 13.5% and above. It was thus confirmed that DCM could provide essentially equal ingot quality to the products of the conventional casting method.

ii. Low-cost monocrystals

For information on the cost comparison and viability of monocrystals and polycrystals, references from Siemens were studied, and the output increase of monocrystalline cells, cost composition of monocrystalline cells and that of polycrystalline cells were studied.

(ii) Techniques for cell fabrication

a. Techniques for monocrystalline cell formation

Techniques for cell formation disclosed by various research institutions commonly use FZ substrates and surface passivation with SiO_2.

b. Techniques for polycrystalline cell formation.

Whereas many techniques for polycrystalline cell formation are applications of one monocrystalline cell formation technique or another, techniques for cost reduction also pose a major challenge.

Gettering, bulk passivation techniques, low-temperature passivation techniques and techniques to reduce surface reflection in place of texture etching for monocrystalline cells, among others, are under continuing research as unique techniques for polycrystalline cells. More recently, research attempts were started on thin substrate polycrystalline and emitter wrap through (EWT) cell structures in pursuit of higher efficiency for low-quality cells.

(iii) Research on achievement of ultra-high efficiency

The following items were studied technically with respect to the aspects cited under each subheading.

a. New cell structure

Utilization of the long wavelength range (impurity PV cells and cells of defective crystals), utilization of the short wavelength range (generation of multiple carriers and of field-assisted carriers) and high-efficiency multi-layered PN-junctioned cells of low-quality materials.

b. Hetero junctions

Tandem type elements, uni-junctioned elements, combination with Si, honeymoon cells, HIT cells and hetero-junctioned cells.

c. Thin-substrate cells

Thin-substrate Si solar cells for use in space, BSC solar cells, thin substrate polycrystalline Si solar cells (with a CVD-Si/ZMR/Si substrate) and thin film polycrystalline Si solar cells (with a ceramic substrate).

d. Defects in crystals— effects of Cu in Si

Variation in lifetime versus the depth directions of N-type and P-type samples, DLTS spectra of N-type and P-type samples, and variation in resistivity versus the depth direction.

e. MBIC measurement of electromagnetically cast Si wafers

Results of PL measurement.

f. Lifetime

Lifetime evaluation of Si minority carriers by PL, evaluation of long carrier lives according to PL frequency characteristics, technical problems and future prospects.

g. Surface/interface

Effects of fixed electric charges in the passivation film, capture cross section at the SiO_2/Si interface level, relationship between the surface recombination rate and the fixed charge density, passivation using hydrogen radicals, passivation using a low-temperature formed film, and separation of surface/interface of solar cell materials and bulk properties as determined by non-contact measurement.

h. New electrode structure

Reduction of optical shield loss, restraint of recombination on the electrode/substrate interface, and effect of the difference in work function.

(iv) Surveys of technical trends in scholastic societies, etc.

In order to survey technical trends regarding solar cells, our delegates participated in international conferences and visited research institutes.

a. European Material Society Meeting
b. 12th European Photovoltaic Solar Energy Conference
c. 2nd International Rapid Thermal Processing Conference
d. Centre National de la Recherche Scientifique
e. Laboratoire de Physique des Interfaces et des Couches Minces Ecole Polytechnique
f. 7th International Symposium on Passivity
g. First World Conference on Photovoltaic Energy Conversion

(v) Surveys on industrial trends

Trends were surveyed regarding the domestic and overseas situations of raw materials, production and external conditions for solar cells.

(vi) Future technical tasks

a. Situation of technological development of crystalline Si solar cells

i. Current status of efficiency improvement

The conversion efficiencies of cells using cast polycrystals and cells using CZ monocrystals (some using FZ) are as follows.

Type	Laboratory level	Factory prototype level	Factory mass production level
Polycrystalline cells	17 - 18%	15 - 17%	13 - 14%
Single crystalline cells	22 - 24%	18 - 20%	16 - 17%

ii. Current status of cost reduction

The focal point at present of technical issues regarding cost reduction is the development of low-cost high-quality cast crystals.

Currently, Wacker's casting techniques are mainly employed, and attempts are under way to enlarge the bore and improve the quality. According to a prediction of the future of monocrystalline Si solar cells formulated by Mr. Mitchell of Siemens Solar , the cost can be reduced to \$2/Wp even with monocrystals. Even if this forecast is too optimistic, it has to be noted that, although the cost up to the wafer stage accounts for some 50% of the total at present, its proportion at the mass production level will be reduced to 33% and that of the module cost will become the greatest, 48%, in relative terms. This calculation suggests the importance to future developmental attempts of the technologies to simultaneously improve efficiency and reduce costs, such as the low-temperature process and the continuous process.

b. Future developmental tasks

- High efficiency

i. Development of high efficiency modules

Good prospects are now being gained for the development of modules having an efficiency of 15%, and even higher efficiency should be sought in the future. Monocrystalline Si manufacturing technology and new technologies suitable for application to mass production instead of laboratory production should be developed, for which research findings on ultra-high efficiency Si solar cells can be utilized.

ii. Development of high-efficiency cells of medium-quality crystals

Although electromagnetic casting developed by NEDO is the most promising technology for cost reduction, its weakness lies in product quality. Technological development to enable high-efficiency cells to be manufactured, even though of medium quality, requires the development of techniques to eliminate defects in crystals and impurities which are harmful to solar cells in the low-temperature passivation and cell fabrication stages as well as low-temperature process techniques.

- Cost reduction

i. Development cell/module mass production technology

Development of mass production technology, fully utilizing automation techniques to handle large quantities of cells and modules, is essential.

ii. Development of technology compatible with application systems

Integration with building materials is now attracting note as a promising application system, and this requires a different technology from the traditional orientation of module development, whose overriding consideration is electric power. One of the likely themes of such technological development is a low light condensing module.

(vii) Surveys through invitation of lecturers

a. Wolfgang Koch (from Bayer, Germany)

A survey was made on the ingot fabrication method, characteristics of BAYSIX wafers and the lifetime of minority carriers in the solidification by planar interface (SOPLIN) process. A technical survey was also made on the principles, ribbon raising speed and continuous casting stage in the ribbon growth on substrate (RGB) process.

b. Shinya Tsuda (from Sanyo Electric)

A survey was made on the characteristics of a-Si/c-Si hetero junctions, the HIT structure, approaches to efficiency improvement, characteristics of ACJ-HIT and p/n hetero junctioned cells, characteristics of polycrystalline cells, their application to polycrystalline thin film Si cells and the future outlook for the use of the HIT structure.

(b) Technical research concerning practical application of thin substrate solar cell manufacturing technology

Regarding the commissioned research project to develop thin substrate solar cell technology, a "subcommittee on thin substrate related technology," comprising experts from the industries concerned, the government and the academic community, was set up and convened twice to check the progress of work by each company sharing the responsibilities, to identify problems, to analyze phenomena and to study solutions.

(3) Future Tasks

The themes to be taken up concerning polycrystalline silicon solar cells include further pursuit of technical problems in the raw material refining process and the substrate fabricating process, together with mass production at lower cost.

Regarding monocrystalline silicon solar cells, techniques to enable further improvement of efficiency will be sought and studied. Recent market trends relevant to the development of solar cells also require research.

2. Research on Fabrication Technology for Thin-Film Solar Cells for Practical Use

2.1 Research on Low-Cost Fabrication Technology for Large-Area Modules

2.1.1 Technological Development for Fabrication of Amorphous Solar Cells and Modules (Technological Development for Advanced Structure Integrated Amorphous Solar Cells)

(1) Objectives and Work Program

(Objectives for FY1996)

Module cost: ¥170/W at an annual output of 100MW

Conversion efficiency after light-induced degradation: 8.5% or above (at 30cm x 40cm or larger)

(Work Program)

Various approaches will be attempted to develop materials, unit cells and stack cells with an eye to improving the efficiency and reliability of multi-bandgap structure solar cells, and study will be made to improve the quality and reliability of a-Si and a-SiGe in the aspects of material and structure, and to optimize the structure of solar cells.

Attempts will also be made to develop a reverser-type through-hole contact (THC) integrated-type structure, which is more suitable for the multi-bandgap structure than is the conventional integrated-type structure.

(2) Summary for FY1994

(a) Development of highly efficient and reliable solar cells

This year, in regard to materials, fine structural control was studied, taking into account the effects of trace impurities and the SiH_2/SiH dependence of light-induced degration, as were, in regard to structure, design guidelines using a new stack cell simulating method. Further improvement of efficiency after photodegradation was sought through the development of these elemental technologies.

(i) Technology to improve stabilized conversion efficiency through microstructure control

Already, in order to control the state of combination of Si and H and the network, techniques to improve the quality of the i-layers to provide high hydrogen-dilution buffer layers through fine control of the deposition rate and substrate temperature during the formation of the i-layer had been developed on the basis of a high quality amorphous film produced by the super-chamber method. This year, with a view to improving the stabilized conversion efficiency of a-Si solar cells, further efforts were made to reduce SiH_2/SiH in the i-layer and optimize the film thickness through fine structural control, and a stabilized conversion efficiency of 8.8% ($1cm^2$) was achieved, which is the highest in the world for single cells. Further improvement of the stabilized conversion efficiency of single cells can be expected by optimization to enhance the stabilized conversion efficiencies of TCO, the p-layer and the buffer layer.

The effects of oxygen, nitrogen and p-type boron having infiltrated into the i-layer of a-Si solar cells on the performance characteristics of solar cells were also quantitatively assessed. The efficiency was observed to be deteriorated significantly by the influence of the weakened electric field on the n-layer at an oxygen content of between 10^{20} and $10^{19}cm^{-3}$ or more, or a nitrogen content of $10^{18}cm^{-3}$ or more, and by that on the p-layer side at a boron content of $10^{16}cm^{-3}$ or more. This time, with an eye to investigating the effects of impurities in further detail, the compensatory effect of simultaneous doping with oxygen, nitrogen and boron was assessed. Observation of variations in photoconductivity and dark conductivity when an a-Si film containing $1 \times 10^{20}cm^{-3}$ of oxygen and $3 \times 10^{18}cm^{-3}$ of nitrogen was doped with a trace amount of boron revealed that the dark conductivity, which had been raised by the mixture of oxygen and nitrogen, was reduced by the compensatory effect of boron to about the same level as that of a low-impurity film. The photoconductivity also showed a variation which seems attributable to the Fermi transition. Also in the evaluation of the defect density using CPM, a similar trend was observed. These findings will prove useful for designing the electric field in cells.

(ii) Reliability improvement of multi-bandgap cells

Study was made to improve the reliability of a-SiGe:H as a narrow-bandgap i-layer material for the bottom cells of multi-bandgap cells, and the stabilized conversion efficiency of 10.6% was achieved, the highest level in the world for $1cm^2$. This time, study was further made on "the composition-dependence of the light-induced degradation characteristics of a-SiGe:H cells whose optical gap is constant." As a result, it was found that, although the light-induced degradation rate of a-siGe cells is higher in the region where the hydrogen quantity is smaller, the performance after stabilization is superior where the hydrogen quantity is smaller. It was also found that the time constant of photodegradation is not dependent on the composition. Analysis of the light-induced degradation characteristics of a-SiGe single cells with different optical gaps by a stretched exponential formula revealed that the narrower the optical gap, the greater the time constant of light-induced degradation. These findings are expected to contribute to the elucidation of the light-induced degradation mechanism of a-SiGe:H alloys and the realization of more stable stack cells.

As the stack cell structure consists of unit cells connected in series, not only its initial but also the stabilized characteristics are greatly affected by their amperage balance. Furthermore, as the I-V characteristic after light-induced degradation varies with the film thickness or quality of the i-layer especially after light-induced degradation, the optimal design of the stack cell structure was difficult previously. This year, a technique to precisely calculate the performance characteristics of the stack cell before and after light-induced degradation has been developed for the first time, to make optimal designs possible.

Characteristically, this technique combines a theoretical approach to finely reproduce the stacked state of individual unit cells constituting the stack cell structure, each formed independently, by using their I-V characteristics before and after light-induced degradation, and an experimental approach, applied to the light-induced degradation part, to precisely calculate the I-V characteristics after light-induced degradation. For this purpose, the technique takes into account spectrum dependence and the soaking intensity dependence, varies the film thickness in calculation from the measurement of the photo I-V and dark I-V characteristics of unit single cells before and after light-induced degradation, and thereby figures out the I-V characteristics of the stack cell structure. The stabilized conversion efficiency of a-Si (1.55eV)/a-SiGe (1.33eV) is predicted by this technique to be close to 11%, and the light-induced degradation efficiency achieved by experiment is 10.6%, endorsing the validity of this technique.

Then, this technique was also applied to three-stack cells, and calculation was made with the supposition of using 8.75eV and 1.28eV i-layers, which are highly appreciated as high-quality i-layers, more specifically as front and bottom cell i-layers, respectively. This calculation used cells whose stabilized FF is thought to be the same whether the bandgap is widened or narrowed on the basis of the performance characteristics of the unit cells of the highest currently available quality. As a result, it was found that a stabilized conversion efficiency of 12% or more can be attained. Based on the design guidelines obtained by this study, further improvement in stabilized efficiency can be expected in the future by enhancing the reliability of these unit cells.

(b) Development of a new modular structure

Attempts are being made to develop a reverse-type through-hole contact (THC) integrated-type structure solar cell which permits resistance loss reduction with transparent electrodes in addition to expanding the effective area. This year, optimization of the conditions for the integrated formation of the inverse type structure was attempted by means of high-precision analysis of the temperature distribution by a laser processing simulation method, and laser patterning techniques were developed for the back side electrode and the a-Si film. Furthermore, for transparent electrode patterning, which had been difficult with the conventional processing which basically relies on thermal techniques, a high-precision and loss-damage processing method was developed by utilizing laser abrasion. With this laser abrasion technique, combinations are directly cut with optical energy, and its very principles make the technique minimally susceptible to damage. Evaluation of the performance characteristics of cells for which this technique was used led to the discovery of favorable processing conditions for selective patterning of transparent electrodes alone.

(3) Future Tasks

With a view to achieving targets for fiscal 1996, the development of elemental technologies is successfully under way, including the achievement of the highest stabilized conversion efficiency for single cells in the world. In order to realize low-cost large-area solar cell modules, the following tasks remain to be accomplished.

- Realization of materials and a structure for high-stability a-Si-based solar cells
- Development of techniques for area expansion, including ones for a high-output module structure

To solve these problems, integrated accomplishment of the following steps would enable large-area modules to be manufactured at low cost.

- Development of elemental technologies to improve the stabilized efficiency
- Development of elemental technologies for large-area high-output modules

2.1.2 Technological Development for the Fabrication of Amorphous Solar Cell Modules (Technological Development for Film Substrate Amorphous Solar Cells)

(1) Objectives and Work Program

(Objectives for FY1996)

Module cost: ¥170/W at an annual output of 100MW

Conversion efficiency after light-induced degradation: 8.5% or above (at 30cm x 40cm or larger)

(Work Program)

Techniques to form SCAF-structured a-Si solar cells on a plastic film and techniques for performance improvement will be developed, and film-substrate solar cell submodules will be produced on a trial basis and tested.

Film formation experiments will be carried out to improve the quality and narrow the gap of a-Si film, and the film thereby formed will be applied to cells with an eye to efficiency improvement.

(2) Summary for FY1994

(a) Research on high-throughput process technology

(i) Process technology for trial manufacture of film substrate solar cells

Process technology development and trial production of and experiments with submodules were carried out for film substrate a-Si solar cells to which was applied the Series-Connection through Apertures on Film (SCAF) structure, a new series-connection structure whose principles had been successfully endorsed by trial production in fiscal 1993.

A substrate punching mechanism, which would be a key to successful production of SCAF-structured solar cells, was added to the film substrate pretreatment apparatus introduced in fiscal 1993. A mechanical punching system was selected for this mechanism from the viewpoint of throughput. Development of a stepping roll (SR) film formation system was attempted for the formation of thin film over the film substrate. Last year, an SR testing apparatus consisting of a plasma CVD chamber and a sputtering chamber was produced on a trial basis. This year, on the basis of the findings of the study on technical problems using this trial apparatus, a multi-chamber SR apparatus comprising five plasma CVD chambers and one sputtering chamber was designed and produced, and experiments were carried out with it to produce SCAF-structured film substrate cells on a trial basis.

To check the uniformity of the film formed by the SR system over a large area, eight consecutive frames of 64 single-junctioned $1cm^2$ cells were formed in a matrix over a 40cm x 40cm area, which is the effective film formation area of the SR testing apparatus developed in fiscal 1993, and the distribution of film formation characteristics were assessed. More than 99% of the cells gave a Voc above 0.85V, and this finding revealed that the occurrence of short-circuiting in cells produced by the SR system was practically negligible. An SCAF-structured double-layer tandem submodule was produced on a trial basis with the SR testing apparatus (for single-chamber film formation), and a 7.2% efficiency was achieved in a $980cm^2$ area (70 in series). An SCAF-structured double-layer tandem submodule of $64cm^2$ in area (16 in series), whose a-Si layer was formed by cutting the film substrate after the formation of a metallic film and using an IEV apparatus (for multi-chamber film formation) for conventional glass substrates gave an efficiency of 8.0%.

(ii) Techniques for improving the efficiency of film substrate solar cells

For their application to film substrate solar cells, an attempt was made to improve the efficiency of substrate type tandem cells. As the diffusion of phosphorus from the i-layer to the n-layer in nip-structured cells has a significantly adverse effect especially on thin top cells, the influence of counterdoping with boron on top cells was studied this time. Substrate type single cells (glass substrate/metallic electrode/nip/ITO-structured cells), whose i-layer thickness was reduced to 100nm, were prepared, and the relationship between the quantity of counter doping of the i-layer with boron and cell performance was studied.

It was found that Jsc and FF increased with boron doping, resulting in improvement in conversion efficiency. Especially at a boron doping quantity of 1.5ppm, a favorable FF level of 0.743 was achieved. Study on the spectral responses of cells revealed that counter-doped cells were improved in inner quantum efficiency in the long wavelength range, which is presumably attributable to the cancellation of the effect of phosphorus diffusion to uniformize the inner electric field. Furthermore, attempts were made to narrow the optical gap of the i-layer of bottom cells by high-temperature film formation and to improve the short-circuit current (Isc)m by optimizing the film forming conditions of Ag, which constitutes metallic electrodes, the film thickness of ITO, which constitutes transparent electrodes, and the transmissivity.

(iii) Modulization technology

Conditions for the thermocompression bonding and cross-linking of EVA as sealant were studied. It was found that cross-linking takes more than twice as long at a temperature of less than 130°C than at 140°C. Based on this finding, experiments were conducted on rubber roll type lamination as a modulization system with a view to increasing the throughput of the laminating process. In these experiments, wrinkling was observed when tension was applied unevenly. For this reason, study is being made to work out a system which can apply uniform tension to each material.

(b) Research on techniques for performance improvement

(i) Techniques for forming narrow-gap materials

For the purpose of application to bottom cells of tandem cells, qualitative improvement of aSiGe:H film of around 1.6eV in optical gap (Eg) and its application to cells were tried. A mixture of $SiH_4 + GeH_4 + H_2$ was used as reactive gas, $SiH_4 + GeH_4$ and H_2 were, respectively, kept at 40sccm and 200sccm (constant), the gas flow rate ratio of GeH_4 was adjusted, and Eg was kept constant at 1.6eV all the time. The plasma electron temperature (Te) was measured by double probing, and its relevance to the optical/dark conductivity ratio was checked. It was found that Te tended to drop, and sph/sd to rise, as intervals between electrodes were extended. The resultant a-SiGe:H film had sph/sd of 3.0×10^5 and sph of 1.4×10^{-5}S/cm. The defect density (Nd) of this film determined by PDS was relatively low, 4.4 x 1016cm^{-3}. Use of this film for the i-layer of pin cells 1cm^2 in size resulted in an efficiency of 8.35%.

In order to clarify the bombardment effect of ions brought to incidence on the film growth surface during a-Si film formation, an ion energy-controlling plasma CVD method was developed. Two parallel electrodes of the same size were inserted as double probes into the plasma parallel with the discharge electrode, and film formation was carried out, with an electroconductive substrate fitted using one of the probes as susceptor.

Experiments were also conducted to form an a-Si:H film by mixing SiH_2Cl_2 into SiH_4 and applying the plasma CVD method. The experimental conditions included the dilution of SiH_2Cl_2 and SiH_4 with H_2, $SiH_2Cl_2 + SiH_4$ = 30sccm, H_2 = 30sccm, an $SiH_2Cl_2/(SiH_2Cl_2 + SiH_4)$ ratio of 0 to 1/3, a gas pressure of 0.1torr and a substrate temperature (Ts) of 230 to 275°C. At an $SiH_2Cl_2/(SiH_2Cl_2 + SiH_4)$ ratio of 1/12 or less, films having an sph/sd ratio of above 106 were obtained. Concerning the photodegradation characteristics of the photoconductivities (sph) of these films, films of less than 1/30 in $SiH_2Cl_2/(SiH_2Cl_2 + SiH_4)$ ratio were found about half as fast as films of SiH_4 alone in light-induced degradation rate, and those of 230°C in substrate temperature proved less susceptible to light-induced degradation than those of 275°C.

(ii) Techniques for efficiency improvement of double-layer tandem cells

For the purpose of assessing the expected power generation performance of tandem cells in practical use and feeding back the findings to the efforts to work out a more stably operating device structure, the outdoor exposure tests were continued, and at the same time study was made on a simplified model for simulating the average monthly output. In addition to the effect of the solar spectrum which had been studied, the influences of temperature and solar irradiation were taken into consideration this year. This model was intended to permit prediction of the average generated wattage in each month if the average maximum cell temperature, the total solar irradiation intensity per day, the ratio of the spectral solar irradiation intensity in each month and the conversion efficiency of the a-Si solar cell module in its standard state were given. For this purpose, it was necessary to know the effective temperature and solar irradiation in each month, and the illuminance coefficient relative to the aforementioned parameters. Regarding the temperature, a substantially constant compensation coefficient was discovered between the maximum cell temperature and the effective temperature. Concerning the illuminance, a proportional relationship was found between the total solar irradiation intensity per day and the effective solar radiation intensity. On the basis of these findings, the spectrum was compensated and the wattage generated was calculated from the conversion efficiency in the standard state, and the result was in good agreement with the actual measurements, testifying to the validity of this method.

(3) Future Tasks

(a) Research on high-throughput process technology

With a view to improving the performance of SCAF-structured large-area solar cells, the trial process will be further improved, focusing on the multi-chamber SR type film formation apparatus and the roll type laser scriber apparatus, and film substrate solar cell submodules will be produced and subjected to experiments.

(b) Research on technology for performance improvement

To further improve the stabilized efficiency of tandem cells, attempts will be made to enhance the quality of narrow-gap a-Si-based films and to apply the obtained films to those cells.

2.1.3 Fabrication Technology for Large-Area Amorphous Solar Cell Modules (Technical Development for Sealing Materials)

(1) Objectives and Work Program

(Objectives for FY1996)

For assumed large-area amorphous solar cells ($0.4m^2$ or above), a coat-sealing type modulization technique, by which the back side can be sealed at an application rate of $0.24m^2/min$, will be developed.

(Work Program)

(a) Trial production and analysis of small and medium-area modules will be continued, and a decision will be made on the choice of a sealing resin blend suitable for mass production of reliable modules.

(b) The module structure and processing procedure designed in fiscal 1993 for a assumed simplified frame will be applied to the solar cells to be produced under the next subject, and work to identify and solve problems will be started.

(c) In order to confirm the multi-purpose applicability of the modulization techniques, many ZnO/Ag-structured cells will be modulized to identify problems in reliability and productivity.

(d) While building up data from field tests and accelerated tests of small-area and medium-area modules, evaluation of the reliability of the modules produced on a trial basis under the foregoing subject will be started.

(2) Summary for FY1994

Unlike crystalline solar cells, amorphous solar cells permit greater freedom in the choice of the substrate and ready expansion of the square measure, and accordingly are compatible with substrate-integrated structures in which solar cells are formed directly on a large-area glass substrate. Research was undertaken for the purpose of reducing the cost by developing a coat-sealing type modulization technique suitable for amorphous solar cells.

This year, coat sealing was applied to solar cells having double ZnO/Ag layered backside electrodes, which are considered particularly vulnerable to corrosion, to identify and solve problems. For the wiring leading to the terminal box, neither transparent electroconductive nor deposited metallic film is sufficient for reducing the resistance, and copper foil is used instead. In a substrate-integrated module, as the length of copper foil wiring is extended, if its adhesion to the module is not adequately secured, the wiring may get broken by any distortion of the module or a difference in expansion coefficients due to the heat cycle. Furthermore, this lead section, because of its level difference, is known to drag bubbles in when liquid resin is being applied. For this reason, there is added a process to fill resin in with a dispenser in advance of coating, but this also is known to be insufficient by itself. Moreover, since amorphous cells have an electroconductive layer all over, in order to secure sufficient dielectric strength between the frame and terminals, they require a different contrivance from what conventional modules do.

Regarding sealing resins on the other hand, it is required to strengthen their adhesion to Ag so as to prevent backside electrodes from corrosion, not to let gas, which would give rise to bubbles, generate during hardening, and improve their thixotropy to facilitate application.

(a) Study on the blending of sealing resins

To check the corrosion of double ZnO/Ag layered electrodes, mock-up samples were made of liquid resin blends hypothesized in fiscal 1993. Their variations in high-temperature high-humidity tests were observed, and it was confirmed that the performance characteristics of cells did not change in accelerated tests for up to 1,000 hours.

Meanwhile, though no change in shape was detected in microscopic observation, the color was found to vary somewhat, and it was found that the adhesion strength of the ZnO/Ag interface might change sometimes. For this reason, various additives were tried, and it was discovered that the addition of appropriate quantities of diisocyanate and an isocyanate-based silane coupling material in combination could suppress variations in the adhesion strength of members. However, as it was also found that their addition raised the thixotropy of blends and invited trouble in the coating process, filler materials and other factors were reviewed, and a blending prescription to suppress thixotropy and facilitate the flow of resins was obtained.

(b) Study on module structure and processing procedure

Although there is no relevance to the improvement of reliability in weathering tests, the selection of a cover film to ensure mechanical strength against scratches and the like had been undertaken. Mainly fluorine-based films were evaluated with respect to reliability (against light, heat, humidity and so forth), mechanical strength, workability, cost and appearance, and glass cloth was eventually chosen.

While the cover glass-substrate integrated structure has an advantage in cost reduction, it involves the problem of withstand voltage, which poses no major problem in the conventional structure. JIS requires a withstand voltage of twice the system voltage plus 1kV between terminals and the frame. To a super-straight structure in which submodules are arranged on a cover glass, it is relatively rare for the withstand voltage to pose a problem unless there is some trouble in the process. However, in an a-Si solar cell module, where a transparent electroconductive film is formed all over the cover glass, it is very likely that continuity to the frame will arise, including the possibility of the transparent electroconductive film extending to the frame, and accordingly insulation from the frame should be achieved somehow or other. Insulation of the substrate surface by laser scribing was tried, and the laser scribing conditions which would permit simultaneous steady patterning of the transparent electroconductive film, a-Si and back side metallic electrodes were discovered by optimization. Modules with different widths of the laser-insulated pattern were produced on a trial basis, and their withstand voltages were measured, resulting in a relatively favorable relationship to the patterning width.

(c) Development of low-cost module sealing process

Bubbles in sealing resin, which could invite corrosion of the module, should be kept to a minimum. In fiscal 1993, a curtain coater type apparatus was developed, and its utilization in the process was studied. In experiments on actual coating, it was found that the generation of bubbles could be substantially reduced by optimizing the arrangement of T-dies and the coating conditions including the rates of discharge and coating. This year, the process was scrutinized in further detail to study how the generation of bubbles could be suppressed. It was discovered that bubbles are more likely to occur around the lead wiring, which is a projecting part of the module, than elsewhere, the most likely between the resin filled in with the dispenser and the subsequently applied back side sealing resin. But bubbles do not arise around the part of the lead wiring parallel to the direction of resin application, while they do occur in the rectangular part of the lead wiring. These bubbles, it was found, could be driven away in the direction of application by laminating the cover film. It was confirmed that the greater the length of lamination to the lead wiring or the narrower the clearance against the thickness of laminated coat, the greater the amount of bubbles that could be driven away. It was found that, given the current position of the lead wiring, the problem could be averted by utilizing these behaviors during lamination.

At the same time, the presence of minute bubbles generating from within the resin was noticed in addition to the bubbles occurring from the process, and their cause was searched for, together with a way to reduce them. As a result of the search, it was suggested that a reaction decomposing the SiH radical of the curing agent was taking place to a minute degree as a competitive reaction to the usual hardening reaction by hydroxylation. This means that SiH radicals react with the trace moisture in the resin and active hydroxyl radicals which seem to be present on the surface of inorganic filler. A part of an anti-aging agent could catalyze this reaction. Since the hydrogen thereby generated diffuses rapidly in the resin, it is usually dispersed into the atmosphere before the resin hardens, but, in the presence of a cover film, part of this hydrogen is presumably taken into the resin to become bubbles.

As changing the hardener would affect the very choice of the oligomer, the remedy was sought mainly in the choice of the anti-aging agent and cover film. As a result, a correlation was found between the state of bubbling and the melting point of the anti-aging agent, and this correlation was taken into account in selecting the anti-aging agent. Then, using this blend, the occurrence of bubbles was checked with different kinds of cover film, and no bubble formation attributable to the generation of hydrogen during hardening was detected when glass cloth with high gas permeability was used for the cover film.

Furthermore, along with the changes in blend and cover film material, the standard condition (0.3m/min) for coating and lamination using T-dies, which had been tentatively determined last year, were reviewed, and this process was confirmed to be still possible with a slight modification of the conditions. Then, study was made on the possibility of accelerating the coating and lamination, which are key factors to the productivity of this process, and acceleration up to 1.9m/min was found feasible. On the other hand, along with the acceleration, the tolerance of the coating condition was significantly narrowed, and its upper limit is estimated at 2 to 3m/min.

(d) Confirmation of the long-term reliability of new type modules

The various PIB-coated type modules fabricated last year were put to continued reliability tests, involving outdoor exposure, in and out of Japan, and data were thereby accumulated. For solar cells having ZnO/Ag electrodes, modules were prepared on a trial basis under the optimal sealing conditions currently available, and some of the tests endorsed their freedom from degradation.

(3) Future Tasks

(a) Economic evaluation will be carried out of the resin blends, which have been determined with both reliability and processing ease taken into consideration, and the blends will be further studied from the viewpoint of the material cost with an eye to reducing the sealing cost.

(b) Structural problems with and processing ease of low-cost modules produced for trial will be checked, and the final module structure will be determined by optimization on that basis.

(c) Sealing resin film thickness reduction and productivity enhancement through improvement of the coating apparatus will be attempted from the viewpoint of cost saving.

(d) Data accumulation from the field test of small-area and medium-area modules will be continued, and the fireproofing of coated type modules will also be studied to identify problems relevant to practical use.

2.1.4 Technological Development for the Fabrication of CdTe Solar Cell and Modules)

(1) Objectives and Work Program

(Objectives for FY1996)

Module cost: ¥170/W at an annual output of 100MW
Conversion efficiency: 10% (40cm x 80cm or larger)

(Work Program)

In order to achieve the above-listed targets, technological development will be attempted in the following aspects.

(a) A high-transmissivity and low-resistance CdS film and a high-quality CdTe active layer will be developed by improving the materials and process, and the efficiency of large-area CdS/CdTe solar cells will be thereby enhanced.

(b) For the purpose of reducing the cost of large-area CdS/CdTe solar cells, study will be made on the possibility of accelerating coat patterning, and a high-productivity uniform baking system will be studied to achieve a uniform large-area sintered film in a short period of time so that the production line speed can be increased. Furthermore, development of techniques for the utilization of low-cost materials and low-cost but reliable and safe modules will be attempted.

(2) Summary for FY1994

(a) Research on techniques to improve the efficiency of large-area solar cells
   (i) Study for qualitative improvement of CdTe active layer

It is known that the film quality of the CdTe active layer may greatly vary with the composition and grain size of the mixture of Cd, Te and CdTe obtained by crushing Cd and Te, and accordingly the control of these factors is essential for improving the film quality. As it was impossible to individually control the crushed grain size and the mixture composition with the conventional ball-medium mill, a ring-medium mill was introduced this time to study crushing conditions.

While the CdTe/peak ratio by X-ray diffraction varied from 0.27 to 0.57 and 1.06 when the crushing duration was extended from 5 to 10 and 15 minutes, respectively, with the revolutions of the ring medium mill being fixed at 2,500 rpm, the average grain size did not change significantly, only from 1.50μm to 1.42μm and 1.32μm, respectively. Therefore, it was made possible to separately control the CdTe output with the grain sizes of the Cd, Te and CdTe kept constant. From the results of this experiment with the ring medium mill, it was confirmed that the greater the CdTe output, the smaller the quantity of sulfur (S) taken into the active layer during the sintering of CdTe, and the more improved the Voc as a cell performance characteristic.

(ii) Study on bandgap widening of window layer

When a mixed crystal film is to be made from CdS powder and ZnS power by coating and sintering, increasing the proportion of Zn would result in a film with less growth of grains due to the combination of material particles and more voids within. This phenomenon seems to be due to the inhibition of sintering by the high content of ZnS powder, which is thermally inactive, in the material. A film with many voids has low light transmissivity, permits no sufficient expansion of the bandgap and has high electrical resistance and these disadvantages as a window layer prevented the production of efficient solar cells from such films.

The $Cd_{1-x}Zn_xS$ mixed crystal powder newly developed in the recent study was prepared by introducing H_2S gas into a pH-adjusted aqueous solution containing $CdSO_4$ and $ZnSO_4$ and heating the deposit, resulting from the coprecipitation of CdS and ZnS, in the atmosphere at 500°C for four hours to increase its crystallinity.

Sintered films were formed from the $Cd_{1-x}Zn_xS$ mixed crystal powder (with a Zn proportion of 10% to 60%) prepared in this manner as coating paste material, their optical and electrical characteristics were evaluated, and solar cells were fabricated from them.

The grain size of a mixture of CdS powder and ZnS powder is a few μm at most. On the other hand, in the mixed crystal powder, the grain was confirmed to have grown to 20μm or more at a Zn proportion of 20%. At a Zn content of no more than 40%, no void was observed in the sintered films, which were found tightly adhered to the substrate surface in every case. This difference in sintered film quality is attributed to the presence of ZnS powder.

The optical bandgap calculated from the spectral transmissivity, in either mixed crystal powder or mixed powder, proved narrower than that expected from the starting material, but the sintered film made from the mixed crystal powder was found to have a greater bandgap than that from the mixed powder.

The resistivity of the sintered film, at every level of Zn content, was found to be lower with the mixed crystal powder than with the mixed powder by two digits or even more. This seems due to the reduction of voids within the sintered film and the resultant fine texture.

Solar cells were fabricated from the mixed crystal films described above. Compared with cells from mixed crystal sinters of mixed powder, they were found to excel in collecting efficiency and in photoelectric characteristics. They were also sensitive to light of 470nm or more in wavelength owing to the widened bandgap of the window layer.

Regarding cell performance characteristics, the films from the mixed crystal powder had Jsc of $19.8mA/cm^2$ at $X = 0.1$, much improved over the $18.0mA/cm^2$ of those from the mixed powder and surpassing the Jsc of cells using CdS as window material, indicating an expansion of the sensitive wavelength range. However, along with an increase in Zn proportion, FF and Voc tended to decline, failing to surpass the conversion efficiency of cells using CdS film as window material. The declines in FF and Voc seem attributable to increased resistance due to the higher Zn proportion and the effect of lattice defect consequent on the difference in lattice constant between the $Cd_{1-x}Zn_xS$ mixed crystal film and CdTe. No cells of $X = 0.4$ or 0.6 gave any output.

(b) Research on techniques for the formation of large-area coat-sintered film

(i) Study on techniques for compression of CdS film

Study was made on the possibility of improving the quality of the CdS film by compressing the CdS printed film. When the CdS film was subjected to pressure after printing and drying, the CdS printed film was compressed, and the film density was found increased. The compressed CdS printed film was found to have lost many of the pores in the sintered film, become more dense and improved in beam transmissivity (4%).

(ii) Study on techniques for levelling of CdTe Film

Whereas the CdTe film prepared by printing and sintering consists of an active layer of 1 to 3μm in thickness and a porous layer of 1 to 3μm in grain size, formed over a CdS film, the porous layer is uneven in thickness as the printed layer is varied in thickness by the effect of the screen mesh. This unevenness was anticipated to adversely affect the uniformity of the resistance of contact with a carbon layer to be formed subsequently and of acceptor diffusion, and the film thickness should be made as uniform as possible. Last year, ultrasonic treatment was developed as a technique to form a CdTe coat uniformly, but levelling was insufficient as vibration was applied to the glass substrate only in the horizontal direction. This year, the apparatus was remodelled to permit simultaneous excitation in both horizontal and vertical directions, and used in the experiment, resulting in an evenly smooth film. When the film, after smoothing, was subjected to roll compression to increase the filling density of the material powder, its density was greatly enhanced. As a result of the trial production of cells, it was found that those made of films having undergone ultrasonic treatment plus compression were improved in every PV parameter.

(3) Future Tasks

This year, in pursuit of higher efficiency for large-area CdS/Cd/Te solar cells, qualitative improvement of the CdS film and the CdTe active layer was attempted, and an effective conversion efficiency of 9% ($265cm^2$) was attained. For further efficiency improvement, it is necessary to reduce the resistance of the $Cd_{1-x}Zn_xS$ film and to form satisfactory junctions between this film and CdTe. For this purpose, a low-resistance film should be developed by doping $Cd_{1-x}Zn_xS$ mixed crystals with donor impurity and thereby improving the FF. More specifically, the conditions of the addition of Al to the powder preparing solution and of coprecipitation are being studied as a method to dope mixed crystal powder of X = 0.2 or more with Al, and R&D efforts are under way to work out a baking method suitable for that purpose. Concerning the lattice defect attributable to the difference in lattice constant between the mixed crystal film and CdTe, study will be made on buffer layer formation methods, including the CdS coating of the $Cd_{1-x}Zn_xS$ mixed crystal sintered film, and the conditions of CdTe film formation with a view to Voc improvement.

2.1.5 Development of Fabrication Technology for Tempered Glass Over-Layered Transparent Conducting Film

(1) Objectives and Work Program

(Objectives for FY1996)

Glass substrate cost: ¥40/100cm² at an annual output of 100MW

(Work Program)

(a) Research on fabrication technology for thermally resistant over-layered transparent conducting substrate

A quantitative evaluation method will be established concerning the thermal distortion of substrates with a view to identifying the cause of warping and finding a method to reduce it. A method of low-temperature heat treatment will also be developed in order to improve the performance of the conducting film while maintaining the strength of the tempered substrate.

(b) Development of low-cost technology

A normal pressure CVD apparatus will be produced that can continue the formation of a conducting film to the tempering process without letting the glass temperature drop. Tempered TCO films will be fabricated to evaluate their strength and warp and to compare their performance with calculated values, and at the same time problems in the designing of a tempering apparatus will be identified.

(2) Summary for FY1994

(a) Research on fabrication technology for thermally resistant over-layered transparent conducting substrate

(i) Improvement of thermal resistance of TCO substrate

In order to form a conducting film on tempered glass, it is necessary to reheat in the atmosphere the glass substrate on which the conducting film has been formed. Therefore, various TCO films produced by the normal CVD method were reheated in the atmosphere, and the quantities of warp occurring on the substrates were measured. It was found that the quantity of warp is dependent on the carrier concentration of the TCO film, and the higher the carrier concentration, the greater the warp. This presumably was due to a temperature difference between the surface of the glass substrate on which the film was formed and that on which no film was formed owing to the effect of heat wave reflection attributable to the electrons that constitute the conducting carrier in the film. The substrate temperature distribution was calculated from the radiation from the furnace and the heat wave reflecting performance of the glass, and the temperature difference between the two sides of the glass was predicted to be about 400°C.

(ii) Analysis of TCO crystal distortion by high-temperature X-ray diffraction

To assess the deformation of substrates while being heated, variations in the lattice distortion of TCO films were directly observed by high-temperature X-ray diffraction. It was found that changing the glass substrate underneath would change the way in which the lattice distortion varied, and that the effect of the difference in thermal expansion could be quantitatively evaluated. From now on, this technique will be applied to a higher-temperature region to advance the analysis for identifying the cause of warping during heating.

(iii) Development of low-temperature heat treatment method

Because the resistance of a TCO film increases when it is heated in the atmosphere in the neighborhood of its tempering temperature, it is necessary to reduce the resistance by heat treatment with nitrogen. The previous treating temperature was 500°C, but treatment at this temperature invited easing of the tempering stress. Although glass is not usually susceptible to stress easing at a temperature below its distortion point (around 500° for soda lime glass), stress easing is known to occur even at a temperature below its distortion point (less than 300°C) in the presence of a heavy stress, such as the tempering stress. Therefore, study was made on a method of low-temperature heat treatment in order to prevent the tempering stress from dropping. As a result, it was found that a resistance reduction comparable to that under the previous standard conditions of treatment (500°C for 10 minutes) can be achieved by heat treatment with nitrogen at 300°C for 20 minutes. Furthermore, low-temperature heat treatment proved effective for ZnO-coated TCO films as well, and technical prospects were gained for reducing the resistance of TCO films by heat treatment without affecting the tempered state of tempered TCO substrates.

(b) Development of low-cost technology

(i) Experiment on subsequent tempering of TCO

TCO films differing in thermal resistance and thermal warping were formed by CVD, and subjected to a subsequent tempering experiment. TDO substrates were charged by roller conveyance into a tempering furnace heated to above 600°C, and tempered by wind cooling while varying the heating conditions. It was found that, though tempering was impossible at a high temperature of 650°C or above because cracks resulted from the thermal deterioration (oxidation) and warping of the film, TCO could be tempered by asymmetrical heating at a temperature reduced to 620°C. Evaluation by a falling-sphere test using a 227g steel ball revealed that the TCO film could withstand a sphere drop from a 1.5m height, a requirement for solar water heaters. However, though the average resistance of TCO after tempering weakened from 27Ω/□ to 19Ω/□, there were some high-resistance parts. The plan is to search for more favorable conditions for film formation and tempering together with numerical calculations to reduce the warp and improve the resistance distribution.

(ii) Development of a roller-conveyed type CVD apparatus

A large-area CVD apparatus (compatible with substrates of 30 x 40cm^2 in actual size) connectable to the tempering apparatus was produced. On the basis of findings in the preceding year, a mesh belt type conveyor system was adopted, which is switched to roller conveyance at the outlet. The substrate heating system is configured so as to uniformize the temperature distribution based on the research findings on the improvement of the thermal resistance of TCO.

The CVD apparatus as such is 1.8m wide, about 19m long and 2.2m tall. It is structured so that glass substrates of up to 4mm in thickness are conveyed by a mesh belt and shifted to roller conveyance after four-stage CVD film formation, and is connectable to the tempering furnace. The previous normal pressure CVD apparatus had a structure in which a gradual cooling zone was provided following the CVD film formation zone for cooling down to room temperature, but this new apparatus has a buffer zone in place of the gradual cooling zone. This zone is intended to prevent the strong wind generated in the tempering furnace from affecting the inside of the CVD apparatus. The configuration is unique to in-line tempering apparatuses.

(3) Future Tasks

(a) Research on fabrication technology for thermally resistant over-layered transparent conducting substrates

In order to realize a tempered TCO substrate satisfying the requirements of 5Ω/□ in sheet resistance and 85% in transmissivity, the conditions for the formation of conducting films and their tempering and nitrogen-annealing will be optimized. Along with improving the warping and resistance distribution, optimization will also be attempted, on the basis of the evaluation of solar cells, regarding the surface texture of temperable conducting films.

(b) Development of low-cost technology

A wind-cooled tempering apparatus and accessory units will be connected to the latter stage of the normal-pressure CVD apparatus produced this year to complete an in-line tempering TCO manufacturing apparatus.

2.2 Technological Development for Qualitative Improvement

2.2.1 Technological Development for Efficiency Improvement of Amorphous Solar Cells after Initial Degradation

(1) Objectives and Work Program

(Objectives for FY1996)

Stabilized conversion efficiency: 12% or above (for 1cm x 1cm or larger)

(Work Program)

(a) Development of deposition technology for photostable a-Si films

Attempts will be made to improve the control technique for combined hydrogen atoms which would make it possible to control the quantity and form of hydrogen content in amorphous a-Si films, and to develop formation technology for photostable films with a view to reducing the defect density after irradiation with light.

(b) Design development for photostable elements

In order to develop design technology

for stacked type solar cells which are photostable elements, development of a resistant transparent conducting interface layer and an interface recombination facilitating layer will be attempted. Furthermore, photostable a-Si films prepared under control of combined hydrogen atoms will be applied to cells to develop an appropriate element structure and, at the same time, study will be made on the improvement of cell performance.

(2) Summary for FY1994

(a) Development of deposition technology for photostable a-Si films

With an eye to achieving photostabilization of the a-Si material by working out low-hydrogen narrow-bandgap a-Si films, attempts were made to develop techniques for film formation/hydrogen plasma treatment to control hydrogen atoms combined in the film, a heating gas plasma CVD method and a pre-excited plasma CVD method. Developmental work was also carried out to upgrade the quality of a-Si-Ge as i-layer material for bottom cells of double-layer tandem cells.

(i) Development of technique to control hydrogen content in a-Si films

To improve the quality of and to photostabilize a-Si films, development of a technique to control hydrogen content in the films was attempted by applying the alternately repeating deposition and hydrogen plasma treatment (ADHT) method. The a-Si films prepared by the ADHT method had a defect density of no more than 1 x $10^{16}cm^{-3}$ in a broad optical bandgap range of 1.66eV to 1.92eV, and made it possible to reduce defects especially on the wide gap side above 1.8eV. This reveals the remarkable effect of hydrogen plasma treatment to compensate for defects. The defect density of these a-Si films after irradiation with light was 3 x $10^{16}cm^{-3}$ or less, indicating the advantage of the treatment in photostabilization. Furthermore, the stability of wide-gap films with greater quantities of combined hydrogen atoms (20at% or more) was found comparable to that of low-hydrogen a-Si films, indicating no correlation between SiH_2 combination or the quantity of combined hydrogen atoms and photostability.

The photostable wide-gap film (prepared by the ADHT method) was applied to the i-layer (100mm), and the stability of a-Si films was evaluated on a single cell basis. With 1.9eV films formed by the ADHT method, a high open-end voltage of 0.94V was achieved. Their FF also proved higher than the products by the earlier method, remaining at 0.68 or above even after irradiation with light. The degradation rate of the conversion efficiency, too, was found more stable, at about 7% with a wide gap.

(ii) Qualitative improvement of narrow-bandgap a-SiGe material

With an eye to enhancing the efficiency of double-layer tandem cells, study was made on the possibility of improving the quality of the a-SiGe film, which is a narrow-bandgap material. Deposition was based on plasma CVD of a mono-silane/mono-germane mixture diluted with hydrogen. For qualitative improvement, the ADHT method, which had proved effective in compensating for defects in a-Si films, was used. Regarding the dependence of the optical bandgap and the hydrogen content on the duration of hydrogen plasma treatment in the ADHT process, the optical bandgap widened and the addition of hydrogen occurred with the extension of the hydrogen plasma treatment duration, resulting in an increased ratio of Ge-H/Si-H in the film. This revealed the possibility of controlling the selective combination ratio of hydrogen, which is the ratio of combination of hydrogen atoms with Ge and Si atoms, and to preferentially combine Ge atoms with hydrogen. In comparing the photosensitivities of hydrogen-diluted films and of the products of the ADHT process, the latter were found more photosensitive and superior in quality. These findings suggest that the selective combination of hydrogen compensates for defects and improves photosensitivity.

Study was further made on undiluted film formation using no hydrogen. By slowing down the film formation rate, the quantity of Ge in the film was increased, entailing the narrowing of the optical bandgap, but the photoconductivity was enhanced. Undiluted film formation at a suppressed formation rate of 0.2A/s or less resulted in successful production of a-SiGe films superior to hydrogen-diluted films in photosensitivity in the narrow-bandgap range of 1.35eV to 1.55eV. It was confirmed by IR observation that films formed at a rate of 0.2A/s or below had more hydrogen atoms combined with Ge atoms (GeH) than films produced by the hydrogen-dilution method. To evaluate the device performance of a-SiGe films produced by the ADHT method and nondilution method, single cells were fabricated, resulting in conversion efficiencies of 8.9% (1.61eV) and 8.2% (1.47eV) for the ADHT and undiluted formation products, respectively. These results mean a nearly 10% improvement in conversion efficiency over the cells fabricated of films produced by hydrogen-dilution method, and the ADHT method was found effective in defect compensation while the low-rate undiluted film formation proved useful in improving the material quality.

(iii) Hot gas plasma CVD method

Development of a technique to deposit a-Si films by subjecting film-forming gas, excited by heating, to plasma decomposition was attempted. Mono-silane, used as the film-forming gas, was heated to a prescribed temperature by a gas heating system, and introduced into the space of parallel flat plate type RF electrodes for plasma generation. In producing the a-Si films, the substrate setting temperature was kept constant and the gas heating temperature (Tgas) was varied. When the gas heating temperature was raised, the optical bandgap tended to narrow, particularly conspicuously at substrate temperatures of 160°C and 180°C, where the optical bandgap was reduced by 0.04eV. This corresponded to an approximately 60°C rise in substrate temperature. The a-Si films produced from heated gas had narrower optical bandgaps at the same quantity of combined hydrogen than those prepared by the usual method, and this seems attributable to the accelerated relaxation of the a-Si mesh structure at a relatively low substrate temperature, which resulted in a finer film texture. Single cells were produced of films prepared by the heated gas formation method, and their collecting efficiency at 700nm improved in step with the narrowing of the bandgap by gas-heated film formation, reaching 21% at a bandgap of 1.74eV (i-layer film thickness: 300nm). Furthermore, when these cells were compared with single cells whose i-layer film, with the same optical gap, was prepared by the usual method, the collecting efficiency at 700nm was found to be the same, but the cells of heated gas-formed films showed about 7% higher efficiency at 400nm. This finding revealed that the thermal damage due to the substrate temperature was alleviated for heated gas-formed films and that these films would provide a higher curvilinear factor and greater sensitivity to short wavelength.

(b) Development of photostability cell structure

(i) Wide-gap a-Si/a-Si tandem cells

High-quality wide-gap a-Si films, prepared by the ADHT method, were applied to a-Si/a-Si double-layer tandem cells, which were found to give a high open-end voltage.

The tandem cells so produced had top i-layers of 1.86 to 1.92eV in optical bandgap and bottom i-layers of 1.77eV in optical bandgap. The bandgaps were controlled through the thickness of the film treated and the substrate temperature. As samples for comparison, tandem cells were used whose top i-layers were prepared by dilution with hydrogen (Eopt = 1.82 to 1.83eV). As the ADHT process yields a-Si films having a greater bandgap than dilution with hydrogen does, the resultant tandem cells yielded a greater open-circuit voltage. Their curvilinear factor was also found higher. Therefore, optimization of the doped layer and the interface layer among others was attempted, and the resultant tandem cells having 140nm top and 400nm bottom i-layers gave an open voltage of 1.85V, a short-circuit current of 7.57mA/cm^2, a curvilinear factor of 0.75 and a conversion efficiency of 10.5% (1cm^2).

(ii) a-Si/μc-Si tandem cells

Study was made on the possibility of applying an intrinsic microcrystalline film to the optically active layer and using a narrow-bandgap material. Microcrystalline silicon (μc-Si) films were deposited by an RF plasma glow discharge as a source gas of mono-silane greatly diluted with hydrogen. X-ray diffraction results indicated that the crystal grain size and crystalline content ratio of the films thereby obtained were 10nm to 30nm and 30% to 70%, respectively. Their activation energy was 0.5eV to 0.7eV. They were found to have a considerably greater absorption coefficient for long-wavelength light of 900nm or above than a-SiGe films. To try the application of these μc-Si films to optically active layers, pin type single cells were fabricated by using these films for the i-layer (1μm). By inserting a p/i interface layer, the open-circuit voltage was raised by 1.6% over cells having no such interface layer, and a conversion efficiency of 4.6% was achieved. The photosensitivity of these single cells was high enough to collect long-wavelength light of up to 1,000nm, and the possibility of using a narrow-bandgap material was confirmed accordingly.

Furthermore, a-Si/μc-Si tandem cells having a usual a-Si film (Eg = 1.77eV, 250nm in thickness) and a μc-Si film grown to 1.6μm as their top and bottom i-layers, respectively, were produced. These cells proved as capable of collecting long-wavelength light as the single cells. Their performance characteristics included a short-circuit current of 11mA/cm^2, an initial efficiency of 8.0% and a stabilized efficiency of 7.5% (a degradation rate of 6%).

(iii) Improvement of photostability of single cells

With a view to improving the conversion efficiency after light-induced degradation and the efficiency of double-layer tandem cells made of a narrow-bandgap material, study was made on the possibility of enhancing the open-end voltage ratio for the i-layer bandgap as a technique to achieve a higher Voc. For single cells, materials were chosen (a-Si/a-C layer, wide-gap a-Si:H film and a-SiC film), the p-layer and the p/i buffer layer were optimized, film forming conditions for the i-layer (including film formation/treatment, temperature lowering and dilution with low-temperature hydrogen) were sought, an i/n interface layer was adopted, and the n-layer was optimized. As a result, Voc levels of 0.94V and 0.99V were achieved. For a-Si single cells, a stabilized efficiency of 8.2% was obtained.

(3) Future Tasks

High-quality narrow-bandgap a-Si films will be developed along with the film formation techniques that will permit the reduction of defect density after degradation. Furthermore, these a-Si films will be applied to double-layer tandem cells with a view to developing high-efficiency, high-reliability amorphous solar cells.

2.2.2 Development of Manufacturing Technology for Thin-Film Polycrystalline Silicon-Based Solar Cells (Development of Technology by Melting Recrystallization Method)

(1) Objectives and Work Program

(Objectives for FY1996)

Conversion efficiency: 18% (10cm x 10cm or larger or larger)

(Work Program)

(a) Techniques for qualitative improvement of silicon films

Techniques for qualitative improvement of films will be developed to suppress and reduce crystal defects of thin-film polycrystalline silicon, which would constitute the power generation layer of solar cells, and enhance the 100-orientation by melting-recrystallization. For this purpose, a melting-recrystallizing apparatus will be developed which will steadily give high-quality crystals of high uniformity over a large area.

(b) Techniques for the fabrication of light-carrier confining structure

An element fabricating process will be developed, centering on techniques to form a textural structure in thin-film polycrystalline silicon cells and techniques to enhance the light-carrier confining rate, including clean technology-utilizing surface and grain boundary passivation.

(c) Low-cost processing techniques

Basic study will be made on film separating/substrate recycling and surface electrode eliminating techniques, constituting the basic process of VEST cell fabrication.

(2) Summary for FY 1994

(a) Techniques for qualitative improvement of silicon films

Study was made on a hardware system for uniform and steady melting-recrystallization (ZMR) over a large area. Previously, ZMR had been carried out with a carbon strip heater in a vacuum chamber, but the new apparatus uses a lamp heating system based on a rapid thermal processing (RTP) formula. The previous system required the arrangement of a melt heater right above the sample, and the difficulty of adjusting and maintaining the optimal gap between the heater and the sample gave rise to the problem of low repeatability in ZMR over a large area. Moreover, the large thermal capacity of the heater entailed such disadvantages as the long time taken to raise or lower the temperature, maintenance difficulty inherent in a vacuum system and the complexity of the wafer conveyance. By contrast, the new apparatus can solve most of those problems by simplifying the scanning mechanism and allowing a greater margin for the optimal gap because the lamp light is optically condensed for ZMR. It also shortens the time taken to raise or lower the temperature, enhances cleanness and increases the potential for throughput improvement. At present, fundamental conditions are being identified by using this apparatus, which enables ZMR to be accomplished all over the wafers of 6 inches in diameter at an extremely high level of repeatability.

Next, the findings of detailed investigation of the relevance of the sample structure (polysilicon thickness) to the conditions of ZMR will be described. Previously, optimization of the ZMR conditions had been studied within a fixed polysilicon thickness range of 3μm to 5μm, but this time the dependence of crystal quality (defect density) on the melt heater scanning speed was checked in a broad thickness range of 1μm to 60μm. Whereas the defect density is reduced by thinning the film, a particularly notable finding was that, when the heater scanning speed was increased, thinning of polysilicon resulted in a level of crystal quality comparable to what was obtained at a lower speed with a thicker film. This suggests the possibility not only of improving the throughput but also reducing the material cost. From now on, study will be made on the SiO_2 film thickness for the polysilicon base and cap as well on optimizing the sample structure and ZMR conditions.

(b) Techniques for the fabrication of light-carrier confining structure

The previous study focused on the defect passivation (carrier confinement) of filmy polycrystalline silicon by treatment with hydrogen, and substantial performance improvement of thin-substrate cells was reported. This year, it was checked whether thin-substrate silicon solar cells treated with hydrogen were degraded by irradiation with light or not. No degradation was noticed after irradiation with light for a long period, and high reliability was confirmed irrespective of whether hydrogen treatment had been conducted or not. Study had also been made on inactivation of the grain boundary by phosphorus atoms, the so-called phosphoric passivation, in addition to hydrogen-passivation. The purpose was to prevent the photogenerated minority carrier from crossing the crystalline grain boundary by utilizing the faster diffusion of phosphorus atoms along the grain boundary of polycrystalline silicon than within grains to subject the crystalline grain boundary of the p-type polycrystalline silicon film to n-type diffusion, and this phosphoric passivation is expected to suppress recombination of the minority carrier. This year, regarding techniques for phosphorus diffusion, study was made on such basic aspects as sheet resistance and the uniformity of the diffusion profile within the surface, and their applicability to filmy polycrystalline silicon was confirmed. On the other hand, study was also made on fabrication techniques for the optical confinement structure by disposing of the ruggedness (texturing) of the cell surface, and a fine textured structure was successfully fabricated with high repeatability and steadiness. From now on, further progress will be pursued in the development of more efficient thin-substrate polycrystalline silicon solar cells by integrating these techniques for carrier confinement and optical confinement.

(c) Low-cost processing techniques

One of the most vital aspects of the VEST process is the design of viaholes (in terms of size, pitch and so forth). Thus, viaholes not only are necessary for film separation but also have a role in collecting the generated photoelectric current, and have to be designed so as to satisfy the requirements regarding both process ease and cell performance. In the following paragraph, after stating the cell performance that can be realized with this structure as estimated by simulation, the results of elemental experiments required for cell fabrication and the performance characteristics of the cells produced on a trial basis will be reported.

In roughly estimating the effects of viaholes on the performance of VEST cells, standard Jo and n values (which would make the reference pn junction characteristic FF equal to 0.78 at a cell thickness of 100μm and a diffusive layer (n) sheet resistance of 60Ω/□, with the electrode and contact resistance not being taken into consideration) were supposed, the cell surface was divided into equal rectangles, each having a viahole at its center, and the I-V characteristic was calculated by adding only the voltage drop in each such area and that in each viahole to the aforementioned junction characteristic. As a result, it was discovered that performance characteristics comparable to or even better than those of conventional cells could be achieved with viaholes of 200μm to 300μm in bore, arranged in a 1mm to 1.5mm pitch. On the other hand, a problem with actual cells is that all viaholes cannot be bored in an equal size because the film used is polycrystalline. Yet, as the films obtained by ZMR have a substantially 100 orientation as already reported, a major problem lies in the crystalline grain boundary. Findings through observation of samples in which holes were bored indicate that the shapes of holes formed across a grain boundary are distorted. However, since even wide variations in hole size do not affect the etching rate of SiO_2 directly underneath the film, some unevenness in hole size in or on a grain boundary could be assumed to have little influence on separation. Investigation of the relevance of the hole pitch to the time taken for film separation by varying the temperature of etchant HF revealed that a higher HF temperature and a narrower hole pitch would be effective to accelerate the film separation. The possibility of junction formation to perform diffusion before the film separation was also studied. The pn junction section of the sample formed by this method manifested the formation of junctions on the side and back faces of viaholes. Furthermore, it was confirmed by evaluating the impurity profile by SIMS that as much diffusion had taken place on the back side as on the front side. A cell is completed by sticking, after this film separation and junction formation process that constitutes the core of VEST cell fabrication, the film to glass with transparent resin and forming electrodes. In practical application, optimization through the improvement of various detailed conditions of each process will be required in the future, and the development of techniques for steady handling of films will pose another challenge. Concerning the performance of cells produced so far on a trial basis, though the films are rather thick, 100μm, an efficiency of 14.4% has been achieved (Voc = 589mV, Isc = 3.245A, FF = 0.745).

(3) Future Tasks

This year's research work mainly consisted of study on a new ZMR hardware system and the development of a through process to realize VEST cells, and feasibility was confirmed in both respects. From now on, continued efforts will be made to further improve the quality of filmy crystalline silicon and, at the same time, to optimize the detailed conditions of the cell fabrication process. It is further planned to realize a high practical technology with a high throughput by developing, among other things, steady film handling techniques to make filmy silicon solar cells fabricated by this process available for practical use.

2.2.3 Development of Fabrication Techniques for Thin-Film Polycrystalline Silicon-Based Solar Cells (Development of Low-Cost Technology by the Plasma Spray Method)

(1) Objective and Work Program

(Objective for FY1996)

Conversion efficiency: 12% or above
(1cm x 1cm or larger)

(Work Program)

A thin-film polycrystalline silicon active layer will be developed by combining a technique to fabricate thin-film polycrystalline silicon on a low-cost substrate by plasma spraying or otherwise and a technique to reform it.

(2) Summary for FY1994

(a) Development of fabrication techniques for filmy polycrystalline silicon
    (i) Fabrication of polycrystalline silicon films (remodelling of plasma spraying apparatus)

In fiscal 1993, the apparatus was remodelled to alter the materials of the raw material feeder and substrate heater and the feeding system, resulting in a successful reduction of the SUS content to the permissible level for solar cells or even below. However, the infiltration of W and Cu, attributable to the plasma torch part, remained a problem to be solved this year. In order to reduce the quantities of these impurities, the use of the DC torch, which was accountable for these contaminants, was discontinued, and study was made on the possibility of fabricating polycrystalline silicon films by a plasma spraying method using RF plasma alone.

As a preliminary experiment, film formation by RF plasma spraying, with the DC plasma turned off, was tried, and such problems were identified as the RF plasma's own instability, difficulty in controlling the molten state of particles and the low proportion of molten particles reaching the substrate. On the basis of these findings, remodelling of the plasma spraying apparatus to an RF plasma type was attempted.

The remodelling involved the plasma torch section and particle feed nozzle. More specifically, the DC-RF hybrid torch was replaced with an RF plasma torch, and the raw material feed system was changed. Previously, the particles of raw material were fed from the DC plasma torch into the plasma, but the new arrangement has a feed nozzle inserted into the central part of the RF plasma to supply the raw material. This particle supply nozzle is provided against impurities by using a graphite material for its tip, which comes into direct contact with the particles. This arrangement to directly feed the raw material particles into the central part of the RF plasma makes it possible not only to control the instability of the RF plasma due to fluctuations at the time of feeding the particles but also to considerably restrain the damage to the RF quartz pipe arising from the adhesion of silicon, melted and vaporized in the plasma space, to the pipe.

This remodelling greatly changed the velocity of silicon particles, spread of molten particles and temperature distribution in the hot plasma, so no fine-textured silicon films were obtained until such basic parameters as the distance between the torch and the substrate, substrate heater temperature, high-frequency power density, plasma gas flow rate and feed gas flow rate were substantially altered. By improving these conditions, silicon films of a larger grain size than before were produced. The difference between film formation under the recently adopted conditions and that under the previous conditions include sufficient melting of the area into which silicon flies due to the increased central temperature of the spray and a slowdown in cooling owing to the increased substrate temperature. Both of these changes contribute to expanding the crystal grain size.

It was confirmed by analyzing the impurities that W had been reduced to about 1/4 the previous level. The diffusion length was further assessed by a non-contact SPV method, and a diffusion length range of 15μ to 20μ was confirmed as a result. This is about three times as great as the corresponding range of the films fabricated last year, indicating significant improvement in film quality.

(ii) Fabrication of low-cost supporting substrate

So far, silicon films were formed on substrates of a carbonic material, such as carbon fiber cloth, carbon/carbon composite or glassy carbon. Carbon fiber cloth is produced by spinning and weaving carbon fibers. It is inexpensive, but is not strong enough to support filmy polycrystalline silicon, and a sheet substrate of a self-sustaining material such as carbon/carbon composite or glassy carbon is more preferable for the fabrication of a film of 200μ or less. These carbonic substrates, however, are expensive at present, and their cost needs to be reduced.

To fabricate a thin substrate of sintered carbon or silicon without slicing, first a green body is prepared by forming raw material powder into a product shape in a self-sustaining state. Quantitatively suitable fabrication methods for this green body include the use of a doctor blade or press molding.

The doctor blade method, which uses slurry, is likely to involve many problems in producing substrates of a low impurity concentration.

Press molding, on the other hand, is the most common method of fabricating green sheets. By this method, powder is supplied from a powder feeder into a metallic mold, and molding is accomplished with a single spindle press. Although the product shape available by this method is limited to relatively simple ones, its production efficiency far exceeds those of other methods. Generally, obtaining a well-molded sintered product heavily depends on the quality of the raw material granules, whose properties including bulk density, fluidity and grain size distribution should be favorable and highly repeatable. The biggest problem in fabricating a carbonic plasma-sprayed supporting substrate by press molding lies in the choice of a self-sintering carbon material. In this study, metho-carbon made from petroleum residue pitch was used as raw material. Adding an appropriate quantity of phenol resin (20wt% to 30wt%) was found to provide a crack-free satisfactory sintered product of high bulk density.

(iii) Study on silicon-based material for supporting substrate

Carbonic substrate materials have the advantages of "withstanding the high temperature of plasma spraying," "the ability to provide substrates of a relatively low impurity concentration," "a thermal expansion coefficient close to that of silicon, which results in relative insusceptibility to the cracking of the film formed" and "potential for low-cost supply in the future." On the other hand, its disparity from silicon in terms of the thermal expansion coefficient may cause stress in the growing silicon film and may eventually cause various crystal defects. As this disadvantage is likely to increase as the thickness of silicon films fabricated by plasma spraying is progressively reduced in the future, study was made on a simple method to prepare a silicon-based material for supporting substrates which would help avert these problems.

Green sheet fabrication by press molding and sintering in an electric furnace was tried as a method to fabricate silicon green sheets. Baking in an inactive gas atmosphere under normal pressure, which seems to be the most common ambience for the heat treatment of silicon, resulted in a very low level of sintering irrespective of the grain size of the raw material powder or the sintering temperature. Thus, at a maximum temperature of heat treatment below the melting point of silicon (1,413°C, no sintered sample was found to contract at all, and many pores were witnessed in the SEM observation of cross sections. On the other hand, once the maximum temperature of heat treatment surpassed the melting point of silicon, all the compressed powder began to melt and, when the sample was taken out after the temperature was lowered, it was found completely adhered to the setter and impossible to remove.

Following the sintering experiment in the inactive gas (argon) atmosphere under normal pressure, sintering tests were carried out under reduced pressure (with argon) or with the addition of hydrogen gas (10%) under normal pressure. Under these conditions, improved sintering was confirmed.

(b) Fabrication of thin-film polycrystalline silicon solar cells

The research work until last year had revealed the usefulness of the low-temperature junction plasma film formation emitter and the BSF layer for increasing the efficiency of the n-type active layer.

This year, study was made on techniques

for the fabrication of film-formation type solar cells with respect to the p-type active layer with a view to effective utilization of the carrier performance of electrons.

While an a-Si (p+) film was found to be the most suitable emitter layer for n-type substrates, for p-type substrates μc-Si (N+) gave a higher Jsc because of its greater sensitivity to short wavelengths, a roughly equal level of Voc and a higher efficiency. For technical evaluation of film-formation type junctions, an experiment for efficiency improvement was conducted with CZ-Si substrates. Standard substrates for solar cells of 1 to 1.5 Ωcm in resistivity were used. The BSF layer was formed by aluminum paste baking, which is a low-cost cell formation technique.

Although somewhat less sensitive to long wavelengths than the film-formation BSF layer type solar cells developed by the preceding year, the newly developed solar cells surpass 85% in collecting efficiency at 1,000nm, and their Jsc (calculated from spectral sensitivity) is as high as 39.1mA/cm^2. Their Voc, 0.640V for small-area cells, is also very high. As a result, such high levels of efficiency were achieved as 19.5% in intrinsic efficiency for small-area cells and 17.2% (at an effective area ratio of 92%) in effective efficiency for large-area modules, revealing the usefulness of film-formation type junctions by the plasma CVD method for p-type substrates as well.

As raw material for plasma-sprayed silicon, p-type silicon particles of $3 \times 5^{15}/cm^3$ to $5 \times 10^{15}/cm^3$ in carrier concentration were used. Although the carrier concentration and other factors of the plasma-sprayed silicon on glassy carbon cannot be measured, at least it is likely to be of the p type. Therefore, the above-described junction formation techniques were applied to the plasma-sprayed silicon film developed this year. As regards the performance characteristics of solar cells, Voc and FF were significantly improved over last year, and a conversion efficiency of 8.3% was achieved.

(3) Future Tasks

For further efficiency improvement, it is essential to make the cooling process more sophisticated and establish post-treatment methods including treatment with hydrogen.

Incidentally, to realize a substantial cost reduction, it is necessary to establish a hardware concept that would make it possible to maintain a high efficiency without sacrificing the high deposition rate, which is an advantage of the spraying method, and to develop such peripheral technologies as methods for low-cost substrate fabrication and electrode formation.

2.2.4 Development of Fabrication Techniques for Thin-Film Polycrystalline Silicon-Based Solar Cells (Development of Low-Temperature Crystallization Technology by Solid Phase Crystallization)

(1) Objective and Work Program

(Objective for FY1996)

Conversion efficiency: 12% or above
(1cm x 1cm or larger)

(Work Program)

(a) Development of high-quality solar cell material

On the basis of the partial doping method, with the core generating layer and the crystalline growth layer being separated from each other, study will be made on a new solid-phase crystallization process in which a mixed mono-crystalline/amorphous film is applied to the core generating layer to develop a solid phase growth method by which core growth can be elaborately controlled, and thin-film polycrystalline silicon of a large grain size and high quality will be developed to achieve high efficiency.

(b) Development of high-efficiency solar cell structure

In order to find out the most suitable junction and highly absorbent element structure in textured structure, attempts will be made to further improve the techniques for HIT structure junction formation and the optical confinement effect of the texture.

(2) Summary for FY1994

(a) Development of high-quality solar cell material

Qualitative improvement of filmy polycrystalline silicon, which is a material for the next generation of solar cells, has been pursued by solid phase growth. It has been discovered that, in the formation of filmy polycrystalline silicon by solid phase crystallization using amorphous silicon, qualitative improvement can be achieved by solid phase crystallization with partial doping, with the core generating layer and the crystalline growth layer being separated from each other, and study has been made on the optimization of the core generating layer and the crystalline growth layer. The theme of this year was a new solid phase crystallization process applying a mixed mono-crystalline/amorphous film, in which monocrystals are scattered in the amorphous phase, to the core generating layer in the partial doping process as part of sophisticated control of core generation with a view to further qualitative improvement of filmy polycrystalline silicon.

First, the formation of the mixed mono-crystalline/ amorphous film was studied. At a relatively high substrate temperature of 550°C, the Raman spectrum of the film deposited under high dilution with hydrogen manifested a peak in the vicinity of $480cm^{-1}$ attributable to a-Si and another steep peak in the neighborhood of $520cm^{-1}$ ascribable to crystalline silicon, which revealed that this film consisted of an amorphous phase and a crystalline phase. SEM photographs showed that fan-shaped grains were scattered in the cross section of the film. Evaluation of the internal structure of these grains by TED pattern disclosed that the grains had a mono-crystalline phase inside. A starting material was formed by using a mixed mono-crystalline/amorphous film as a new core generation layer and using an undoped a-Si film with large structural disturbance as crystalline growth layer. Crystalline growth in the vertical direction, suitable for the device structure of solar cells, was confirmed by cross-sectional TEM photography after solid phase crystallization. The hole mobilities in filmy poly-Si depending on whether the new core generation layer was applied or not were compared using a flat substrate and a rugged substrate. It was found that the hole mobility after solid-phase crystallization would be improved by the use of the new core generation layer. On the rugged substrate, a hole mobility of $808 cm^2/Vs$ was achieved by using a mono-crystalline/amorphous film as core generating layer. This level is far higher than the previous maximum of $623 cm^2/Vs$ by solid phase crystallization, equivalent to approximately 80% of mono-crystalline silicon at the same carrier concentration, and at the same time the highest in the world for solid-phase crystallization poly-Si. As so far described, a new solid phase process of applying a mono-crystalline/amorphous phase to the core growth layer was demonstrated to further improve the quality of filmy poly-Si.

Applying mono-crystalline grains to the core generation layer, optimizing the HIT structure, using a rugged substrate and treating with hydrogen plasma, thin-substrate poly-Si solar cells were produced on a trial basis. A high collecting efficiency of 56% was achieved for long-wavelength light, to which a-Si cells are insensitive. Furthermore, in spite of the film's mere 10μm thickness, a high short-circuit photocurrent of $31.3 mA/cm^2$ was achieved, surpassing the previous record by more than $10 mA/cm^2$.

Reliability of thin-substrate poly-Si cells by solid phase crystallization was assessed. They were subjected to light irradiation tests under the conditions of 5 sun, AM1.5 and 50°C. As a result, they were found subject to no photodegradation when exposed to light irradiation equivalent to the outdoor exposure of a-Si single cells for a full year or more, and it was thereby confirmed that thin-substrate poly-Si solar cells by solid phase crystallization have fully satisfactory reliability.

(b) Development of high-efficiency solar cell structure

The homo junctioning previously used for crystalline solar cells involves such problems as a high process temperature close to 1,000°C and the difficulty of forming shallow and steep junctions due to the mutual infiltration of impurities. These problems make it difficult for homo junctioning to be applied to solar cells formed at low temperatures using low-cost substrates. By contrast, HIT-structured solar cells are formed by the very simple process of successively stacking i-type and p-type a-Si films over n-type c-Si by plasma CVD at low temperature (of 200°C or less), and accordingly they permit the formation of shallow and steep junctions, also attracting keen interest as a junction formation method for low-cost solar cells.

This year, further study revealed on the basis of the sensitivity spectrum, when light was brought to incidence from the back side, that the effective recombination rate in the HIT structure was quite satisfactory, 50cm/s or even less. To confirm reliability, a light irradiation test (at 5 sun, AM 1.5 and 50°C for 5 hours) and a thermal resistance test (at 160°C for 7 hours) were carried out, and the absence of performance deterioration was confirmed in both cases. Further, with a view to checking the performance characteristics in the temperature range of actual use, the temperature dependence of the conversion efficiency was assessed. As a result, HIT-structured solar cells were found less susceptible to performance deterioration in the temperature range above room temperature and would give a greater output in the state of actual use than the conventional homo-junctioned crystalline silicon solar cells.

(3) Future Tasks

(a) Establishment of a filmy poly-Si layer formation method for even higher quality and higher efficiency

(b) Optimization of techniques for device fabrication

2.2.5 Development of Fabrication Techniques for Thin-Film Polycrystalline Silicon-Based Solar Cells (Development of Techniques for Initial Film Formation over Substrate by Excimer Laser)

(1) Objective and Work Program

(Objective for FY1996)

Conversion efficiency: 12% or above
(1cm x 1cm or larger)

(Work Program)

Techniques will be developed to form an initial silicon film (seed layer) over the substrate, which is essential for the formation of a high-quality polycrystalline silicon film. Especially in excimer laser annealing, grain enlargement and orientation control of the initial silicon film will be attempted by controlling the interface energy and other factors during crystalline growth. Then, a polycrystalline silicon film will be formed over this initial film at a relatively low temperature by using a process involving hydrogen plasma treatment and with a view to improving the efficiency of solar cells.

Specific subjects to be studied are the following three.

- Qualitative improvement of the Si initial film formed by laser annealing (grain enlargement and orientation control)
- Low-temperature formation of filmy polycrystalline Si solar cells by chemical annealing
- Performance characteristics of low-carrier filmy polycrystalline Si solar cells

(2) Summary for FY1994

(a) Qualitative improvement of Si initial film formed by laser annealing

In order to form high-quality filmy polycrystalline Si at low temperature, it is essential to develop a high-quality Si initial film (seed layer). This study focused on crystallization to form the Si initial film at low temperature by KrF excimer laser annealing. The laser annealing was performed in a vacuum (1 x 10^{-8}Torr) with irradiation at an energy density of 150 to 350mJ/cm^{-2} as measured in the sample position.

The resistivity of polycrystalline silicon films formed by laser annealing of a-Si films greatly varied with the quantity of doping. The resistivity of laser-annealed films significantly dropped as the proportion of the flow rate of B_2H_6 in the mixed gas of B_2H_6 and SiH_4 was increased. Furthermore, by optimizing the energy density in laser annealing, the Si initial film became less resistant and larger in grain size. The formation of crystals of 1 micron or more in grain size was confirmed by TEM photography of the inside of the surface, and X-ray diffraction showed a significant orientation (111). Comparison of n-type and p-type laser-annealed films indicated that the resistivity of the latter could be reduced more readily, and a sheet resistance of 5Ω/□ was achieved at a thickness of 300nm by laser annealing under the conditions of the formation of large grain-size Si initial films. Assessment of the distribution of boron in 300nm thick laser-annealed films revealed segregation, with more boron found on the surface of the film and the film-glass interface while the boron concentration in most parts of the film was about $1 \times 10^{21}cm^{-3}$. Study is being made on the effects of the segregated structure on the resistivity reduction of films.

(b) Filmy polycrystalline Si solar cells over glass substrate

(i) Whereas a number of methods of forming a polycrystalline Si film over a laser-annealed Si initial film were studied, an orientation (100), which is useful for improving the efficiency of crystalline solar cells, was successfully achieved by the CVD method. X-ray diffraction of polycrystalline Si films formed by CVD on $p^{+}Si$ (laser-annealed)/ glass showed that the orientation (100) excelled, with growth in orientations (220) and (331) restrained.

(ii) Low-temperature formation of filmy polycrystalline Si solar cells

Where cheaper green glass is used for the substrate of filmy polycrystalline solar cells, the process temperature should be even lower. An active layer was formed at 350°C over a $p^{+}Si$ (laser-annealed)/glass substrate by chemical annealing (alternate repetition of plasma CVD and treatment with hydrogen atoms), and cells were produced. A cell in which the active layer was deposited to a thickness of about 2 microns gave a conversion efficiency of 3.31%. As the spectral sensitivity spectrum showed effective sensitivity in the wavelength range of 800nm and above, it was found that polycrystalline type Si solar cells could be formed at the low film formation temperature of only 350°C.

It was further found that low-temperature-formed films have a characteristic of susceptibility to the effects of the base carrier concentration. The I-V characteristic of cells with different bases, formed under the same conditions, revealed the increase of the open-end voltage Voc in the order of metal, iSi (laser-annealed)/$p^{+}Si$ (laser-annealed)/glass and $p^{+}Si$ (laser-annealed)/glass bases. This finding seems to suggest that the active layer has characteristics close to the i-layer when formed at low temperature.

Next, an active layer was formed over $p^{+}Si$ (laser-annealed)/glass by CVD (PCVD) at 550°C, and a conversion efficiency of 3.54% was achieved at a film thickness of 2 microns. The short-circuit current and open-end voltage of this cell are close to the model calculated values of cells having a greater effective diffusion lens than their film thickness. The remaining presence of microcrystals on the interface between the laser-annealed layer and the active layer was recognized by TEM photography of the cross sections of the cells, revealing the absence of epitaxial growth. Further enhancement of efficiency will require improvement of the interface characteristics to facilitate epitaxial growth and an increase in the film thickness of the active layer to about 10 microns.

Depending on the conditions of active layer formation, a short-circuit current of nearly $20mA/cm^2$ was sometimes achieved even at a film thickness of 2 microns. Especially when the active layer is formed at low temperature, it is possible that the carrier is not sufficiently activated by impurities, and the internal electric field attributable to a pin structure, such as in a-Si solar cells, contributes to taking out the carrier. By varying the carrier concentration of the i-layer by using PCID in a pin cell structure of 2 microns in thickness, the dependence of the short-circuit current on diffusion length was assessed. It was found that, when the carrier concentration was less than $10^{14}cm^{-3}$, a short-circuit current of nearly $20mA/cm^2$ could be taken out even if the diffusion length was insufficient. Polycrystalline Si of such a low carrier concentration type seems to permit efficiency improvement also by utilizing it in a stack structure together with a-Si solar cells and covering the infrared region of 800nm and above. Actual measurement of the sensitivity spectrum of polycrystalline Si solar cells of 2 microns in film thickness revealed a high enough sensitivity in the wavelength range of 700nm and above.

Comparison of the diffuse reflectivities of a sample having a relatively flat surface and one with a texturized surface showed that the effect of texture is conspicuous in the range from ultraviolet rays to visible light, where the reflectivity dropped to give an optical confinement effect. On the other hand, in the wavelength range of 700nm and above, no appreciable difference was witnessed between the two samples. This is consistent with the texture size, which is on the order of hundreds of nm. Observation of the surfaces of solar cells, whose 2-micron-thick films were formed at 350°C and 500°C, by AFM showed ruggedness of 200nm to 300nm in height on the surface of the cell whose film had been formed at 550°C, but the cell with a film formed at 350°C was found to have a flat surface. In order to increase the optical confinement effect in the near-infrared region, a surface structure of a few microns' size should be formed.

(3) Future Tasks

Research work from now on will focus on efficiency improvement of cells especially by controlling the initial Si film/Si film interface as well as increasing the cell thickness (to 10 microns). Specific themes include the following.

• Qualitative improvement of Si initial films formed by excimer laser annealing (increase of grain size and control of orientation) by controlling the interface energy and optimizing the materials. At the same time, by controlling the interface between the Si initial film and the Si film (chemically annealed) over it (purification of the surface and control of impurity concentrations), the quality of the Si film, which constitutes the active layer, will be improved to enhance the efficiency of solar cells.

• Attempts will be made to improve the cell performance by further developing low-temperature film formation techniques and optimizing the device structure.

2.2.6 Development of Fabrication Techniques for $CuInSe_2$ Solar Cells (Development of Control Techniques for Composition and Crystallinity of Solid Solution Films by Multinary Vapor Deposition and Otherwise

(1) Objective and Work Program

(Objective for FY1996)

Conversion efficiency: 15% (1cm x 1cm or larger)

(Work Program)

(a) Development of manufacturing techniques for high-quality CIS-based filmy light-absorbing layer that permit area expansion

With an eye to developing a manufacturing process that permits area expansion together with manufacturing technology for a high-quality CIS-based filmy light-absorbing layer, a stacked layer precursor film will be prepared by sputtering, and CIS and CIGS filmy light-absorbing layers will be produced by a gaseous phase selenization method by which selenization is carried out in a selenium atmosphere.

This year, conditions for selenization for the production of a CIS filmy light-absorbing layer containing no Ga will be studied.

(b) Establishment of peripheral technologies

For CIS filmy solar cells, which have a stacked structure, the establishment of peripheral technologies, including the development of techniques for the fabrication of layers other than the light-absorbing layer, is essential. This year, a novel Zn compound buffer layer was proposed in pursuit of improved performance characteristics of the pn junction interface and toward the formation of its satisfactory junction with a five-element filmy light-absorbing layer in the more distant future, as part of the development of technology for high-resistance buffer layer fabrication by solution growth, which is a low-cost technique for area expansion.

(2) Summary for FY1994

(a) Development of manufacturing techniques for high-quality CIS-based filmy light absorbing layer permitting area expansion

In order to develop manufacturing technology for a high-quality CIS-based filmy light-absorbing layer that permits area expansion, attempts were made to work out a technique to fabricate a CIS-based filmy light-absorbing layer by gaseous-phase selenization. This year, first to establish a CIS-based filmy light-absorbing layer production process by this method, conditions of selenization (thickness of the Cu/In stacked-layer precursor film, selenization temperature and H_2Se gas concentration) for the fabrication of the CIS-based filmy light-absorbing layer were studied. The Cu/In stacked-layer precursor film was prepared by sputtering. Selenization was carried out in an H_2Se atmosphere. The results revealed that the "degree of selenization" is the function of the three variable conditions of selenization. When the film thickness of the CIS-based filmy light absorbing layer after selenization was 0.5μm, the degree of selenization greatly varied with the selenization temperature, and deterioration in film quality attributable to growth in such a hetero-phase as the $MoSe_2$ phase or the Cu_xSe phase was observed. In this case, the open voltage (Voc) and the curvilinear factor (FF) significantly declined.

On the other hand, when the film thickness of the CIS-based filmy light absorbing layer after selenization was 1.0μm, variations in selenization temperature and H_2Se concentration were found to have little effect on the degree of selenization. It was also revealed that Voc may greatly vary depending on the combination of the selenization temperature, including the pace of its rise, and the H_2Se concentration. It was found that, in order to achieve Voc of 400mV or above, if the selenization temperature is 450°C, the H_2Se gas concentration should be 3vol% to 4vol% or, if the temperature is 500°C, the concentration should be 6vol% to 8vol%. Furthermore, it was also discovered that, to provide some leeway in the manufacturing process, the CIS film thickness after selenization should be at least approximately 1.0μm.

On the basis of these findings, thin-substrate solar cells of ZnO/CdS/CIS structure, using a CIS filmy light-absorbing layer of about 1.0μm in thickness prepared at a selenization temperature of 500°C and an H_2Se gas concentration of 6vol%, were fabricated, and an average conversion efficiency of 11.6% (the difference between the highest and the lowest was 6%) was achieved. In this case, 16 thin-film solar cells (of 3.2cm^2) of ZnO/CdS/CIS structure were fabricated over a 10cm x 10cm substrate and evaluated.

Next, to obtain basic data for the production of a CIGS filmy light absorbing layer, Cu-Ga/In stacked-layer precursor films were prepared by a sputtering process using Cu-Ga targets of different Ga contents and In targets, and the relationship of the Ga content in the Cu-Ga target to the quantity of Ga taken into the precursor film, together with the sputtering conditions for controlling the Cu/(In + Ga) ratio, was identified. Attempts to develop manufacturing technology for selenizing these precursor films in an H_2Se gas atmosphere will be started next year.

(b) Development of high-resistance buffer layer fabrication technology

This year, a technique to fabricate a sulfur-containing Zn compound buffer layer by a solution growth method was developed. The addition of sulfur was found to be effective in improving the electrical characteristics of filmy solar cells of ZnO/Zn(O, OH, S) x/CIS structure, using a buffer layer prepared in the sulfur concentration range of 0.3mol% to 0.4mol% in the solution.

FF was not improved so significantly and, moreover, the improvement was limited to the narrow sulfur concentration range of around 0.4mol%. By contrast, Voc was found to rise in a broad sulfur concentration range, suggesting the effect of sulfur in improving the surface of the CIS light-absorbing layer.

Furthermore, FF was found to improve in an annealing temperature range of up to 250°C. A temperature of 300°C proved too high, where the deterioration of the interface between the light absorbing layer and the buffer layer presumably occurred.

Thin-substrate solar cells of ZnO/Zn(O, OH, S) x/CIS structure fabricated by putting together the findings so far obtained gave a conversion efficiency of 12.1%. (Voc = 0.480V, Jsc = 37.8mA/cm^2, FF = 0.67 = 0.95cm^2, AM 1.5, 100mW/cm^2)

The thin-substrate solar cells using this buffer layer manifested a significant light irradiation effect. The maximum efficiency was attained in 1 hour of irradiation with light. This suggests room for improvement in the performance of the junction interface. However, it can be concluded that the findings obtained this year have resulted in substantial establishment of fabrication technology for a high-resistance buffer layer comparable to CdS.

(3) Future Tasks

(a) Development of techniques for efficiency improvement and of film formation techniques excelling in repeatability and uniformity

In order to manufacture large-area thin-substrate solar cells, it is necessary to develop film formation techniques excelling in repeatability and uniformity in addition to techniques for efficiency improvement. This year, 16 CIS thin-substrate solar cells were formed over a 10cm-square substrate, and the repeatability and uniformity were evaluated. As a result, the fluctuation of the conversion efficiency on the substrate was reduced to ±3%. In order to achieve the target for fiscal 1996, this fluctuation should be further reduced to improve uniformity.

(b) Development of patterning techniques

As elemental techniques for area expansion, it is necessary to develop patterning techniques for fabricating monolithic mini-modules consisting of series connection over a substrate. As such patterning techniques, laser scribing and mechanical scribing will be studied.

(c) Development of fabrication technology for filmy light-absorbing layer for achievement of high open voltage (Voc)

For the purpose of minimizing patterning-related losses of the effective power generating area, the open voltage (Voc) will be improved. Thus, Voc improvement will be accomplished by expanding the forbidden bandwidth and, at the same time, controlling the forbidden bandwidth within the light absorbing layer, and a reduction of the number of patternings will be thereby attempted.

(d) Establishment of peripheral technologies

Since CIS-based thin-substrate solar cells have a stacked-layer structure, it is essential to establish peripheral technologies for such elements as the ZnO window layer, Zn compound buffer layer and Mo back metallic electrode layer, including the glass substrate.

2.2.7 Development of Fabrication Techniques for $CuInSe_2$ Solar Cells (Technical Development for Large-Area Film Formation by Selenization

(1) Objective and Work Program

(Objective for FY1996)

Conversion efficiency: 12% (1cm x 1cm or larger)

(Work Program)

(a) Formation of high-grade CIGS-based thin film (bilayer method)

Conditions of CIGS-based film formation on a Mo metallic film by a bilayer method will be studied so as to establish bandgap control technology for the CIS film.

(b) Formation of high-grade CIGS-based thin film (three-stage method)

Conditions of CIGS-based film formation on a Mo metallic film by a three-stage method will be studied so as to establish formation technology for high-grade DIS films.

(c) Fabrication and evaluation of $CuIn_3Se_5$ and $Cu(In, Ga)_3Se_3$ films

$CuIn_3Se_5$ and $Cu(In, Ga)_3Se_3$ techniques for $CuInSe_2$ present on the CIS film surface will be formed into films, and their basic physical properties will be revealed.

(d) Research and development of low-cost film formation process

Cu-In-Ga-O films will be formed by sputtering, and their precursor films will be treated in hydrogen sulfide to form $Cu(In, Ga)S_2$ films.

(e) Trial production of $CuInSe_2$-based solar cells

Solar cells of MgF_2/ITO/ZnO/CdS/CIGS/Mo/glass structure will be produced on a trial basis by using the CIGS films formed by the bilayer and three-stage methods.

(2) Summary for FY1994

(a) Formation of high-grade CIGS-based thin film (bilayer method)

Mo was vapor-deposited on glass substrates by sputtering, and CIGS films of different Ga/In ratios were formed over the Mo layer by simultaneous quaternary vapor deposition at different vapor deposition rates for In and Ga. TEM observation revealed that a solid solution of Ga, though smaller in grain size, manifested decreases in twin crystals within grains and decreases in stacking defects. This finding suggests not only a Voc rise through expansion of the forbidden band width but also such other factors as an increase in carrier concentration due to a decrease in defect density contributing to the efficiency improvement of CIS solar cells brought by the solid solution of Ga. A CdS film was deposited over the CIGS film that was formed, and ZnO and ITO films were further vapor-deposited over it by sputtering, to fabricate solar cells. When their performance characteristics were assessed by irradiating them with light of $100mW/cm^2$ (AM1.5), the highest efficiency was achieved by a cell using a CIGS film of Ga/(In + Ga) = 0.21. EBIC signals of the cross sections of CIGS cells having different Ga contents indicated that the collection area of the carrier extending from the junction toward the CIGS film side narrowed with an increase in Ga content. This result is highly consistent with the finding of C-V measurement that the hole concentration rises with an increase in Ga content.

(b) Formation of high-grade CIGS-based thin film (three-stage method)

By a three-stage method by which a Cu_2Se layer is formed over an $(In, Ga)_2Se_2$ film, the conditions for CIGS film formation were studied, and a certain correlation between the substrate temperature and the CIGS film composition was discovered by monitoring the substrate temperature during film formation. The first layer of $(In, Ga)_2Se_2$ film was formed to a height of about 1μm at a substrate temperature of 200°C to 300°C and then, with only Cu and Se fluxes being supplied, film formation was carried on until the overall film composition came to have an excess Cu content. Furthermore, in order to apply this film to solar cells, it was irradiated with fluxes of In, Ga and Se so as to give the final composition excess (In, Ga). When the substrate temperature began to drop, the overall film composition began to have an excess Cu content. Irradiation with In, Ga and Se made the substrate temperature rise again. Thus, by using a newly developed composition control technique, it was possible to precisely control the CIS (CIGS) film composition, which is an essential factor for CIS-based solar cells.

(c) Fabrication and evaluation of $CuIn_3Se_5$ and Cu(In, Ga)$_3$Se$_3$ films

Recently, the presence of a $CuIn_3Se_5$ phase over the surface of the CIS thin film has come to be claimed, and it is attracting note as a possible factor to dominate the conversion efficiency of solar cells. In view of this possibility, single-phase films were formed by alternate vapor deposition of CIS/In_2Se_3, and the resultant $CuIn_2Se_3$ films were evaluated electrically and optically. The $CuIn_2Se_3$ films manifested n-type electroconductivity at high resistance, and their optical bandgap was found to be 1.23eV.

Next, Cu(In, Ga)$_3$Se$_3$ films, which are likely to exert a significant effect on CIGS solar cells, were formed, and examined for variations in crystallographic properties and optical and electrical characteristics dependent on the solid solution of Ga. It was found that the lattice constant uniformly decreased with an increase in the quantity of Ga, and was tetragonal below, and cubic above, Ga/(In + Ga) = x = 0.5. Measurement by the van der Pauw method showed that the electroconductivity was 10^{-6} to $10^{-5}/\Omega$cm (n-type conductivity) for films having an x value of less than 0.3 and $10^{-6}/\Omega$cm or less for films containing more Ga. The bandgap continuously varied from 1.2eV (x = 0.0) to 1.8eV (x = 1.0).

(d) Research and development of low-cost film formation process

The selenization process using an oxide precursor was further extended, and Cu(In, Ga)S_2-based solid solution films were thereby produced. Cu-In-Ga-O-based precursor films were prepared by a sputtering process using oxide powder as target. The resultant precursor films were amorphous, and showed no definite peak in X-ray diffraction. The precursor films were converted into sulfide films by sintering in a hydrogen sulfide atmosphere. With an increase in the quantity of Ga solid solution, the X-ray diffraction peak shifted toward the steep angle side. The sulfide films identified by X-ray diffraction were confirmed to consist of a Cu(In, Ga)S_2-based solid solution in the chalcopyrite phase.

(e) Trial production of $CuInSe_2$-based solar cells

Solar cells of MgF_2/ITO/ZnO/CdS/Cu(In, Ga)Se_2/Mo/glass structure were produced on a trial basis from CIGS films formed by the bilayer method. Solar cells of 0.1cm^2 in square measure that were obtained gave a conversion efficiency of 15.2% (Voc = 0.616V, Jsc = 33.9mA/cm^2, FF = 0.732). Similar solar cells were also fabricated on a trial basis from CIGS films formed by the three-stage method. Resultant solar cells of 0.5cm^2 in square measure gave a conversion efficiency of 13.7% (Voc = 0.595V, Jsc = 31.5mA/cm^2, FF = 0.730), and other solar cells of 1.0cm^2 achieved a conversion efficiency of 13.0V (Voc = 0.583V, Jsc = 32.3mA/cm^2, FF = 0.693).

(3) Future Tasks

(a) Qualitative improvement of the light-absorbing layer: enhancement of film quality and uniformity

(b) Optimization of the window layer: Qualitative improvement of the buffer layer and the transparent electroconductive film

(c) Optimization of cells

2.3 Research Concerning Analysis for Practical Application

(1) Objectives and Work Program

Technical trends regarding thin-film solar cells in and out of Japan will be monitored for prompt and accurate analysis to effectively reflect the analytical findings in the research and development of technology for the practical application of filmy solar cells for power supply use and to thereby support research on practical fabrication technology for thin-film solar cells.

(2) Summary for FY1994

(a) Monitoring of technical trends regarding practical application of thin-film solar cells

For the purpose of supporting the practical application of thin-film solar cells, a working group for thin-film system monitoring was established, comprising experts from industry, the government and the academic community, and the group met five times to discuss and analyze current technical trends which had been monitored and to identify the technical challenges involved. The objects of monitoring were amorphous Si-based, chemical compound-based including CdTe-based and Cu-based, and polycrystalline Si film-based thin-film solar cells. The monitoring by the working group is outlined below.

(i) New developments and findings regarding physical properties of materials and in the area of film formation technology

Regarding the physical properties of materials for amorphous solar cells, surveys were made on the possibility of structural reduction of defects, inclination at the band end and defect density, new techniques to evaluate physical properties and reappraisal of existing techniques. Concerning new film formation technology, a triple-electrode plasma CVD method, which would use, as a third electrode, a mesh electrode for controlling the quantity and energy of ion seeds in addition to the usual twin-electrode discharge, was proposed as a method of film formation from high-mobility materials. As a formation method for highly photostable films, a hydrogen radical CVD method using dichlorosilane as input gas was reported. Progress was achieved in understanding the mechanism of film growth and, in place of the heat balance theory which had constituted the main stream, a model concerning the reaction to determine the defect density in the film, referring to the constant state in the surface reaction process of film growth, was proposed and became the new main stream.

Concerning $CuInSe_2$-based solar cells, such physical properties of materials as dynamic characteristics, microscopic crystalline structure, physical properties of epitaxial films, those of $CuIn_3Se_3$ films and those of $Cu(InGa)Se_2$ were examined. Regarding film formation techniques, surveys were made mainly on what seemed to be particularly important ones including multi-source simultaneous vapor deposition, multi-stage vapor deposition and selenization, newly developed by NREL and at the University of Stuttgart. For the moment, only the multi-source simultaneous vapor deposition and selenization processes have achieved conversion efficiencies of more than 16%.

As regards polycrystalline Si film-based solar cells, the carrier concentration, minority carrier diffusion length and mobility were checked for each film formation method to collect experimental data concerning the physical properties of films. Regarding film formation techniques, the precedents of polycrystalline Si film formation were investigated, and the current state of the structure and performance characteristics of solar cells were described for each precedent.

(ii) Device technology for efficiency improvement and life elongation

In order to enhance the performance (the initial and stabilized efficiencies) of amorphous solar cells, increasingly important are research and developmental efforts to reduce defects in and photostabilization of the optically active layer, increase light absorption (narrow the bandgap), further ameliorate and develop better materials for the doped layer, and improve the characteristics of TCO/p, p/i and n/electrode interfaces and that of the transparent electroconductive film. Recently reported R&D attempts on amorphous solar cells do not include any on a material or technical breakthrough, but do include many on high-Voc single cells surpassing 1.0V per cell, achieved by low-temperature a-Si film formation or controlling hydrogen in the film. Also, systematic conditions of a-SiGe film formation were studied, resulting in high-efficiency tandem cells embodying consideration for stabilized efficiency after photodegradation. Concerning the doped layer, many reports were found on attempts to raise the Voc by using a crystalline p-layer or on interfacial problems of TCO/p-layer and n-layer/electrode interfaces.

Significant progress was achieved in the work on $CuInSe_2$ solar cells. For small-area cells, NREL reported a practical conversion efficiency of 16.8% and the EURO-CIS group an intrinsic conversion efficiency of 16.9%. Thus, though for only small-area cells, conversion efficiencies comparable to those for polycrystalline Si cells have been attained, and even higher efficiencies are likely to be reported. Japanese developers, including Matsushita Electric (having achieved 15.2%), are closely behind their Western competitors. The rapid progress in the enhancement of the conversion efficiency is mainly due to an enlarged grain size made possible by high-temperature film formation and an improved CIGS light-absorbing layer brought about by control of the forbidden band profile. Remaining problems to be solved in order to achieve further improvement in efficiency include, for the light-absorbing layer, control of the forbidden band profile by the addition of S, conduction type control by utilizing the substrate effect and doping with impurities, and formation of pn homo junctions, together with control of the buffer layer and of the CdS/CIS interface, and performance improvement of the window layer.

Regarding CdTe-based solar cells, no top data were newly reported this year. In the area of efficiency improvement, reports were made on diverse aspects of treatment with $CdCl_2$ after CdTe film formation, including the method and effects of treatment and prospects of mass production. The commonest treating method is annealing for about 30 minutes in the vicinity of 400°C after the application of $CdCl_2$ gas or solution, and one of the reported effects of this treatment is enhanced Voc and FF through the improvement of CdTe film quality.

(iii) Technologies for cost reduction and mass production

For amorphous solar cells, the improvement of performance and the development of production technology for practical size are making significant progress. So far, a stabilization efficiency of 10% has been achieved for a practical square measure. Production technology, too, is advancing remarkably, making it possible to manufacture large-area solar cells at a high yield. For cost reduction, one conceivable way is to improve the throughput, and in this regard, a roll-to-roll process using a flexible substrate is attracting note. This had not been a majority approach, but its advantages gained renewed appreciation in serious thought on cost reduction, and at present several companies are trying this approach. This and related techniques may offer a key to the future development of solar cells for practical application.

For $CuInSe_2$-based solar cells, in the United States, Energy Photovoltaic, Inc. (EPV) in 1995 announced its plan to build a commercial plant and start production. $CuInSe_2$-based solar cells are expected to become available for practical application in the relatively near future, and the development of technology for cost reduction and mass production have taken on even greater importance than before. This year, surveys were made on the progress of projects at NREL, DPV, International Solar Energy Technology, Inc. (ISET), Solarex and Siemens to develop low-cost mass-production processes. All these processes either permit or are intended to permit the production of large-size cells.

As regards CdTe-based solar cells, at present only Matsushita Battery Industrial Co. is engaged in commercial production, but there were reports that Solar Cells Inc. (SCI) is planning a 20MW/year plant and that Golden Photon Inc. (GPI) will start commercial production. This year, reports were received on activities geared to commercial production, such as manufacturing of many large-area cells on the mass-production line, followed by examination for any unevenness of performance among the products and their outdoor exposure for reliability evaluation. There were also reports on the integration of techniques for efficiency improvement into mass-production technology and a pursuit of higher efficiency by using soda glass to reduce costs.

(iv) Estimation of module fabrication cost

This year, the cost of large-area modules was calculated for each different thin-film solar cell manufacturing method on the basis of the cost estimates so far made. As a result, it was found that, if the annual output of each type of solar cell reaches 100MW, the cost can be reduced to around ¥100/W. The economies of scale would be significant for any type of solar cell under study, but the difference in process for the same type of solar cell would result in an unexpectedly small cost difference.

The remaining tasks include study on the overall power generation cost including peripheral costs, which may differ with the efficiency level.

(v) Applied systems

The latest output level of thin-film solar cells was investigated, and at the same time suitable areas of application for thin-film solar cells were studied, with particular focus on systems to which thin-film solar cells had been actually applied.

Whereas thin-film solar cells had been applied mainly to consumer items (electronic items), their use as a power source for micromachines was reported as an example of a new application in this area.

Attempted applications other than in consumer products include those of transparent solar cells to building windows and automobile sun roofs, taking advantage of the characteristics of thin-film solar cells, and to solar cars or solar planes.

In the field of housing and nonresidential buildings, on the other hand, panels for ordinary houses, glass roofing, integrated roofing and integrated walling are either being developed or already commercially available. In addition to these, themes for future development include insulating roof panels consisting of solar cells integrated with surface protecting material, glass, roofing, insulator and sheathing among others, and plain roof tiles using CdTe solar cells or unitized roof panels combining tiles, roofing, sheathing and so forth. The point is maximum utilization of such advantages of thin-film solar cells as compatibility with curves, thinness, light weight and uniform appearance.

Whereas the cost reduction is the most important requirement for medium and large-scale power supply systems, thin-film solar cells have potential for cost reduction, and accordingly are expected to prove most suitable for use in this area.

(b) Safety check on compound-based thin-film solar cells

Of the different types of thin-film solar cells, CdTe-based and $CuInSe_2$-based cells were checked for safety. This year, such aspects of safety control measures were studied as the impact of the manufacture of CdTe-based and Cu-$InSe_2$-based thin-film cells on the surrounding environment, that of the installation of such cells on the surroundings, and the problems of waste matter resulting from the manufacture of solar cells and the disposal and recycling of used modules.

CdTe-based solar cells were put to small-scale combustion experiments in anticipation of accidental fire involving them, and the extent of the scattering of heavy metals, such as Cd and Te, constituting solar cells into the atmosphere was assessed.

(c) Survey on technical trends abroad

In order to find out technical trends regarding thin-film solar cells, representatives were sent to nine international conferences to obtain the latest technical information, which was reflected in committee discussions.

- Materials Research Society Spring Meeting
- 12th European Photovoltaic Solar Energy Conference and Exhibition
- 1st World Conference on Photovoltaic Energy Conversion
- 3rd World Renewable Energy Congress
- Materials Research Society Fall Meeting

Nine lecturers were invited from abroad to give lectures on the topics indicated below and participate in discussions regarding technical development of amorphous solar cells among thin-film solar cells.

- H in Si Network and Under Deposition

  Warren Jackson (Xerox, U.S.A.)
- Bridge Between Materials and Devices

  David Carlson (Solarex, U.S.A.)

  Christopher Wronski (Pennsylvania State University, U.S.A.)
- Microstructures

  Robert Collins (Pennsylvania State

University, U.S.A.)

Arvind Shah (University Neuchatel, Switzerland)

Bernard Drevillon (Ecole Polytechnique, France)

- High Growth Rate

Subhendu Guha (United Solar Systems, U.S.A.)

Friedhelm Finger (ISI-Research Center Julich, Germany)

Sigurd Wagner (Princeton University, U.S.A.)

(d) Technical research regarding practical application of thin-film solar cells

Concerning the technical themes of commissioned research projects, the commissioned companies were visited to analyze the problems involved and contemplate possible solutions. The technical working group on thin-film cells was convened twice to discuss technical problems arising along with the progress of research.

(3) Future Tasks

In order to support research work regarding practical application of thin-film solar cells, it is necessary to continue surveys to keep track of technical trends in Japan and elsewhere, analyze the technical problems involved and search for possible solutions. The technical problems concerning thin-film solar cells include those described below.

Future tasks regarding amorphous solar cells can be classified into 1) development of technology for low-cost module production, 2) development of revolutionary materials and devices which would contribute to enhancing efficiency and reliability, and 3) technological development to achieve ultra-high efficiency. As regards the cost, major requirements will be to reduce direct materials costs, including that of substrates, reduce the depreciation costs of hardware among others, and achieve technological development for low-cost modulization. Concerning efficiency enhancement, in order to further improve the stabilized efficiency, technological development is desired to improve the optical confinement effect and to raise the open voltage by a large measure. Concerning measures against photodegradation, with a view to preventing degradation, research is being undertaken in two aspects including 1) development of degradation-free materials and 2) development of device structures less susceptible to degradation. In regard to devices in particular, much hope is pinned on a tandem arrangement.

For CdTe solar cells, what is basically needed is development of technology to form high-quality CdTe films. If it is made technically possible to produce large-area modules with an efficiency of about 10%, practical application may become feasible at a relatively early opportunity.

$Cu(InGa)Se_2$-based thin-film solar cells have an advantage of future potential for a high efficiency of 18% to 20%. No degradation was observed even in long-term outdoor exposure tests. At present, small-area cells have achieved a high efficiency of 16% to 17%, but cells of this type are behind amorphous cells in the development of production technology. The immediate developmental themes for $Cu(InGa)Se_2$ thin-film solar cells include 1) achievement of a far higher efficiency than amorphous cells, 2) development of film formation technology suitable for mass production, and 3) development of methods for the evaluation and control of intrinsic defects.

For polycrystalline Si film-based cells, developmental work is focusing on film formation technology at the moment, and the immediate objective is to achieve a conversion efficiency of over 10% in a low-cost process.

For thin film-based solar cells, the immediate target is a module efficiency of 10 to 12%, but realization of modules surpassing that in conversion efficiency is hoped for in the early 21st century. At present, a major breakthrough in conversion efficiency improvement for thin-film solar cells is sought by using a tandem (hybrid) structure of thin-film compounds, and this remains a major future challenge.

3. Technological Development for Super-High Efficiency Solar Cells

3.1 Technological Development for Super-High Efficiency Single-Crystalline Silicon Solar Cells

3.1.1 Technological Development for High-Quality Single-Crystalline Silicon Substrates

(1) Objective and Work Program

(Objective for FY1996)

Crystal quality enabling a conversion efficiency of 24% or more for ingots 15cm or more in diameter

(Work Program)

Study will be made on new methods of manufacturing high-quality monocrystals from granulous silicon material. In the first method, the granulous silicon material is electromagnetically cast into a round rod shape, and the ingots in this round rod shape are monocrystallized in a single round of melting by the float zone (FZ) method. The second method melts the granulous silicon material by induction in a state of non-contact with a cold crucible, and monocrystals are picked up from this molten silicon by the Czochralski (CZ) method. The third puts the granulous silicon material to electron beam melting in a cold crucible, and similarly picks up monocrystals by the CZ method.

Technical problems and opportunities in these three methods will be studied.

(2) Summary for FY1994

(a) Electromagnetic casting + one FZ pass method

(i) Change in power frequency

In order to achieve successful monocrystallization without displacement by the electromagnetic casting plus one float zone (FZ) pass method, complete melting of the raw material was necessary (to prevent unmelted residue from remaining on the ingot surface). The induction frequency during electromagnetic casing had been increased (to 180kHz) to strengthen induction heating, but there occurred an electric discharge between the crucible and the molten bath, posing the problems of damage to the crucible and its contamination with copper. Accordingly, the induction frequency was reduced (to 30kHz) this year, and the casting experiment at this frequency resulted in satisfactory melting of the raw material without problem and prevention of the discharge.

(ii) Improvement of furnace parts

To prevent both contamination and cracks in ingots, a heat insulating cylinder consisting of a low-resistance silicon heater and an insulator was developed, and this proved fairly effective in the experiment. The use of carbon and iron parts, which could also be contaminants, was avoided wherever possible, and it was made possible to produce high-purity polycrystalline ingots of 1,500Ωcm or more in resistivity.

(iii) Results of electromagnetic casting + one FZ pass method

The electromagnetic casting plus one FZ pass experiment gave the following results.

- By one FZ pass, 600mm long monocrystals were successfully obtained for the first time.
- What remained without being monocrystallized had a high carbon concentration, and contained unmelted substance.
- The resistivity of non-doped electromagnetically cast ingots was no less than 1,500 Ωcm, demonstrating the effectiveness of the precautions taken to suppress the infiltration of impurities.

(iv) Optimal grinding margin for electromagnetically cast ingots

It was found necessary to develop a technique to evenly grind the skin surface of ingots containing much unmelted matter or impurities.

(b) Electromagnetic melting CZ method

(i) Electromagnetic melting CZ experiment using shield

In the electromagnetic melting Czochralski (CZ) method, the vibration of the molten bath surface and the difficulty of temperature control, among other factors, inhibit the pick-up of single crystals. To address these problems, molten bath surface vibration suppression and temperature control were attempted by applying a magnetic shield from the top side of the crucible. The optimal conditions were studied for the surface temperature and shape of the molten bath and the control of the vibration of the molten bath surface. As a result, the use of the shield was found to be somewhat effective in suppressing the shaking and vibration of the molten bath surface, but not sufficiently to permit the steady pick-up of single crystals. It was impossible to achieve a satisfactory balance between the molten bath temperature and the vibration of the molten bath surface on the one hand and the source power output (electromagnetic force) on the other. As enlargement of the size was likely only to aggravate the problem, this method was regarded as having little technical potential.

(c) Electron beam melting CZ method

In the electron beam melting CZ process, several consecutive batches of 25mm-diameter single crystals were successfully picked up by taking the measures described below. It is expected that steady single-crystallization can be made possible by further improving these measures, and guidelines in this respect were obtained.

(i) Measure against drop of vapor-deposited silicon

It was confirmed that the more cores of vapor-deposited silicon were allowed to be formed and the strength of vapor deposition was increased, making it more difficult for the deposited silicon to peel off and drop, by using a porous material for the inner wall of the furnace. Even in 30 or more hours of use, no deposited silicon was found to drop.

(ii) Distribution of vapor deposition in furnace

It was confirmed that vapor deposition may be unevenly distributed depending on differences in distance from and angle to the crucible and the position in the furnace. In order to achieve even distribution of deposition, it is necessary to improve the furnace structure, and this improvement is expected to enable the furnace to withstand vapor deposition for an even longer period of time.

(iii) Measures against bumping of raw material

No major bumping was found after the methods of raw material inputting and of beam scanning were improved. However, observation of the surface of the picked-up single crystals revealed the presence of small liquid drops. Since even small such drops could inhibit single-crystallization, preventive measures are under study.

(d) Magnetic field analyses for optimal designing of electromagnetic casting furnace

(i) Analysis of source-linked oscillator circuit constant

The electromagnetic casting furnace was analyzed by the finite element method using the voltage input to find out the source-linked oscillator circuit constant. The analytical value and the measured value were in close agreement, making it possible to determine the circuit constant by analysis.

(ii) Analysis of water-cooled copper crucible structure

Regarding the water-cooled copper crucible, the optimal values of the number and shape of slits, which are its main structural factors, were sought by analysis. The optimal number of slits was found to be about 30. Concerning the width and shape of slits, it was found that, by adopting a convex-concave shape of 0.3 mm on the molten bath side and 2.0mm on the coil side, a melting efficiency comparable to that of 0.8mm wide slits could be attained with no penetration of the molten bath.

(iii) Analysis at different power source frequencies

Analysis was carried out at five different frequencies including 6, 20, 50 and 180 kHz, and the melting efficiency was found to improve with an increase in frequency. However, the higher the frequency, the more the crucible tended to be damaged by erosion by electric discharge, posing a problem to the durability of the crucible.

(iv) Analysis of factor causing erosion damage to crucible

Models in which the molten bath is in contact with the crucible were analyzed to compare current densities in the contact section. It was confirmed that, when the molten bath came into contact with the crucible between slits, the current density in the contact section sharply rose. The higher the frequency, the greater this current density. The discharge damage inflicted on the crucible presumably arises from a thermal load which results from the sharp rise in current density due to the penetration of the molten bath between slits and melts the crucible surface. By determining the correlation between this current density level and the crucible damage, it is possible to select by analysis a frequency which would not give rise to crucible damage.

(3) Future Tasks

The following subjects will be studied from now on.

(a) Electromagnetic casting + one FZ pass method

(i) Improvement of non-dislocation single-crystallization yield

(ii) Quality improvement by shutting out impurities

(iii) Optimization of grinding margin of electromagnetically cast ingots

(b) Electron beam melting CZ method

(i) Non-dislocation single-crystallization

(ii) Achievement of steady single-crystallization by improving measures to prevent vapor deposits from dropping and raw material from bumping

(iii) Basic experiments toward size enlargement (securing sufficient molten bath volume, studying optimal pick-up conditions, etc.)

3.1.2 Technological Development for Super-High Efficiency Single-Crystalline Silicon Solar Cells (1)

(1) Objective and Work Program

(Objective for FY1996)

Cell conversion efficiency of 24% (5cm square)

(Work Program)

(a) Development of a high-performance front surface

Along with research on formation technology for light receiving side electrodes, formation technology and junction structure for high-quality passivation layer and anti-reflection coating will be studied with an eye to improving the open voltage.

(b) Development of technology for back-side hetero junction formation

A stacking method and a processing method for a wide bandgap layer, suitable for the back side structure, will be studied to improve the performance characteristics of cells.

(c) Analytical study for conversion efficiency improvement

Along with structural analysis of the junction structure and performance evaluation of the substrate, numerical simulation will be carried out regarding the cell structure.

(2) Summary for FY1994

The achievements in fiscal 1994 are listed below.

• A conversion efficiency of 21.1% was achieved for back-side low-high hetero junction cells (5cm square, confirmed at IQA).

• Improvement of the curvilinear factor attributable to a design of the light receiving face electrode pattern was confirmed.

• Improvement of the short-circuit current and the open voltage by annealing with N_2 immediately after oxidation of the light receiving side passivation film was confirmed.

• Improvement of all such aspects as the short-circuit current, open circuit voltage and curvilinear factor by heat treatment of the microcrystalline silicon film was confirmed.

• Improvement of the short-circuit current by inserting a silicon nitride film between the microcrystalline silicon film and the back-side electrode was confirmed.

• As maximal values for performance parameters, 41.0mA/cm^2, 665mV and 0.802 were confirmed for the short-circuit current density, open circuit voltage and fill factor, respectively.

Achievements for each subtheme are described below.

(a) Development of a high-performance front surface

(i) Study to reduce series resistance of the front surface

The advisability of altering the front contact pattern from a comb type to a fishbone type was assessed. By making the subgrid very fine and expanding the pitch, the series resistance was reduced without allowing the electrode occupancy rate to increase, and a high curvilinear factor was obtained.

(ii) Study on qualitative improvement of passivation effect

With a view to improving the passivation effect of the oxidized film formed on the surface, processing by N_2 annealing immediately after the oxidized film formation was studied. It was found that annealing at 800°C for 15 minutes resulted in qualitative improvement of the oxidized passivation layer, and that both the short-circuit current density and the open circuit voltage were significantly enhanced.

(b) Development of technology for back-side hetero junction formation

(i) Structure of back-side low-high hetero junction cells

PN junctions were formed, with the light receiving side of a P-type substrate (FZ, $\rho = 2\Omega\cdot$cm) fabricated in a textural structure, and a passivation layer of oxidized film and an anti-reflection layer of silicon nitride film were formed over the surface of the N^+ layer. Ti/Pd/Ag three-layered electrodes were formed on the light receiving side by the lift-off method. Over the whole back face of the substrate, P^+ microcrystalline silicon film and silicon nitride film were formed by plasma CVD, and the P^+ microcrystalline silicon film and the Al back side reflective electrodes were brought into contact by patterning the silicon nitride film.

(ii) Study on qualitative improvement of microcrystalline silicon film by heat treatment

Resistivity is reduced by heat treatment of microcrystalline silicon film, and so is the hydrogen concentration in the film. Regarding cell performance, all such characteristics as the short-circuit current density, open circuit voltage and fill factor were found improved.

(iii) Study to improve back-side reflection of light

To further improve back-side reflection, the advisability of inserting silicon nitride film between the microcrystalline silicon film and back-side electrodes was assessed. The insertion serves to increase the back-side reflection in the wavelength range of 1,030nm and above, and to improve the spectral sensitivity. This was found to increase the current density by about 2%.

(iv) Cell performance

In the back-face low-high hetero junction cells fabricated to embody the findings of these studies, a particularly high 41.0mA/cm^2 short-circuit current density was obtained, and a conversion efficiency of 21.1% (JQA measurement) was achieved at an open voltage of 657mV and a curvilinear factor of 0.785.

(c) Analytical study for conversion efficiency improvement

For back passivation cells on whose back surface a P^+ layer is partially formed, the relationship between the back-side recombination rate on the interface between the P-type substrate and the back passivation film and the internal collection efficiency when probing light is brought into incidence from the back side was investigated by simulation. As a result, it was discovered that the back recombination rate of cells can be evaluated by fabricating cells of a structure which would permit the incidence of light from the back side and measuring the spectral internal quantum efficiency with respect to the back-side incidence of light.

(3) Future Tasks

A conversion efficiency of 21.1% was achieved for back-side low-high hetero junction cells (5cm square). In order to achieve the 24% conversion efficiency which is the target for fiscal 1996, the following aspects of performance parameters should be studied to improve the performance characteristics. The open circuit voltage is likely to be increased by improving the quality of the passivation film by optimizing the conditions of oxidation and post-oxidation processing, enhancing the quality of the microcrystalline silicon film by raising its crystallization rate and appropriately controlling the interface between the substrate and the microcrystalline silicon film. The short-circuit current is expected to be improved by achieving more effective utilization of light through proper matching of the passivation oxide and the anti-reflection coating, and so is the curvilinear factor by reducing the resistance of the microcrystalline film, ameliorating the interface characteristics and reducing the contact resistance of electrodes.

3.1.3 Technological Development for Super-High Efficiency Single-Crystalline Silicon Solar Cells (2)

(1) Objective and Work Program

(Objective for FY1996)

Cell conversion efficiency of 25% (2cm square)

(Work Program)

(a) Development of technology for highly light-confining ultra-thin cell formation

As part of the work to develop technology for cell designing and formation, with a view to enhancing the open voltage, the field effect type surface passivation structure will be analyzed, and methods to restrain surface recombination will be studied. In parallel with these efforts, attempts will also be made to improve the short-circuit current with particular regard to, among other aspects, wave-optical light confining structures and techniques to passivate the surface on which ultra-fine convexes and concaves are formed.

(b) Development of technology for wide-bandgap emitter cell formation

As part of the endeavor to improve the open voltage of cells, study will be made on the formation of high-quality junctions by expanding the bandgap of emitter materials and its effect to enhance the open voltage.

Conditions for microcrystalline film formation by plasma film formation techniques will be studied, and the effect to enhance the open voltage will be confirmed with cells in whose contact section over the emitter junction a wide-bandgap (WBG) film is formed.

(c) Development of technology for high open-voltage contact formation

As part of the attempt to develop contact-related techniques for enhancing the open voltage of cells, study will be launched on the suppression of carrier recombination on the electrode interface by potential control on the silicon-(oxidized film)-contact metal interfaces utilizing the difference in work function among electrode materials.

(2) Summary for FY1994

(a) Development of technology for highly light-confining ultra-thin cell formation

(i) Surface passivation by field effect

Even if the cell surface is passivated by an oxidized film, the recombination rate of the carrier may vary depending on the surface potential of the cell. With an eye to quantitatively assessing this effect and identifying a cell structure which would lend itself to further improvement of efficiency, the performance characteristics of back-side contact type and conventional two-side contact type cells were simulated. As a result, with about 250μm thick substrates which are commonly used, it was found that conversion efficiencies of 25.5% and 26.5% or more could be expected for two-side contact type cells and back-side contact type cells, respectively. Since this finding was obtained under the realistic assumption of $6.5 \times 10^{11} cm^{-2} eV^{-1}$ in interfacial capture level density, prospects were confirmed for the attainment of an efficiency of more than 25% by applying passivation by the field effect.

(ii) Trial production of high-voltage cells

Improvement of the passivation performance of the oxidized film was attempted by normalizing the oxidizing atmosphere and optimizing the conditions of oxidation. Attempts were also made to establish boron diffusing techniques free from the risk of giving rise to defects in the bulk. By utilizing these improvements in process technology, back-side local P^+ cells were produced on a trial basis. An open voltage of 700mV, the highest in Japan, was achieved, testifying to the improvement in passivation technology. The surface recombination rate estimated from correspondence to one-dimensional simulation was as low as 150cm/s, clearly indicating a reduction in recombination in the bulk and on the back side.

(b) Development of technology for wide-bandgap emitter cell formation

In order to further reduce the surface recombination rate, it is necessary to restrain surface recombination in the contact area as well as to improve surface passivation techniques. If the recombination rate of minority carriers on the electrode interface is reduced, the open voltage can be further enhanced. For this purpose, it seems effective to use a wide-bandgap material and form hetero junctions on the interface with silicon. In this developmental study, microcrystalline silicon (μc-Si) was used as wide-bandgap material. The uc-Si hetero film was formed by plasma CVD after forming the passivation oxidized film on the silicon cell surface.

While n-type μc-Si had been formed via a naturally oxidized film in the research until last year, this year no naturally oxidized film was placed in-between, and instead an attempt was made to form a hetero contact via an a-Si film which is less resistant and more readily permits film thickness control. Various hetero film structures were fabricated, and the best passivation effect was achieved when hetero contact formation was carried out via an n-type a-Si film. This method was applied to the contact part on the n-diffused layer in the trial production of cells, and the open voltage was found about 50mV higher than in direct contact with metal electrodes. The voltage also was about 10mV higher than in the presence of an n^+ diffused layer, and neither the short-circuit current nor the curvilinear factor dropped.

In improving the efficiency of back-side local p^+ cells, too, it is essential to reduce the recombination of minority carriers on the p^+/electrode interface. In the p-type as well as in the n-type, the open voltage can be further enhanced if hetero contacts are formed. However, by the RM (13.56MHz) plasma CVD method used for n-type film formation, it is impossible to form a microcrystalline p^+ layer of a high crystallization rate. With an eye to forming a microcrystalline p^+ layer, a plasma CVD method applicable to the VHF (up to 100MHz) region, which is suitable for microcrystalline film formation, was developed. The VHF plasma method makes suitable film forming conditions for crystallization more readily available as a result of an increase in plasma density with a rise in frequency. A discharge experiment with a plasma CVD apparatus provided steady discharging virtually free from reflected waves in the 50–120MHz range, indicating good prospects for applicability to trial production of cells.

(c) Development of technology for high open-voltage contact formation

In the MOS configuration of silicon-(oxidized film)-metal, the field effect on the semiconductor interface and the state of static potential linkage between the semiconductor and metal heavily depend on the thickness of the oxidized film in-between and the density and distribution of the carrier capture level on each interface. In order to utilize the difference in the work function of contact metal, the thickness of the oxidized film intervening in the interface between silicon and the contact metal has to be precisely controlled, and the state of oxidation of the metal to be formed into film also has to be accurately controlled.

Metals with low work functions are generally highly reactive and readily oxidized. Formation of a metal film requires an ultra-high vacuum, and this condition is desirable for a metal with a high work function as well. When a contact is to be formed of a readily oxidizable metal, such as magnesium, it has to be formed from the outset in a multi-layered structure together with a thin film which would serve as oxidation barrier so that oxidation may not progress in the atmosphere after film formation. To meet these requirements, an apparatus which would permit consecutive formation of metal films in an ultra-high vacuum was designed and produced. The film forming apparatus consisted of three chambers, one each for the introduction of the sample substrate, pretreatment and film formation. The degree of vacuum to be reached in the pretreating and film forming chambers was designed to be in the order of 10^{-11} Torr, and that in the latter was confirmed to be no less than 1.3 x 1^{-10} Torr. A basic performance to form films of Cu at 0.03nm/s under a pressure of 4 x 10^{-8} Torr was confirmed, and arrangements were thereby established for systematic study on contact metal materials.

Whereas surface purification of the silicon substrate prior to metal film formation is an important step as pretreatment for film formation, the finished state of the surface depends on the oxygen dissolved in the pure water used for washing. If the dissolved oxygen is supplied in the ozone form, the surface of the substrate is subjected to forced oxidation at low temperature. The ultra-thin oxidized film that is formed permits thickness control to some extent, and can be used for such purposes as the prevention of rediffusion from the high-concentration diffusion area of the substrate and surface protection until the metal film is formed in the vacuum vapor-depositing apparatus. The substrate was washed with high-purity high-concentration ozone-dissolved water, utilizing the electrolysis of water, and it was confirmed that the oxidized film can be used for the aforementioned purposes.

(3) Future Tasks

(a) Development of technology for highly light-confining ultra-thin cell formation

Since the cells fabricated on a trial basis have a flat surface structure with a combined anti-reflection and passivation oxidized film, the short-circuit current is 32.2mA/cm². With an eye to substantially increasing the current, cells of a PERL-resembling structure having an inverted pyramid configuration will be produced on a trial basis.

(b) Development of technology for high-open voltage contact formation

In order to achieve a surface recombination rate of no more than 10cm/s constantly irrespective of the operating state of the solar cell, it is necessary to restrain surface recombination in the contact region as well as to continue the efforts to develop surface passivation technology. One conceivable approach to this end is to reduce the contact area, but this would involve the problem of increased resistance, necessitating study on optimization. Hetero junctioning techniques using wide-bandgap materials and controlling the work function of the contact metal would also be effective in restraining recombination, and cells with an open voltage far surpassing 700mV will be worked out through the development of these high-open voltage contact techniques.

3.2 Technological Development for Crystalline Compound Solar Cells

3.2.1 AlGaAs/GaAs/Si Solar Cells

(1) Objective and Work Program

(Objective for FY1996)

Conversion efficiency of 35% or more (1cm²)

(Work Program)

Technology for the formation of AlGaAs/GaAs/Si tandem hetero-structured solar cells by the MBE and GSMBE methods will be developed.

(2) Summary for FY1994

(a) Development of lattice-mismatched epitaxial growth techniques

(i) GaAs/Si growth with InGaAs intermediate layer inserted

With a view to reducing the dislocation density attributable to the lattice mismatching and the difference in thermal expansion coefficient of a GaAs layer grown on an Si(100) substrate, optimization of the strained InGaAs intermediate layer structure was attempted. Observation of the relationship between the strain energy and the surface dislocation density measured from the cross-sectional TEM image revealed that reducing the strain energy resulted in a decrease in the number of dislocations on the GaAs layer surface. The effect of the strained layer to reduce dislocations was witnessed only when the strain energy was 250dyne/cm. At that time, the influence of the In composition was insignificant, indicating the scarcity of any effect attributable to the difference in the physical property constants of InGaAs ensuing from a difference in In content. These findings revealed that the strain energy has its optimal level, and that any increase in In content would have little effect on dislocations.

(ii) Basic study on formation of thin-film compound cells by epitaxial lift-off (ELO) technique

The ELO technique was studied to realize the formation of thin-film GaAs-based cells and Si cells in tandem. An AlAs layer (0.1μm), which would serve as release layer, and then an AlGaAs/GaAs/AlGaAs DH structure were grown and, after wax was applied onto the surface and dried, the DH-structured film was lifted off by immersion in HF solution for about 18 hours. The size of the peeled film was 5mm square. The film was transferred onto an Si substrate and a quartz substrate, and deprived of water by baking for 30 minutes at 120°C. Evaluation of the film before the peeling and after the transfer by a photo luminescence method revealed no significant change in the position of the peak. On the quartz substrate, the intensity was less and the peak position shifted toward the low energy side as compared with the pre-peeling state, suggesting the effect of strain. As the intensity was somewhat greater on the Si substrate than before the peeling, the possible effect of photon cycling also deserves study.

(b) Development of high-efficiency tandem cell structure

(i) Lattice-matched tandem cells

a. Cell formation process

The cell formation process was improved in the following two aspects.

i. The electrode material for the p-layer was altered from AuZn to a Pt-based substance. This will make it possible to form the emitter in a thinner film and contribute to the reliability of electrodes.

ii. SiO_2 was formed for the purpose of protecting the surface during the process. In addition, the MBE growth conditions were reviewed to improve the uniformity of film thickness.

These conditions were applied to the trial production of GaAs cells, resulting in a reduction of performance unevenness in the wafer surface. Although the conversion efficiency was 19.5% at the maximum, this was due to the low MBE growth temperature of 580°C, and prospects were gained for achieving an efficiency surpassing the 20.9%, obtained by the earlier process, by setting the growth temperature between 600 and 700°C.

b. Efficiency improvement by optimization of GaAs, AlGaAs and InGaP growth by CBE/GSMBE method

With an eye to cost reduction by efficient utilization of raw materials and efficiency improvement by introduction of InGaP-based materials, crystal growth techniques by chemical beam epitaxy (CBE) and gas source MBE (GSMBE) were studied. This time, GaAs layers grown by CBE and GSMBE were evaluated by their photo luminescence (PL) characteristics. The raw materials used were AsH_3 and triethyl gallium (TEG) for CBE, and AsH_3 and metallic Ga for GSMBE. The PL of CBE-grown GaAs manifested very weak exciton luminescence, and a strong, broad peak attributable to carbon (C) impurities was observed on the low energy side. For the GSMBE product, stronger exciton luminescence was witnessed than luminescence from C impurities, indicating the low concentration of carbon impurities in the epitaxial film. Since much carbon was taken in from the organic metal material TEG in the case of CBE growth, the application of this product to solar cells would require optimization of the growth conditions. For the time being, optimization of the conditions will be attempted for solar cell formation by the GSMBE method, which is superior in PL characteristics.

c. Optimization of quantum well structure in multi-quantum well-structured cells

Multi-quantum well (MQW) cells, in which an MQW layer is introduced into the i-layer of pin-type GaAs cells, are attracting note as means to improve the efficiency of single-junctioned cells. As the potential depth of the In_xGa_{1-x} layer, which constitutes the well layer, is increased, the number of absorbed photons is increased, but the recombination loss in the well will also increase. Therefore, in pursuit of escape from the well, a solar light spectrum (AM 1.5) was supposed, and the optimal well structure was sought by taking into account the number of photons absorbed in the MQW area. Since the band offset of the conduction band is greater than that of the valence band, the escape efficiency of electrons first drops as the depth of the well increases. By taking into consideration the absorption against the solar light spectrum and the escape efficiency, it was discovered that the output current reaches its maximum when the In composition X equals 0.2.

d. Characteristics of tunnel junctions

Tunnel junctions for use in lattice-matched tandem cells were prepared. Tunnel junctions of p-on-n and n-on-p configurations were formed on n-type and p-type substrates, respectively. The structure of the tunnel junction was the same in both configurations, the thickness and concentration of the p-type high-concentration layer being 0.05μm and 4 x $10^{19}cm^{-3}$, respectively. The high-concentration layer was sandwiched between AlGaAs layers (0.1μm) to restrain the diffusion of impurities. The growth temperature in the MBE process was 450°C for the high-concentration p-type impurity layer, and 580°C for all others. The peak current obtained was 363mA/cm^2 for the p-on-n configuration and 235 mA/cm^2 for the n-on-p configuration.

(ii) Lattice-unmatched tandem cells

a. Optimization of Si cell structure as bottom cell

When an Si cell is to be designed for chemical semiconductor/Si stacked cells, its optical structure should be revealed with respect to the incident light whose short wavelength range is cut by the top cell. In view of this need, the dependence of the Si cell on physical properties and structural parameters was studied by using a simulator for solar cell devices. The parameters taken up in this study were the substrate thickness and impurity concentration of the GaAs cell. The thickness of the GaAs layer was varied from 5μm to 500μm, and doping with impurities was checked in two cases, one of n-type 3.3 x $10^{18}cm^{-3}$ and the other of p-type 2.4 x $10^{18}cm^{-3}$. The n-type doped GaAs layer gave an efficiency of 6.8% when the thickness was 5μm. The efficiency dropped with an increase in thickness, reaching 4.7% at 100μm. When the thickness surpassed 100μm, Voc and Jsc dropped significantly, and the efficiency was 1.8% at 500μm. A similar trend was observed of the p-type doped GaAs layer in the relationship between the thickness and Si solar cell performance, but the efficiency was generally about 1% lower than that of the n-type.

(3) Future Tasks

(a) Development of lattice-mismatched epitaxial growth techniques

(i) Evaluation of crystal quality of thin-film GaAs layer on Si substrate and study on method to improve quality

(b) Development of high-efficiency tandem cell structure

(i) Preparation of twin-junction twin-terminal tandem cells

(ii) Study on elemental techniques for stacking of Si cells and GaAs-based cells.

(iii) Study on restraining of recombination rate by applying InGaP layer using GSMBE method

3.2.2 AlGaAs/Ge Solar Cells

(1) Objectives and Work Program

(Objectives for FY1996)

Conversion efficiency of 35% or more ($1cm^2$)

(Work Program)

Development will proceed for chemical compound semiconductor solar cells which, having a stacked structure in which three types of cells differing in bandgap energy— AlGaAs cells, GaAs cells and Ge cells — are arranged in that order from the light incidence side, would give an ultra-high efficiency of 35% or more.

(2) Summary for FY1994

(a) Efficiency improvement of single cells

(i) AlGaAs cells

a. Cells of high mixed-crystal ratio

In order to improve the efficiency of stacked cells, it is necessary to develop AlGaAs cells of a high mixed-crystal ratio, in which GaAs cells are matched with the operating current. By last year, based on the technology built up with cells with a 0.3 mixed-crystal ratio, $Al_{0.36}Ga_{0.64}As$ cells had been produced on a trial basis. From the performance comparison of these cells and the ones with a 0.3 mixed-crystal ratio, problems in the enhancement of the mixed-crystal ratio were identified.

There was only a 0.01V improvement in open voltage over the cells with a 0.3 mixed-crystal ratio, and moreover the external quantum efficiency was found to have deteriorated near the absorbing end. One conceivable reason for these phenomena is an increase in crystal defects due to the increased ratio of AlAs mixed crystals. From now on, it is necessary to evaluate the crystallinity by measuring the lifetime of minority carriers and otherwise and, on the basis of this evaluation, to optimize growth technology. Especially, it is an essential part of the attempted improvement of the performance to enhance the open end voltage. On the other hand, the curvilinear factor manifested a favorable level of 0.866, and a conversion efficiency of 11.2% was achieved without using an anti-reflection film.

b. Study on bandgap grading of window layer

Study was made on a cell structure in which the bandgap of the window layer is gradually narrowed in the depth direction from the surface.

First, growth conditions were sought by the MOCVD method for the gradual variation of the mixed crystal ratio in the depth direction. As a result, it was confirmed that the mixed crystal ratio of an AlGaAs layer of a prescribed thickness in the depth direction can be controlled almost linearly by maintaining the feed volume of AsH_3 during growth and varying those of TMGa and TMAl.

Next, $Al_{0.36}Ga_{0.64}As$ cells, to which a graded-bandgap window layer was applied under these control conditions, were produced on a trial basis, and their performance characteristics were evaluated. Their external quantum efficiency was found generally lower than those of conventional hetero face-structured cells, indicating a failure to achieve a carrier collection effect of the electric field. One conceivable reason is the non-optimization of the structural parameters of the cells. From now on, attempts will be made to optimize the cell structure by the combined use of performance simulation based on more precise identification of crystalline characteristics.

(ii) Ge cells

Regarding bottom cells applicable to AlGaAs/GaAs-based stacked cells, study on GaAs/Ge hetero-junctioned cells was started, based on the assumption of two limiting conditions that the stacked cell structure permits continuous growth by the MOCVD method and that cells of the upper stage can be matched with the operating current. This year, the basic structure of the cells was designed, and trial production and evaluation of the cells were carried out. Concerning the performance of cells, note was taken of the possibility of matching AlGaAs/GaAs stacked cells with the operating current.

In the cells produced this time on a trial basis, pn junctions were formed of an n-type Ge substrate and a p-type GaAs layer grown over it. The p-type GaAs layer was composed of a 0.2μm thick layer, grown at a temperature of 610°C and a 0.1μm layer grown at 650°C. Concerning the performance characteristics of the cells that were produced, though there was room for improvement in open voltage and curvilinear factor, a short-circuit current of 27.68mA/cm^2 was achieved without using an anti-reflection film. The intrinsic efficiency, under irradiation with approximated AM1.5 light, was 2.97% without using an anti-reflection film.

In respect to spectral sensitivity, the external quantum efficiency on the short-wavelength side is significantly lower than at the GaAs absorbing end. This is due to the failure of the electrons excited by the p-type GaAs layer to contribute to the short-circuit current, and therefore it is necessary to improve the crystallinity of the GaAs layer grown over Ge. Calculation of the short-circuit current in the wavelength range of 900nm to 2,000nm on this spectral sensitivity and the spectrum of AM1.5 global light gave a value of 16.4mA/cm^2. This is well over the theoretical value of 14mA/cm^2 for the short-circuit current of stacked cells. Accordingly, in regard to the matching of the cells of the upper stage with the operating current, the cells whose basic design was prepared this time could be applied to AlGaAs-based stacked cells.

(b) Efficiency improvement of stacked cells

(i) Formation techniques for anti-reflection film

Development of formation techniques is being attempted for an MgF_2/ZnS double-layered anti-reflection film to prevent wide-band reflection. This year, vacuum vapor deposition was selected as an MgF_2 formation method to replace the earlier sputtering process, and appropriate conditions were sought for the formation of the film. Evaluation of the absorption rate of the films formed on that basis revealed a substantial reduction of the absorption rate over the samples formed by the conventional method. Absorption at or below 400nm was attributable to the ZnS band end, and the absorption rate in all other wavelength ranges was improved to substantially zero. From now on, the optical characteristics of the cell surface will be assessed in detail for further progress in the optimization of the film structure and the conditions of formation.

(ii) Tunnel junction

With an eye to improving the tunnel peak current and thermal resistance, optimization of the growth conditions of the high carrier concentration layer was attempted, and study on tunnel junctions for the double-hetero (DH) structure was started. On the basis of the past findings, Si and C were selected as n-type dopant and p$^+$-type dopant, respectively, and DH-structured tunnel diodes of different junction thicknesses were produced on a trial basis to assess their characteristics before heat treatment. As a result, 0.05µm and 0.03µm thick diodes gave peak current densities of 2.4A/cm^2 and 1.8A/cm^2, respectively. Up to 0.05µm, the smaller the film thickness, the higher the peak current. Whereas restraining the light absorption loss of tunnel junctions is a major challenge in the development of stacked cells, the trends identified in this study are both useful and interesting.

Next, variations in peak current due to heat treatment were assessed. It was confirmed that the thinner the junction, the greater the peak current drop and that decreasing the film thickness and thermal resistance were in a trading-off relationship with each other. Heat treatment for two hours at 650°C, which is the growth temperature for cells, resulted in a peak current drop to 69mA/cm^2 for 0.05µm thick junctions. Elucidation of the degradation mechanism and means for its prevention is the task to be undertaken from now on.

(iii) AlGaAs/GaAs stacked cells

On the basis of the achievements until fiscal 1993, stacked cells consisting of $Al_{0.6}Ga_{0.7}As$ cells and GaAs cells connected by 0.2um tunnel junctions were produced on a trial basis and evaluated. The result was a 16.3% intrinsic efficiency of the cells with no anti-reflection film (approximated to AM1.5, 100mW/cm^2).

Next, by applying the technology for

the formation of the $Al_{0.36}Ga_{0.64}As$ cells studied this year and that for the formation of 0.05μm thick tunnel junctions, $Al_{0.36}Ga_{0.64}As$/ GaAs stacked cells were produced on a trial basis. The cell size was 1cm x 1cm, and the proportion of the shadow section due to electrodes was 11.4%. An MgF_2/AnS double-layered anti-reflection film was formed on the cell surface.

The output characteristics were measured by irradiating these cells with AM1.5 approximated light, and an open voltage of 2.32V was obtained, 20mV less than the simple sum of single cells (2.34V), presumably due to a decrease in incident light striking the GaAs cells in the stacked cells as compared with the single cells. The short-circuit current density obtained was 12.79mA/cm^2. It was confirmed from the spectral sensitivity measured by irradiation with AM1.5 approximated light as bias light that the short-circuit current was limited by the AlGaAs cells. The curvilinear factor was at a satisfactory level of 0.85, and an intrinsic efficiency of 25.2% was achieved for cells on which an anti-reflection film was formed.

(3) Future Tasks

(a) AlGaAs cells

Investigation to improve the efficiency of single cells and AlGaAs/GaAs stacked cells revealed the importance of developing AlGaAs cells with a high mixed-crystal ratio which would best match the GaAs cell short-circuit current. The greatest challenge in this development work is to enhance the open voltage. With InGaP cells, an approximately 0.1V higher open voltage had been obtained. Learning from this experience, it is necessary to investigate the correlation between crystalline characteristics and structural parameters on one hand and the open voltage on the other, and thereby to undertake optimization of crystalline growth conditions. Also regarding sensitivity improvement in the short-wavelength range, which is another major challenge, it is scheduled to carry out simulation of characteristics, with the application of a graded bandgap type window layer being presupposed, and thereby to optimize the cell structure.

(b) Ge cells

In order to improve the performance characteristics of GaAs/Ge heterojunctioned cells, it is essential to ameliorate the crystallinity of the GaAs layer grown over Ge. In view of this need, it is planned to evaluate crystalline characteristics and the distribution of atoms on the GaAs/Ge interface and, on that basis, undertake optimization of the conditions for crystalline growth. Furthermore, by applying the heteroepitaxial growth techniques to be studied in this context, attempts will be made to improve the characteristics of GaAs cells formed over Ge.

(c) Anti-reflection film

Concerning the reduction of the light absorption of the MgF_2 film, which had posed a major problem, prospects for solution were gained by applying vacuum vapor deposition. From now on, it is necessary to optimize the anti-reflection film structure while taking account of matching with the optical constants on the cell surface. In particular, it has been confirmed that a degenerated layer is formed over the cell surface after the etching of the electrode contact layer, and a method must be developed to remove this degenerated layer. It is also necessary to study a wider-band anti-reflection film which would be effective in the wavelength range of Ge cell operation as well.

(d) Tunnel junction

Study on AlGaAs/GaAs stacked cells has revealed the importance of reducing the light absorption loss of tunnel junctions in trying to improve efficiency. From now on, it is essential to enhance the thermal resistance and reduce the film thickness of GaAs tunnel junctions. For this purpose, attempts will be made to elucidate the mechanism of performance deterioration and, at the same time, to optimize the double-hetero structure as well as the growth conditions of the high carrier concentration layer. On the basis of the achievements of these endeavors, technology will be developed for the formation of tunnel junctions which could minimize the light absorption loss.

3.2.3 (GaP-based, AlGaAs-based)/Si Solar Cells

(1) Objectives and Work Program

(Objectives for FY1996)

Conversion efficiency of 35% or more (1cm^2)

(Work Program)

Concerning tandem cells formed by stacking GaP-based, AlGaAs-based and other chemical compound semiconductor cells whose possibility to give ultra-high efficiency has been confirmed by theoretical calculation and Si cells, techniques will be developed for epitaxial growth needed for the achievement of ultra-high efficiency and for cell fabrication.

(2) Summary for FY1994

(a) Efficiency improvement of GaAsP single-junctioned cells by MOCVD process wholly using organic metal materials

In GaAsP-based solar cells, there is lattice strain attributable to differences in lattice constant or thermal expansion coefficient between the GaAs substrate and the pn junctions of GaAs, and they constitute a major factor to deteriorate crystallinity and bring down the conversion efficiency. Usually, a composition-graded layer in which the P composition of GaAsP is gradually varied to alleviate the lattice strain is inserted between the substrate and the pn junctions. This year, the effect of the thickness of this composition-graded layer on cell performance was checked. Study was also made on the influence of the carrier concentration of the p-layer.

Epitaxial growth was carried out in a vertical reduced-pressure MOCVD furnace which uses only organic metal materials to produce cells on a trial basis. A P-composition-graded layer was provided over the GaAs substrate, and pn junctions were formed on it, with the window layer consisting of AlGaAsP (the composition of Al was 0.85).

By increasing the thickness of the composition-graded layer, the diffusion length of the minority carrier of the n-layer was extended, resulting in improved cell performance. Presumably, the thickened composition-graded layer increasingly eased lattice strain and thereby improved crystallinity.

In cells of 0.19 in P-composition in which the carrier concentration of the p-layer was lowered, the quantum efficiency on the short-wavelength side was considerably improved, and the conversion efficiency rose to 14.5% with no anti-reflection film. By further forming a double-layered anti-reflection film, a conversion efficiency of 18.5% (measured by JQA) was achieved though the composition-graded layer was relatively thin. This efficiency is the highest ever attained by GaAsP cells.

(b) Efficiency improvement of GaAs mono-junctioned cells by all-organic metal material MOCVD

GaAs cells were fabricated, using as the window layer GaInP, which has the potential to reduce the surface recombination of the generated carrier more than the conventional AlGaAs window layer does. The window layer to restrain surface recombination was made of GaInP having an In composition of 0.5 which would achieve lattice matching with GaAs. Against the 20.8% conversion efficiency of cells having an AlGaAs window layer, those having a GaInP window layer achieved an improvement in conversion efficiency to 23.3% (measured by JQA). This conversion efficiency is the highest registered by any cell using an organic V family material. Concerning spectral sensitivity, the cells with a GaInP window cell have a considerably higher external quantum efficiency on the short-wavelength side than those with an AlGaAs window layer. Evaluation of the interfacial recombination rate by the time-resolved photoluminescence method revealed that the rate was smaller by almost two digits on the GaInP/As interface than on the AlGaAs/GaAs interface, and this finding endorsed the efficiency-improving effect of the GaInP window layer.

(c) Development of technology for stacked cell fabrication

Basic study was made on the mechanical stacking technique, which is one of the essential elemental techniques for the fabrication of stacked cells. A GaAs substrate, on which surface electrodes and an anti-reflection film were formed, was placed on an Si cell, and its effect on the performance of the Si cell was checked. To reduce the influence of electrode shade, the positions of the upper and lower electrodes were precisely aligned. As a result, the conversion efficiency of the Si cell, which was 14% for the Si cell alone, was improved to 1.2% by stacking the GaAs substrate. Though this still is an insufficient conversion efficiency for a lower cell, a light transmissivity of 60% to 70% was observed in the long-wavelength range of 870nm and above, which the Si cell is to absorb. Since the transmissivity of the GaAs substrate is greatly affected by its carrier concentration, the carrier concentration of the GaAs substrate has to be optimized. The performance of the lower Si cells is likely to be further improved by using Si cells more sensitive on the long-wavelength side.

(3) Future Tasks

Development of high-quality film growth technology by the safety-oriented all organic metal material MOCVD method will be pursued, and at the same time improvement of conversion efficiency will be sought by optimizing each of the chemical compound semiconductor cell structures constituting stacked cells. Furthermore, regarding stacked cell formation technology required for the achievement of ultra-high efficiency, further study will be made on such elemental techniques as mechanical stacking and mechanical interconnection.

3.2.4 InGaP/Si-Based Solar Cells

(1) Objectives and Work Program

(Objectives for FY1996)

Conversion efficiency of 35% or more ($1cm^2$)

(Work Program)

Using InGaP mixed crystals as top cell material and a narrow forbidden bandwidth semiconductor, such as Si, as bottom cell material, ultra-high efficiency tandem-structured solar cells will be developed.

(2) Summary for FY1994

(a) Efficiency improvement of InGaP cells

(i) Efficiency improvement of InGaP mono-junctioned cells

By last year, for $In_{0.5}Ga_{0.5}P$ solar cells on a GaAs substrate, 17.0% and 17.4% conversion efficiencies had been attained with cells with electrode coating ratios of 10% and 5%, respectively. This year, by reducing the electrode coating ratio to 2%, an efficiency of 18.5% was achieved with 1cm x 1cm cells. To reduce the electrode coating ratio, the width of comb-shaped electrodes was narrowed and their thickness increased.

(ii) Trial production of InGaP/GaAs tandem cells

a. Fabrication of GaAs cells

Optimization of the emitter layer thickness (junction depth) of GaAs cells was attempted at an epitaxial growth temperature of 650°C.

Regarding cell performance data, while Isc hardly differed between junctions depths of 0.05μm and 0.1μm (being slightly superior at 0.05μm), FF was somewhat greater at 0.1μm, and accordingly the 0.1μm cells registered the highest efficiency. This difference in FF seems due to a difference in the sheet resistance of the emitter layer. The 0.2μm cells were found inferior in spectral sensitivity and Isc. For tandem cells, whereas the sheet resistance of the emitter layer need not be taken into consideration, a junction depth of 0.1μm was adopted for GaAs cells in the following study. An AlInP window layer is used here, but epitaxial growth of GaAs tunnel junctions should take place over the window layer in tandem cells, and accordingly any defect on the AlInP surface might prevent high-quality tunnel junctions from being formed. Therefore, an InGaP window layer was used in the trial production of tandem cells described below.

b. Formation of tunnel junctions

For electrical junctioning of the upper and lower cells, GaAs tunnel junctions doped in a high concentration were used. While the previous experiments had revealed that the optimal growth temperature for the InGaP top cell is 700°C, a temperature of 650°C was used this time in view of the possible adverse effect of a higher temperature on the tunnel junctions.

Formation of samples under various conditions resulted in a tunnel peak current of 44mA. As the expected short-circuit current of tandem cells is about 15mA/ cm^2, InGaP/ GaAs tandem cells were produced on a trial basis using these tunnel junctions.

c. InGaP/GaAs tandem cells

Trial production of InGaP/GaAs tandem cells was carried out by integrating the InGaP top cells, GaAs bottom cells and GaAs tunnel junctions that had been developed. First, when a 0.1μm thickness was adopted for the p^+ InGaP back-side field layer (BSF layer) of top cells, the spectral sensitivity of the top cells dropped below that of InGaP mono-junctioned cells, failing to achieve the expected performance. The cause was found to be the inadequate functioning of the top cell BSF layer because Zn, which is the p-type dopant of the BSF layer, had diffused toward the base layer side.

SIMS analysis indicated prospects for the suppression of Zn diffusion to some extent by increasing the thickness of the BSF layer. Assessment of the dependence of the spectral sensitivities of the InGaP top and GaAs bottom cells on the BSF layer thickness revealed that the spectral sensitivity of the top cell could recover significantly with an increase in BSF layer thickness. Along with that, the Isc and Voc of the tandem cells were found to increase. As a thicker BSF layer entails a decrease in the Isc and Voc of the bottom cell, this increase in Voc is attributable to a rise in the top cell's Voc. The increased Isc and Voc of the top cell are due to the recovery of the effect of the BSF layer.

The most efficient InGaP/GaAs tandem cell so far obtained had a top cell BSF layer of 0.5μ in thickness. As the Voc of the GaAs cells was increased by about 30mV by raising the growth temperature from 650°C to 700°C, the growth temperature for the bottom and top cells were set to 700°C and 650°C, respectively. The conversion efficiency registered this time was 27.3%, the highest attained in Japan under the condition of AM1.5 1SUN and, in the world, next only to the 29.5% achieved by NREL (the square measure was four times as great as NREL's $0.25cm^2$).

(b) Experiment on formation of InGaP tunnel junctions

As a promising candidate for the method of electrical junctioning of the upper and lower cells of InGaP/Si tandem cells, a method using InGaP tunnel junctions is contemplated. This time, InGaP tunnel junctions were formed over a GaAs substrate, and their performance characteristics were checked. The artificial top cell growth temperature was 700°C. So far, although finite tunnel current characteristics have been obtained, the peak current is only about $5mA/cm^2$, indicating the need to improve the structure and growth conditions in the future.

(3) Future Tasks

For the InGaP/GaAs tandem cells which were produced on a trial basis this time and achieved an efficiency of 27.3%, the highest in Japan, the performance recovery of the top cell was intended by increasing the thickness of the top cell BSF layer at the sacrifice of the bottom cell performance. Now the introduction of a thin but effective BSF layer should be considered. The world's highest efficiency of 30% or more will be sought from now on by using an appropriate structure for the GaAs bottom cell besides working out an improved BSF layer.

For the trial production of InGaP/Si tandem cells, study will be continued on the use of hetero epitaxy techniques over an Si substrate and on the method of junctioning the upper and lower cells.

3.2.5 Super Lattice-Structured Solar Cells

(1) Objectives and Work Program

(Objectives for FY1996)

Conversion efficiency of 35% or more ($1cm^2$)

(Work Program)

With a view to developing ultra-high efficiency solar cells having an Si substrate and a super-lattice layer of chemical compound semiconductor as the light receiving layer, sophistication of crystalline growth techniques will be attempted as well as identification of a solar cell structure which would provide high efficiency.

(2) Summary for FY1994

(a) Droplet epitaxy

(i) Microcrystalline growth by droplet epitaxy

Investigation was made on the generation density of microcrystals and the dependence of their size on the conditions of growth. First, the generation density of Ga droplets was found to vary from $10^6/cm^2$ to $10^8/cm^2$ depending the volume of TMG supply and the substrate temperature.

On the other hand, the size of microcrystals increased with the substrate temperature from $0.1\mu m$ to $1\mu m$. These findings revealed the heavy dependence of the size and generation density of microcrystals on the volume of TMG supply and growth temperature, and revealed that the size and generation density of microcrystals could be controlled within the ranges of $0.1\mu m$ to $1\mu m$ and of $10^6/cm^2$ to $10^8/cm^2$, respectively, under the growth conditions of this study.

(ii) Experiment on doping of microcrystals

In order to construct a solar cell, microcrystals should be doped under precise control in the n type or the p type. In view of this need, a doping experiment was carried out using Si as the n-type dopant and Zn as the p-type dopant. Crystallinity was confirmed by PL luminescence, and it was also checked whether luminescence attributable to an impurity level was observed. No such luminescence was witnessed in Si-doped microcrystals. On the other hand, Zn-doped microcrystals manifested such luminescence, whose intensity varied with the quantity of doping. The p-type doping seems to have been accomplished somehow, while the n-type doping hardly was. At the moment, no sufficient control has been achieved, but these microcrystals seem usable for cell fabrication.

(b) Trial production of InAlAs/InP hetero cells

Since such cells form a type II energy band, checking their effect on cell performance characteristics would give guidelines to the future pursuit of high-efficiency superlattice cells.

The performance characteristics of hetero cells were compared with those of InP homo cells. The dependence of cell conversion efficiency on the thickness of the emitter film was also assessed. Compared with InP homo cells produced at the same time on a trial basis, both Voc and Jsc of the hetero cells manifested improving trends, and a conversion efficiency of about 15% was achieved by cells of 0.1μm in emitter film thickness. This is a satisfactory efficiency for hetero cells. An even higher efficiency may be attained by improving the cell structure, including the formation of a window layer to reduce surface recombination.

(c) Trial production of GaAs-on-Si cells

Variations in cell performance characteristics with the thermal cycle annealing (TCA) temperature were studied. The TCA temperature was varied from 800°C to 850°C and 900°C, and three TCA cycles were carried out. From the dependence of the conversion efficiency on the TCA temperature, it was found that annealing at high temperature was effective in improving cell performance. Cells whose crystallinity was improved by TCA at 900°C gave a conversion efficiency of about 15%. Voc, FF and other factors are likely to be improved to achieve even higher efficiency by optimizing the structure, including the thinning of the emitter layer.

(3) Future Tasks

The future tasks will include identification of ways to improve elemental techniques needed for the enhancement of cell conversion efficiency so that prospects can be gained for the realization of a 35% conversion efficiency. For this purpose, microstructural formation technology using droplet epitaxy should be made more sophisticated to investigate in detail the characteristics of the microstructural embedded structure, and at the same time the effectiveness of this structure should be clarified by applying it to the cell structure. Furthermore, study will be made on hetero crystalline growth techniques with the focus on the combination which would constitute an type II energy band structure, and these techniques will be applied to the trial production of cells to demonstrate their usefulness.

3.2.6 Research on Chemical Compound Materials for Photoelectric Conversion under Microgravity

(1) Objectives and Work Program

(Objectives for FY1996)

In order to develop high-performance material technology indispensable for the development of ultra-high efficiency solar cells, research will be made on the crystallization, synthesis and evaluation of chemical compound materials for photoelectric conversion in a microgravity environment.

(Work Program)

(a) Techniques for high-quality thin-film crystalline growth by thin-film capillary method

(b) Synthesis of photoelectrically converted crystalline compound particulates by liquid phase method in microgravity environment

(c) Synthesis of photoelectrically converted crystalline compound particulates by combustion-synthetic method in microgravity environment

(d) Techniques to prepare crystalline compounds as photoelectric conversion materials in microgravity environment

(e) Comprehensive study on chemical compound materials for photoelectric conversion in microgravity environment

(2) Summary for FY1994

(a) Techniques for high-efficiency high-quality thin-film crystalline growth by thin-film capillary method

(i) Research and development of thin-film crystallization techniques

On the basis of the experience with the trial-produced furnace in the preceding year, a high-precision electric furnace with further improved temperature characteristics was fabricated, and a total of 26 experiments of thin-film crystal growth were carried out with the new furnace under microgravity. At the same time, with a view to increasing the purity of this series of experiments, a generating apparatus was introduced to improve the thin-film crystals. As a result, stick-free thin-film crystals were obtained for graphite crystal cells, indicating that a refining apparatus could improve wettability.

(ii) Development of evaluation techniques for thin-film crystals

GaSb thin-film crystals (about 300μm thick) were prepared with the aforementioned high-precision electric furnace under gravity and under microgravity, and evaluated with an optical microscope. As a result, rhomboid crystal faces of about 0.25mm in their longer diagonal measurement were observed on the crystals formed under microgravity, manifesting a difference from the set of polycrystals formed under gravity. In regard to the crystal growth orientation, less disturbance of the molten liquid was found in the crystals formed under microgravity, suggesting the effect of the absence of convection under microgravity.

(b) Synthesis of photoelectrically converted crystalline compound particulates by liquid phase method in microgravity environment

(i) Synthesis of cadmium sulfide particulates

Study was made on the effect of gravity on the crystallinity, crystalline structure and particulate morphology of the generated cadmium sulfide (CdS) crystals in synthesizing CdS particulates by the liquid phase method.

Cadmium acetate and ammonium thionyl were selected as precursors, and ammonia or triethanol amine, as ligands. It was confirmed that, while hexagonal wurtzite-type crystals were generated whether under gravity or under microgravity when triethanol amine was used as ligand, cubic crystals were formed when ammonia was used as ligand.

The morphology of the cubic crystalline CdS formed as precipitate was found to be heavily affected by gravity. Thus, while particles generated under gravity were about 8μm in size as petaline Cds crystals gathered, particulates of about 1μm in diameter were formed under microgravity.

(ii) Synthesis of cadmium sulfide thin films and doping with copper ions

The suitable precursor solution for evenly separating a thin CdS film over a glass substrate was found to a mixed aqueous solution prepared by adding ammonia water to an aqueous solution of cadmium acetate of 0.05mol/l in concentration to adjust its pH to 11 and then adding triethanol amine in a quantity double that of cadmium acetate. Placing the glass substrate in this aqueous solution maintained at 60°C resulted in the formation of a thin CdS film. The generated CdS had a sphalerite-type crystalline structure of cubic crystals.

It was also found that a Cu-doped thin CdS film can be formed by adding Cu to the precursor aqueous solution.

(c) Synthesis of photoelectrically converted crystalline composite micro-compounds by combustion-synthetic method in microgravity environment

An experiment to synthesize (Ga, In)P by combustion, taking note of reactions mainly of oxides, gave the following findings. The product of combustion-synthesis from Ga_2O_3 + P using a chemical furnace mainly consisted of GaP, and the proportion of unreacted substance was less under microgravity than under gravity. Light absorption by the reaction products were characteristic of GaP under both conditions. The product of combustion-synthesis from In_2O_3 + P was InP with almost no unreacted substance both under gravity and under microgravity. The products under microgravity, unlike that under gravity, did not flocculate, but were evenly dispersed. The products of combustion-synthesis from (Ga_2O_3, In)P and (Ga_2O_3, In_2O_3)P were mixed (Ga, In)P crystals, indicating that the lattice constant varied according to the ratio between Ga and In and so did the forbidden bandwidth. The lattice constants of the products obtained under microgravity conformed more closely to Vegard's law than did those under gravity, and it was found that, when chemical compounds of the III to V families were synthesized by combustion in a short period of time under microgravity, the achievement rate of reaction improved, particles were dispersed evenly, and mixed crystallization took place, maintaining a blend composition.

(d) Techniques to prepare crystalline compounds as photoelectric conversion materials in microgravity environment

(i) Synthesis of $CuInSe_2$ by coagulation of molten Cu-In-Se

The quantity of Se grains in a Cu-In mixed powder disk was varied, melted by heating to 1,100°C and coagulated. Only $CuInSe_2$ was identified in the coagulated samples under microgravity and on the ground. While the product of melting and coagulation under gravity was poor in surface roughness and manifested wide variations in component distribution from one position of measurement to another, the process in a microgravity environment provided thin-film crystals small in size, excelling in crystallinity and manifesting no unevenness in composition.

(ii) Synthesis of $CuInSe_2$ film by selenization of Cu-In stacked film

CuIn samples were selenized so fast that selenization could be achieved by raising the temperature to 530°C in 10 seconds. Cu-In stacked films selenized under microgravity were found to have sharper absorption ends of light absorption and somewhat wider bandgaps, but they are still inferior to monocrystalline $CuInSe_2$ and accordingly need to be improved.

(3) Future Tasks

(a) Techniques for high-efficiency high-quality thin-film crystalline growth by thin-film capillary method and its evaluation

As this year's work provided GaSb thin-film crystals using graphite samples in a stick-free state, research will be carried out on the conditions of crystallization, using graphite cell materials for the basic structure, to elucidate the states of grain size expansion of and impurities distribution in the thin-film crystals. The evaluation of crystals will be made more precise by measuring Raman scattering and otherwise identifying the effect of microgravity on crystalline growth.

(b) Synthesis of photoelectrically converted crystalline compound particulates by liquid phase method in microgravity environment

Study will be made on the formation of thin films from the fine powder synthesized in a microgravity environment, measurement of the physical properties of CdS thin films, analysis of the state of Cu in the films, effect of gravity of the doping of CdS with Cu and that of Cu doping on the physical properties of the films among other aspects.

(c) Synthesis of photoelectrically converted crystalline composite micro-compounds by combustion-synthetic method in microgravity environment

On the basis of the results obtained so far, the product range will be expanded to include the II to VI families as well in pursuit of combustion-synthesis of more evenly dispersed photoelectrically converted crystalline composite micro-compounds, and at the same time the establishment of techniques for combustion-synthesis of filmy structured products will be undertaken.

(d) Techniques to prepare crystalline compounds as photoelectric conversion materials in microgravity environment

Concerning selenization, which is the most practical production method for $CuInSe_2$ films, attempts will be made to improve the adhesion between thin films and the substrate, uniformity of the films, reduction of the crystal size due to solid dissolution of Ga and S, and interfacing between window materials including Cds and $CuInSe_2$.

3.3 Investigations Concerning Analyses for Practical Application

(1) Objectives and Work Program

(Objectives for FY1996)

Both domestic and international technical trends regarding super-high efficiency solar cells will be quickly and accurately identified and analyzed to support technical development efforts for super-high efficiency solar cells.

Furthermore, for efficient implementation of technical development of super-high efficiency solar cells, the technical problems involved will be analyzed to find out solutions to them.

(Work Program)

(a) Investigation of technical trends regarding practical application of ultra-high efficiency solar cells

With a view to supporting the endeavors for technical development of ultra-high efficiency cells, the Investigation Working

Group for Crystalline Chemical Compounds, in which industry, government and the academic community are represented, will be set up to investigate technical trends regarding solar cells made from III to V family compounds.

- Investigation of crystalline chemical compound-based solar cells
- Investigation of latest technical trends

(b) Technical research regarding practical application of ultra-high efficiency solar cells

For the purpose of efficient implementation of technical development attempts for ultra-high efficiency solar cells, the Technical Working Group on Crystalline Chemical Compounds, in which industry, government and the academic community are represented, will be set up to keep abreast of the progress of developmental work, identify and analyze technical problems, and find solutions to the problems.

To further promote joint research projects, Information Exchange Meetings will be held in which the association and commissioned companies will participate.

(2) Summary for FY1994

(a) Investigation of technical trends regarding practical application of ultra-high efficiency solar cells

(i) Investigation of crystalline compound-based solar cells

a. Trends of, and problems in, technical development of III-V family compound semiconductor-based solar cells

In order to expand the applicable range of solar cells made of III to V family chemical compound semiconductors, the immediate target of research and development efforts is thin-film solar cells of III-V on Si, Ge structure. The ultimate in efficiency improvement should also be sought. The highest efficiency two-junctioned cells can achieve is expected to range from 36 to 39% theoretically. Especially, the stacking of solar cells of III to V family chemical compound semiconductors featuring high efficiency together with low-cost Si solar cells and approaches to their light condensing actions seem to imply the potential for high-efficiency low-cost solar cells. Furthermore, three-junctioned cells can be expected to attain a conversion efficiency of beyond 40%.

However, techniques of on-Si hetero epitaxial growth involve many unsolved problems, necessitating further study on alternative approaches including on-Ge techniques, mechanical stacking and epitaxial lifting-off. At the same time, concerning techniques of on-Si hetero epitaxial growth as well, it is essential to complete basic research and the search for breakthrough technology into practically applicable technology. According to a tentative cost estimate, light-condensing action is a way to reduce the costs especially of cells of III to V family compounds, and it seems that the time has come to assess the advantages and disadvantages of light-condensing technology once again.

b. Ultra-high efficiency solar cell structure with 40% efficiency target

i. Choice of upper and lower cell materials for multi-junctioned cells

For two-junctioned cells, Si is likely to be the most suitable material for lower cells, and a semiconductor of about

1.8eV in forbidden bandwidth is desirable for upper cells. In order to realize monolithic cells, it is necessary to grow such semiconductors hetero-epitaxially on an Si substrate. While a number of combinations are conceivable for three-junctioned cells, in regard to efficiency, a structure comprising a wide forbidden bandwidth material (Eg—1.8eV)/Si/Ge and another wide forbidden bandwidth material (Eg—1.95eV)/GaAs/Ge seems promising. For both two-junctioned and three-junctioned cells, the choice of the material for upper cells is particularly important, and major candidates are likely to include materials of 1.8 to 2eV in forbidden bandwidth such as $Al_xGa_{1-xA}As$, $In_xGa_{1-x}P$, $GaAs_{1-x}P_x$ and InN.

ii. Efficiency improvement of Si solar cells for tandem cells

As a result of simulated study on GaAs/Si tandem cells regarding the relationship between the structural parameters of Si cells and the performance characteristics of the tandem cells, it was found that:

- in order for the Si cells to achieve high efficiency, thinning the GaAs layer is indispensable;
- it is necessary to study the fluctuations of efficiency of top cells whose GaAs substrate is thinned and the structure of top cells which would be able to maintain high efficiency even if thinned;
- study using the GaAs absorption coefficient under doping with Si, a commonly used n-type impurity, is essential, and
- it is necessary to clarify the influence of the interface between top and Si cells.

iii. Advantages and possibility of light-condensing action

The open-end voltage rises in direct proportion to the logarithm of the light condensation ratio (by about 60mV with an increase in the light condensation ratio to the next digit). If the value of the series resistance Rs can be ignored and the value of the curvilinear factor FF remains unchanged, the efficiency will increase. In practice, however, the effect of a temperature increase and that of Rs, among other factors, would emerge along with a rise in the light condensation ratio. Considering the dependence on the forbidden bandwidth at light condensation ratios of 30 and 1,000, it was found that semiconductors having a forbidden bandwidth of 1.14eV (1.1µm) are suitable as light-condensing elements, and reducing the series resistance loss poses a major requirement.

iv. Toward a leap in Voc improvement

As the open voltage is heavily dependent on the physical properties of cell materials and the cell structure, it is essential to have access to correct values of the physical properties of cell materials and to develop techniques for the analysis of cell performance characteristics.

c. Simulation of tandem-structured solar cells

The limit of efficiency was estimated in detail, and that of the tandem type was calculated on that basis. Guidelines on the optimal structure were also studied.

d. Physical properties of mixed-crystal semiconductors and performance characteristics of solar cells

i. Method to evaluate physical properties of III to V family mixed-crystal semiconductors

A long-distance order structure

has been discovered in the epitaxial film of III to V family mixed-crystal semiconductors, such as InGaAs and InGaP. Investigation was made on variations in related characteristics, but relevant experiments are too few, necessitating further study.

ii. Impurities, trap center and minority carrier lives, and solar cell characteristics

In order to improve the efficiency of chemical compound semiconductor solar cells, the minority carrier lives and diffusion length are essential factors, which are affected by impurity defects, the crystalline grain boundary and the surface of the materials among other factors. Inactivation of defects in III-V on Si and other aspects were investigated.

iii. Potential of super-lattice structure for use in high-efficiency solar cells

It was found that, in MQW cells, shifting of the absorbing end toward the long-wavelength side results in improved spectral sensitivity and an increased short-circuit current. On the other hand, it was found that the open voltage is determined by non-radiant recombination and decreases as the bandgap narrows. This point needs further study from now on.

e. Sophistication of hetero epitaxial growth techniques

i. Choice of buffer layer

In fabricating high-efficiency solar cells by hetero epitaxy, the choice of the buffer layer is an essential factor. Problems currently conceivable include the dislocation and stress in crystals, and the structure, features, problems and dislocation density so far achieved, among other factors, of typical buffer layers were studied.

ii. Sophistication of conventional techniques

The available approaches include the insertion of an intermediate layer, two-stage growth by MOCVD, and reduction of stress in the growth layer by removing the layer underneath the growth layer by etching.

iii. Potential of low-temperature growth techniques

The application of the low-temperature MBE growth process utilizing hydrogen atoms to various electronic and optical devices, including ultra-high efficiency solar cells above all, seems to have become a considerably realistic possibility. Research on the method to directly control the growth mechanism by supplying an appropriate substance, such as atomic hydrogen, to the growth, so-called surface metamorphic epitaxy, is expected to make further progress as a new hetero epitaxy technique likely to lead to a major breakthrough.

iv. Van der Waals epitaxial growth technology

Since no chemical combination is needed between two kinds of substances differing in lattice pitch, hetero growth is possible even where lattice matching conditions are not met, nor does any stress arise from a difference in thermal expansion coefficient. This means that II-V/Si hetero epitaxy has the potential for a breakthrough from a structural point of view.

v. Availability of alternative techniques

Attempts are being aggressively made to integrate an Si substrate and GaAs, for which low-cost integration techniques by the ELO method are well advanced. Study was made on the bonding interface and the physical properties of the thin film after adhesion.

f. Particulars of manufacturing techniques for chemical compound semiconductor solar cells

i. Problems in electrode formation techniques and possible solutions

The formation method for GaAs ohmic electrodes, which constitute a basic aspect of chemical compound semiconductors, was studied separately with respect to the n-type and the p-type. Whereas the formation of a high-concentration doping layer or an intermediate layer is important for the n-type and that of a doping layer is essential for the p-type, there are remaining problems of film thickness control, reproducibility and adhesiveness among others.

ii. Problems in anti-reflection film techniques and possible solutions

There are problems including the unevenness and peeling of the anti-reflection film thickness dependent on the cleanness of the substrate, variations in diode characteristics and an increase in surface recombination rate attributable to differences in film formation method, and differences in optical characteristics due to differences in film formation method, and these problems were studied.

iii. Significance of and problems in thin-film substrate techniques and process for continuous production

It is necessary to prepare low-cost monocrystalline substrates or polycrystalline substrates having the smallest necessary grain size over a low-cost substrate material. Centaxy grapho-epitaxy technology is attracting note in this connection. It is also necessary to reduce costs by composing the process in a closed loop for reutilization of raw materials.

g. Cost estimation

Whereas the cell cost is as important as the photoelectric conversion efficiency, conceivable alternatives for cost reduction include increasing the production volume, improving the means of production, reducing the raw material cost, enhancing the utilization rate of raw materials, thinning the cell structure, modulization, and reducing the overall system cost including that of racks.

h. Safety and resource problems

For greater safety, it is desirable that the production of cells flow continuously from the production of raw materials, because the continuity would make it possible to minimize the risks of transit and reduce the required stock level. This would also contribute to cost saving. To provide against contingencies, multiplication of the emergency cut-off system, enlargement of the emergency hazard removing system, and a shift to low-toxicity gas would be required. In regard to material resources, though the cost per unit volume can be dramatically reduced by increasing the production volume, the availability of alternative raw materials is called for from the safety point of view as well.

(ii) Investigation of latest technical trends

a. Investigation of domestic and international technical trends

In order to investigate domestic and international technical trends regarding crystalline compound solar cells, officials participated in various international meetings and visited research bodies including universities and institutes.

i. Domestic investigation

• Inspection of Tsubosaka Temple PV system

• Investigation of Agravic Experiment Center

ii. Overseas investigation

• First World Conference on Photoelectric Energy Conversion (WCPEC-1): Varian Research Center, Photonic Power Systems, Northwestern University

• Third World Renewable Energy Congress

b. Lectures by invited speakers

i. Lectures by foreign speakers

• C. Verie (Centre National de la Recherche Scientifique), "Science and Technology of Tandem Solar Cells"

• T. Cross (EEV Limited), "III-V Compound Space Cells — Conventional and Thin Film Technologies"

c. Investigation of industrial trends

Latest data on the safety of chemical compound solar cells (III-V and II-VI families) were researched with particular regard to materials and manufacturing.

(b) Technical research regarding practical application of ultra-high efficiency solar cells

The progress of developmental work by the companies sharing the tasks of technical development of ultra-high efficiency solar cells was kept track of. Problems were identified, relevant phenomena analyzed, and conceivable solutions discussed.

The Technical Working Group on Crystalline Chemical Compounds was convened according to the following schedule to discuss technical problems arising in the course of the progress of commissioned research projects.

Further to promote joint research endeavors, Information Exchange Meetings were held in which the association and commissioned companies took part.

(i) Technical Working Group on Crystalline Chemical Compounds
First meeting:
Monday, September 12
Second meeting:
Friday, March 10

(ii) Information Exchange Meetings
First: Wednesday, June 29
Second: Wednesday-Thursday, July 27 through 28
Third: Thursday-Friday, September 29 through 30
Fourth: Friday, November 18
Fifth: Tuesday, February 21

(3) Future Tasks

To support endeavors for technical development of ultra-high efficiency solar cells, the Technical Working Group on Crystalline Chemical Compounds was set up to keep track of the latest relevant technical trends. This year, the group's investigation focused on the meaning of the development in pursuit of ultra-high efficiency for III-V/Si(Ge) tandem cells, achievement of ultra-high efficiency, and possibility of cost reduction. Other themes of investigation included basic physical properties of mixed crystal semiconductors, simulation of tandem cells, ultra-high efficiency device structure, elemental techniques for efficiency improvement, trends of hetero epitaxial growth techniques, epitaxial growth and peripheral techniques, availability of resources, and safety. From now on, the development of the latest technical trends should be constantly monitored to update the relevant data on hand.

4. Research and Development of Evaluation Technology for Photovoltaic Power Generation Systems

4.1 Research and Development of Solar Cell Evaluation System

4.1.1 Research and Development of Solar Cell Evaluation System

(1) Objectives and Work Program

(Objectives for FY1996)

(a) Research and development to improve the accuracy of unified performance evaluation techniques

Unified techniques for measurement and evaluation compatible with cells for stacked type solar cells having a wide spectral response will be developed by improving the spectral proximity of double light source type solar simulators and other means.

(b) Research and development to improve the accuracy of unified reliability evaluation techniques

Outdoor exposure tests now under way at four points (Kitami in Hokkaido, Setagaya in Tokyo, Tosu City in Kyushu and Miyako Island) will be continued to collect and analyze further data and, at the same time, various testing techniques relevant to long useful life (20 years or more), including an accelerated degradation test, will be developed on the basis of reciprocal comparison with the findings of outdoor exposure tests.

(Work Program)

(a) Research and development to improve the accuracy of unified performance evaluation techniques

With an eye to improving the calibration accuracy of stacked-type solar cells with artificial light sources and full sky sunlight, attempts will be made to establish outdoor measurement techniques as well as measurement methods for advanced solar cell modules including the chemical compound semiconductor type.

(b) Research and development to improve the accuracy of unified reliability evaluation techniques

Long term exposure tests will be continued at locations with a variety of meteorological conditions, and basic degradation data will be accumulated to establish a testing method for accelerated degradation. Attempts will also be made to establish methods for weatherability tests and durability tests compatible with photovoltaic systems for application to NEDO-size modules.

(2) Summary for FY1994

(a) Development of performance evaluation methods

(i) Research and development to improve the accuracy of measurement of stacked solar cells

For the measurement of stacked solar cells, an effective auxiliary light source method is used, which can realize equivalent reference sunlight. Furthermore, outdoor measurement experiments using natural sunlight were carried out, and the findings were evaluated in comparison with indoor measurements as part of the evaluation of measurement accuracy.

Table 1 shows the comparison of

indoor and outdoor measurements. Though the samples are limited, the measurement deviation between indoor and outdoor measurements was satisfactory, no more than ±2%.

Table 1 Results of Indoor and Outdoor Measurement of Various Cells

Cell type	Indoor measurement value (mA/100mW - cm^{-2})	Outdoor measurement value (mA/100mW - cm^{-2})	Deviation (based on outdoor values)
c-Si	117.1	117.3	-0.2
a-Si/a-Si	26.8	26.9	-0.4
a-Si/a-Si (EVA)	26.4	26.1	+1.1
a-Si/a-Si (EVA)	26.2	26.2	0.0
a-SiC/a-SiGe/a-SiGe	4.50	4.58	-1.7

(ii) Incident angle characteristic of stacked cells

Surveys and experiments were conducted regarding the dependence of stacked cells on the angle of the incident light. As cells were placed on a 37° inclined plane at AM1.5 (42 in solar altitude) in outdoor measurement, the incident angle of the direct sunlight was about 11. The error at an incident angle of 10° was –0.3% for double-layered cells and –1.3% for triple-layered cells. At an incident angle of 60°, it was about –7% and –11%, respectively.

(iii) Survey on power outputs of various modules

Whereas the dependence of module outputs on temperature, irradiation intensity and other factors have been evaluated at the laboratory level, the output of each module, when used outdoors, would delicately fluctuate with changes in weather and other meteorological conditions. In view of this aspect, a survey was carried out on power generation efficiency, utilization rate and other factors at the module level.

Six samples were surveyed, including c-Si (two sheets), p-Si (two), a-Si and a-Si/a-Si tandem modules, each provided by a different manufacturer. The power generation efficiency, characteristically, may manifest completely reverse seasonal variations between crystalline and a-Si-based modules. The best utilization rate was shown by p-Si.

(b) Development of reliability evaluation method

(i) Collection and analysis of degradation data by long-term exposure tests

The long-term exposure tests were intended to collect and analyze degradation data needed for the development of an accelerated degradation test method. Data collected at the Setagaya, Kitami (fourth year), Tosu (third year) and Miyako Island (second year) sites, according to which investigation and research had been conducted to set the conditions of accelerated degradation tests for a service life of 20 years, are not yet sufficient as a basis for this work, and are used merely as a tentative reference.

Since outdoor testing is subject to measurement errors due to the influences of temperature, illuminance and spectrum, among other factors, the modules were brought back regularly for indoor measurement. None of the modules has manifested noticeable progress of degradation after the first year of exposure.

(ii) Outdoor exposure tests of a-Si modules differentiated by starting month

The exposure of the first group was started in September 1993, and every group had been exposed by August 1994.

At the moment, no significant difference in the extent of degradation has been noticed among the groups.

(iii) Experiment to recover performance characteristics of a-Si modules

This experiment was intended to recover the performance characteristics of photodegraded modules by preservation at high temperature, derive various parameters of a recovery model formula expressed in a function of the expansion index, and estimate performance recovery at a given preservation temperature. The temperature levels used were 60°C, 70°C, 80°C and 90°C, and two samples were tested at each temperature level. The parameters of the recovery model formula were derived from standardized recovery rates.

(iv) Accelerated degradation tests of thin-film cells and modules

Investigation and research have been carried out on accelerated degradation tests of various modules for a supposed service life of 20 years. In order to set evaluation test conditions corresponding to this long life, attempts have been made to develop a testing apparatus and find out proper test conditions and pattern with reference to the already-set tentative test conditions for the initial-year degradation rate. As a result, an accelerated photodegradation testing apparatus was developed, which is capable of emitting 10SUN light and controlling the temperature. This apparatus, using a 5kW xenon lamp as light source, has a function to radiate 10SUN by condensing the generated light. As the light source spectrum of this apparatus has unsuitable spectral characteristics for a standard apparatus, a spectral correction filter was inserted to cut the infrared region, and the resultant drop in radiation illuminance in the ultraviolet and visible ranges was compensated for by increasing the capacity of the xenon lamp, so that 10SUN is available at the prescribed spectral radiation illuminance.

(3) Future Tasks

(a) Development of performance evaluation methods

(i) As part of the effort to improve the measurement accuracy of stacked cells, research will be conducted on the spectral distribution of a double-light source solar simulator and management techniques for artificial component cells, and at the same time investigation will be made on measurement techniques for the output characteristics of stacked modules on the basis of measurement techniques for stacked cells.

(ii) While identifying the electric output characteristics of new types of cells including chemical compound semiconductor-based ones, research will be conducted on the methods of measurement and calibration.

(iii) The power outputs of various solar cell modules differing in cell material and structure will be surveyed in the state of actual use.

(iv) Unification of the measurement methods for the performance characteristics of cells and modules used by the companies commissioned by NEDO will be attempted.

(b) Development of reliability evaluation method

(i) The long-term exposure tests at the Setagaya, Kitami, Tosu, Miyako Island and Hamamatsu will be continued to build up basic data and analyze the degradation modes of various modules.

(ii) Experimental research will be conducted to improve the accuracy of the accelerated degradation test method for a supposed long service life.

(iii) Unification of the measurement methods for the weatherability of cells and modules used by the companies commissioned by NEDO will be attempted.

4.1.2 Investigations of Research and Development Attempts Regarding Solar Cell Evaluation Systems

(1) Objectives and Work Program

Investigations will be made to promptly and accurately identify technical trends regarding solar cell evaluation systems, effectively bring the findings to bear on our own research and development, and thereby establish unified, appropriate and fair evaluation methods for the performance and reliability of solar cells.

(2) Summary for FY1994

(a) Investigations regarding development of methods for performance evaluation and reliability evaluation

Five sessions of the Working Group on Performance-Reliability Evaluation were convened to promote technical development for appropriate and impartial solar cell evaluation methods with respect to the "Development of a Performance Evaluation Method" and the "Development of a Reliability Evaluation Method," and technical problems were analyzed and discussed.

Concerning the "Development of a Performance Evaluation Method," analysis and discussions focused on experiments to improve the measurement accuracy of stacked cells and the accuracy of indoor calibration by a double light source solar simulator.

With respect to the "Development of a Reliability Evaluation Method," analysis and discussions centered on the long-term exposure tests at the Setagaya, Kitami, Tosu and Miyako Island sites and accelerated degradation tests.

(b) Database establishment for solar cell-related technologies

It is extremely difficult to keep track of the progress of solar cell development efforts internationally because solar cell technology involves high-tech elements. In view of this background, with an eye to keeping abreast of solar cell developmental activities worldwide and to promote the further development of solar cell systems, information on research achievements by solar cell developing institutes in many countries of the world was collected efficiently, and its integration into a database was attempted. The sources of information were pertinent international conferences and academic journals, and the derived information was classified by the type of material, country and institute.

(3) Future Tasks

Concerning the performance evaluation method, the tasks include the establishment of the spectral distribution of the solar simulator and the management method for artificial component cells, and support of the establishment of measurement techniques for the output characteristics of stacked modules based on measurement techniques for stacked cells.

Regarding the reliability evaluation method, while continuing the long-term exposure tests to build up, evaluate and analyze pertinent data, support should be given from now on to the establishment of a photodegradation testing method.

4.2 Research and Development of Test and Evaluation Methods for BOS Component Devices

(1) Objectives and Work Program

(Objectives)

Required specifications for peripheral components needed to compose both stand-alone and grid-connected photovoltaic power generation systems, such as support structures for solar cells, power inverters and power storage systems will be clarified, and unified testing methods and evaluation methods for these units will be elucidated.

(Work Program)

(a) Studies on specifications for BOS component devices

(b) Studies on unified test method for BOS component devices

(c) Cost evaluation of PV systems

(2) Summary for FY1994

(a) Study on required specifications for peripheral components

(i) Study on practical specifications for BOS component devices

The results of previous study on the specifications for actual use of components peripheral to photovoltaic power generation including storage batteries, inverters and interconnection-protection devices and on ways to effectively utilize storage batteries were put together.

As a result, it was found that effective future orientations of technical pursuit will include utilization of the potential capabilities of the combinations of an inverter and small storage batteries or the like to stabilize voltage, improve power quality and compensate for instantaneous peak loads and identify the value they can add, in addition to seeking cost reduction through drastic simplification of the inverter circuit design and its adaptation to multipurpose use and mass production, among other things.

(ii) Survey on technology for wide utilization of PV systems

With an eye to identifying various forms of application useful for promoting practical application and extensive use of photovoltaic systems, studies of photovoltaic systems in other countries were carried out as they were last year. As a result, information on 1,158 cases in 103 countries was collected.

(b) Study on unified testing and evaluation methods

(i) Study on methods for performance test of BOS devices

a. Performance test methods for advanced-type storage batteries

Two different types, the NEDO-developed (Phase II) new type lead-acid storage battery and the nickel-hydrogen storage battery, were subjected to PSOC cycle tests and accelerated longevity tests.

i. Basic performance tests

As shown in Table 2, both manifested the specified capacities and efficiencies.

ii. Cycle tests

The progress of the long-term cycle tests now under way is traced in Table 3.

The high-rate charge-discharge type lead storage battery and the nickel-hydrogen storage battery, which have high current ratios, showed slight capacity drops in both the PSOC and the accelerated longevity tests. Conversely, a deep-discharge type lead storage battery, whose current ratio is relatively low, manifested a capacity increase.

One of the problems identified was a temperature rise in high-discharge rate accelerated longevity tests. This was particularly intense in 1C repeated cycles; the temperature of the nickel-hydrogen storage battery sometimes surpassed its permissible limit of 50°C, and that of the high-rate charge-discharge type lead storage battery also rose beyond 45°C occasionally. However, discussions by the Working Group on Storage Batteries arrived at the conclusion that this could not be helped in tests for practical application, and the group decided that later development should be watched with a +5°C allowance.

b. Performance tests of commercially available storage battery

The PSOC cycle test of a commercially available storage battery according to the NEDO/DPIE revised profile (GS: SLB-200) has been carried on for about 300 cycles so far, equivalent to about 1,500C in terms of the five-hour rate of discharge capacity (125Ah). The battery has barely reached 90% of its rated capacity, and is expected to take six more months or even longer to reach its age limit.

c. Summary of performance testing methods for peripheral devices

With a view to facilitating future study on JIS requirements among other things, a summary was made on points to be noted in performance tests and the implementation of tests and in designing the testing apparatus for such devices as inverters, storage batteries and interconnection-protecting devices.

(ii) Summary of results of performance tests of peripheral devices

For storage batteries, it is essential to effectively use their rated capacities and extend their service lives as much as possible. Concerning inverters, it is more practical to seek reduction of fixed losses than to try to improve the conversion efficiency at the rated level, and in this connection simplifying and reducing the size of control circuits would make an important contribution to cost saving.

(c) Performance/cost evaluation of peripheral devices

Table 2 Results of the New-Type Storage Battery Basic Characteristics Tests, Including Capacity and PSOC Efficiency

Model	Current rate	$0.1C_{10}$			$0.2C_5$			$0.3C_{10}$			$1.0C_1$			$1.0C_{10}$		
	Test sample	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3	#1	#2	#3
(1) GRE-100 100Ah	Discharge capacity (Ah)	110.4	109.8	111.9	103.9	104.0	105.1				85.2			76.6		
	PSOC efficiency (%)	99.6	98.9	98.9	97.3	96.8	97.4				105.4			93.5		
(2) PSC-500 500Ah	Discharge capacity (Ah)	564.6	559.6	560.9				509.0	544.3	544.9						
	PSOC efficiency (%)	93.3	95.2	95.6				103.3	102.5	98.9						
(3) MH-S100 100Ah	Discharge capacity (Ah)	90.0	102.3	101.0	97.4	102.5	101.6				-			-		
	PSOC efficiency (%)	96.8	95.6	94.8	96.3	96.2	96.0				-			-		
(4) MH-H100 100Ah	Discharge capacity (Ah)	105.1	104.5		99.6	101.7					98.0			92.8		
	PSOC efficiency (%)	96.0	95.1		99.9	98.4					105.4			110.9		

Notes: 1) GRE-100 and MH-H100 are assembled batteries, while PSC-500 and MH-S100 are single cell batteries.

2) Values for MH-S100 represent the results of reexamination after replacing lost electrolyte and retightening the pressure valve.

3) Temperature was compensated at 25°C for lead-acid batteries, while no temperature compensation was made for nickel-hydrogen batteries.

Table 3 Test Items and Long-Term Cycle Test Process of New-Type Storage Batteries

Testing bed	Storage battery		Current rate	Test items		Tested cycles	Discharge capacity (Ah)	PSOC efficiency
				Basic test	Cycle test		Current/Initial	
#1	High current rate lead acid GRE-100	#1	0.1 C	Capacity, efficiency and I-V characteristics	High current rate cycle test I	400	69.0 / 76.6	- / 93.5
#2		#2	0.2 C	Capacity, efficiency and I-V characteristics	PSOC cycle	36	93.9 / 104.0	- / 96.8
#3	Deep discharging rate lead acid PSC-500	#1	0.3 C	Capacity, efficiency and I-V characteristics	Deep discharging cycle test	245	534.6 / 509.0	103.5 / 103.3
#4		#2	0.1 C	Capacity, efficiency and I-V characteristics	PSOC cycle	48	601.2 / 559.6	94.2 / 95.2
-	Nickel-hydrogen long-life MH-S100	#1	1.0 C	Capacity, efficiency and I-V characteristics	High current rate cycle test II	-	-	-
-		#2	0.2 C	Capacity, efficiency and I-V characteristics	PSOC cycle	-	-	-
#5	Nickel-hydrogen high current rate MH-H100	#1	1.0 C	Capacity, efficiency and I-V characteristics	High current rate cycle test II	3,200	78.3 / 92.8	113.6 / 110.9
#6		#2	0.2 C	Capacity, efficiency and I-V characteristics	PSOC cycle	48	93.3 / 101.7	101.7 / 98.4
#9	Common testing bed	#3	Storage characteristics, overcharge and overdischarge characteristics and other supplemental tests					

Notes: 1) High current rate lead-acid and nickel-hydrogen batteries are assembled batteries.
2) Nickel-hydrogen (long life) battery is on standby for a testing bed.
3) One cycle of a PSOC test is four days.
4) Temperature was compensated at 25°C for lead-acid batteries, while no temperature compensation was made for nickel-hydrogen batteries.

A proposal has been put together regarding cost reducing measures for photovoltaic systems.

As a result, while the efforts to reduce the costs of elemental components are important, it was found that optimization of the system configuration by extending the service lives of storage batteries, optimizing the storage battery inverter capacity relative to the scale of solar cells and otherwise could also have very significant cost-saving effects. Besides that, study was made on evaluation techniques for interconnection systems from the power industry's point of view, and model calculation and evaluation were carried out.

(d) Investigation of overseas trends

Officials attended IEA's international conference organizing committee meeting held in Rome to investigate the recent situation of the use of photovoltaic power generation in the utilities industry, and visited the 3MW system recently completed in Serre, Italy to learn about its design, technical features and construction cost, among other aspects. This system achieved a per-watt cost of ¥1,000 by using a rack structure consisting of simple members and a decentralized inverter configuration.

(3) Future Tasks

Various tests of the Phase II storage battery will be continued to verify the rationality of the new type storage battery testing method, and at the same time the performances of various advanced storage batteries will be evaluated by long-term cycle tests.

4.3 Research and Development of System Evaluation Technologies

(1) Objectives and Work Program

(Objectives)

Evaluation methods for systems needed to improve the efficiency of photovoltaic power generation systems will be developed, and the establishment of optimal design methods and optimal operating techniques for various photovoltaic power generations systems will be attempted by utilizing the developed evaluation methods.

(Work Program)

(a) System evaluation technology

(b) Establishment of database

(c) Simulation technology

(d) Overall evaluation

(e) Survey

(2) Summary for FY1994

(a) System evaluation technology

Operational data of the testing equipment constructed in fiscal 1993 were collected, and on their basis various characteristics were analyzed. This year, two or three design parameters, which had not yet been determined, were quantified, and precision improvement was attempted for already quantified parameters as well.

A I-V curve tracer for on-site measurement of the output of solar cell arrays was developed, and measurement tests were carried out with it.

(b) Establishment of database

The sort of data collected in the past solar power generation projects of NEDO continued to be put together in an integrated and unified manner as in fiscal 1993. The database thereby established will be made available for extensive common use as well as for our own research and development purposes. In fiscal 1994, information from 17 NEDO projects was incorporated into the database.

(c) Simulation technology

As simulation of the energy flow, the relationship between the maximum output and the intensity of solar radiation, characteristics parameters of modules and interconnection system were simulated. For the water pump system, a simulation program was developed. Concerning the interconnection system, simulation was carried out using the capacity ratio between the array and the inverter as parameter, and the optimal capacity ratio was assessed.

(d) Overall evaluation

Various design parameters were figured out from the measured data and the results of simulation, and primary estimated values were worked out. The result is shown in Table 4. A design manual was further prepared by utilizing these parameters.

Table 4 List of Design Parameters

Design Parameters		Values of Design Parameters	
K_H	(Incident irradiation modification factor)	$K_H = K_{HD} \cdot K_{HS} \cdot K_{HC}$	
K_{HD}	(Annual deviation)	0.94-0.97 (yearly) 0.81-0.96 (monthly)	155 sites in Japan
K_{HS}	(Shadowing)	Read from Figs. 4. 1-1 and 4. 1-2	
K_{HC}	(Contribution for tracking)	$K_{HC} = K_{HCD} \cdot K_{HCT}$	
K_{HCD}	(Normal direct irradiation)	1.0	Flat plate fixed
		1.0	Flat plate tracking
		0.66	Focus, tracking
K_{HCT}	(Flat plate tracking gain)	1.0	Flat plate fixed
		1.22	Flat plate tracking
		1.0	Focus, tracking
K_P	(PV conversion efficiency modification factor)	$K_P = K_{PD} \cdot K_{PT} \cdot K_{PA} \cdot K_{PM}$	
K_{PD}	(Efficiency deviation by aging)	$K_{PD} = K_{PDS} \cdot K_{PDD} \cdot K_{PDR}$	
K_{PDS}	(Soil)	0.98 - 0.99	At Hamamatsu test site
K_{PDD}	(Degradation)	1.0	Crystalline type
		$(1-d\eta_P)^{n_{YL}}$	Amorphous type
K_{PDR}	(PV response deviation)	$K_{PDR} = K_{PDRS} \cdot K_{PDRN}$	
	(Spectral response deviation)	$K_{PDRS} = 0.97$	Crystalline type
		$K_{PDRS} = 1.02$	Amorphous type
	(Nonliner response deviation)	$K_{PDRN} = 0.97$	Yearly mean (Crystalline type), amorphous: unfixed)
K_{PT}	(Cell temperature)	$1+\alpha P_{max} \cdot (T_{CR} - T_S)$	Crystalline type: 0.98; amorphous: 0.99
		$\alpha P_{max} = -0.0041$	Crystalline type
		$\alpha P_{max} = -0.0020$	Amorphous type
		T_{CR} = Average atmospheric + average 15°C	

Table 4 List of Design Parameters (continued)

Design Parameters		Values of Design Parameters	
K_{PA}	(Array circuit)	$K_{PA} = K_{PAU} \cdot K_{PAL}$	
K_{PAU}	(Unbalance)	1-0.127 x (standard deviation σ / average) when σ=0.02 0.997	
K_{PAL}	(DC circuit loss)	1-(0.6 x rated wiring loss rate + 1 / rated voltage)	
K_{PM}	(Load matching)	0.94	Grid connected
		0.91	Standalone: Stable power supply, except overcharging
		0.89	Standalone: Controlled load by irradiation, except overcharging
K_B	(Battery circuit factor)	$K_B = (1-\gamma_{BA}) \cdot \eta_{BD} + \gamma_{BA} \cdot \eta_{BA}$	
γ_{BA}	(Battery contribution)	0.8	Stable power supply
		0.37	Controlled load by irradiance
η_{BD}	(Efficiency of bypass circuit)	1.0	Without bypass converter
η_{BA}	(Energy storage efficiency)	$\eta_{BA} = K_{B,OP} \cdot \eta_{BTS}$	
$K_{B,op}$	(Battery operation efficiency)	$K_{B,op} = K_{B,sd} \cdot K_{B,ur} \cdot K_{B,au} \cdot \eta_{BC}$	
$K_{B,sd}$	(Self discharge)	1-(self discharge/total discharge) 0.99 self discharte 0.1%/D	
$K_{B,ur}$	(Rebalancing)	1-(rebalancing/total discharge) 1.0 Implemented when overcharging	
$K_{B,au}$	(Auxiliary power)	1-(electrolyte stirrer/total discharge) 0.99 With stirrer	
η_{BC}	(Charge controller)	1.0	Without charging controller, efficiency with charging controller
η_{BTS}	(Battery units efficiency)	0.84-0.87	
K_C	(Power conditioner circuit factor)	$K_C = \gamma_{DC} \cdot K_{DD} + (1-\gamma_{DC}) \cdot K_{IN}$	
γ_{DC}	(DC extraction ratio)	0.0	No DC load
K_{DD}	(DC/DC converter)	$K_{DD} = K_{DCC} \cdot \eta_{DDO}$	
K_{DCC}	(DC/DC circuit factor)	1.0	No DC load
η_{DDO}	(DC/DC converter energy efficiency)	1.0	No DC load
K_{IN}	(Inverter circuit)	$K_{IN} = K_{ACC} \cdot \eta_{INO}$	
K_{ACC}	(Inverter AC circuit)	$K_{ACC} = K_{INAU} \cdot K_{ACTR} \cdot K_{ACFT} \cdot K_{ACLN} \cdot K_{ACSA}$	
K_{INAU}	(Auxiliary circuit energy efficiency)	1.0	Included in inverter efficiency
K_{ACTR}	(Transformer)	1.0	Included in inverter efficiency
K_{ACFT}	(Filter)	1.0	Included in inverter efficiency
K_{ACLN}	(AC line loss)	1-(AC line loss/output power)	
K_{ACSA}	(Auxiliary power)	1-(Auxiliary power/output power) 1.0 Without auxiliary power supply	
η_{INO}	(Inverter energy efficiency)	$\eta_{INO} = \eta_{INR} \cdot \{a/(0.16 + 0.957a + 0.027a^2)\}$ η_{INR}: Inverter efficiency at rated operation a: Load factor /100 When power factor is 0.8, and within the range of a>0.15, subtract 0.02 from calculated value .	

(e) Investigations

With a view to facilitating the prediction of the extent of the future dissemination of photovoltaic systems, performance and cost evaluation, and study on new applicable areas, officials participated in the WCPEC meeting held in Hawaii in December 1994, and conducted a technical investigation. A visit was also paid to a photovoltaic installation in the Republic of Kiribati to survey trends of practical application of photovoltaic systems and techniques to promote their extensive use.

(3) Future Tasks

(a) System evaluation technology

Data will be collected and analyzed, and at the same time technology for on-site measurement will be established.

(b) Database

A database will be established, and made available for use in the evaluation of various systems.

(c) Simulation technology

Techniques which would allow quantitative grasp and evaluation of the efficiency and economic features of various solar photovoltaic systems will be developed.

(d) Overall evaluation

Overall evaluation will be carried out to determine and quantify design parameters. The manual for the rationalization of design calculation formulas will be improved and prepared anew.

5. Research and Development of Systems to Utilize Photovoltaic Power Generation and Peripheral Technologies

5.1 Research and Development of Photovoltaic Modules Integrated with Construction Materials

(1) Objectives and Work Program

(Objectives)

Research and development will be carried out on altogether six methods of three types of building material-integrated modules applicable to a wide variety of installations including personal residences and high-rise buildings with a view to accelerating the expansion of the use of photovoltaic power generation utilizing systems and peripheral technologies as part of the project to develop them.

(a) PV modules integrated with roofing materials: ¥170/W in module cost (PV increment)

(b) PV modules integrated with wall materials: ¥85/W in module cost (PV increment)

(c) Flexible modules integrated with unspecified construction materials: ¥190/W

(Work Program)

Investigation will be carried out on building material-integrated modules usable for roofs and walls of personal residences, and study will be made on the module connecting method and installation and fixing methods taking account of the ease of maintenance including repair and replacement so as to develop reliable and yet low-cost modules. Furthermore, demonstration test units incorporating building material-integrated modules will be built to conduct demonstration tests.

(a) PV modules integrated with roofing materials

(i) Exchangeable PV shingle method: Solar cell roof tiles to replace flat roof tiles, permitting ready installation or replacement needing no special tool will be developed.

(ii) Prefabricated PV roof panel method: Factory-fabricated roof panel modules of solar cell tiles with built-in solar cell modules arranged over a flat tile type base will be developed.

(iii) Heat-insulated PV roof panel method: Roof panels consisting of large amorphous silicon solar cells installed in a factory over thermally insulated roof modules will be developed.

(b) PV modules integrated with wall materials

(i) PV glass curtain wall method: Solar cell curtain walls permitting a wide choice of colors to replace PC panels and glass curtain walls will be developed.

(ii) PV metal curtain wall method: Solar cell curtain walls consisting of solar cell modules with radiator fins installed with an inclination over surface panel units metallic curtain walls will be developed.

(c) Flexible PV modules for roofing: Solar roofing will be developedfor which flexible solar cells, so structured as to permit cutting on site into any desired length, are used in place of waterproofing paper, which is usually laid under roof tiles, with glass sheets installed over them.

(2) Summary for FY1994

(a) PV modules integrated with roofing materials

(i) Exchangeable PV shingle method

a. Trial manufacture and evaluation were carried out on modules integrated with building materials according to specifications close to final specifications. The basic performance free from problems was confirmed and methods of execution and installation of the modules were studied.

b. The design characteristics and forced airflow cooling structure were examined aiming at practical application.

Fig. 1 is a conceptual drawing of the exchangeable PV shingle method.

(ii) Prefabricated PV roof panel method

a. The roof panel module and solar cell roof tile structures were examined. A series of wind resistance and water spray tests were carried out and the performance was affirmed.

b. As for improvement of the quality of execution of the prefabricated PV roof panel method, fluctuations in frame accuracy were grasped. As a result, the on-site fitting workability to complete installation smoothly in 3 hours and 20 minutes (about 6 minutes per panel) was demonstrated.

c. The PV module basic structure, PV module structure and component materials were studied. Prototype modules compatible with thin 6-mm thick roof tiles satisfying the necessary conditions of the roof tile-integrated structure were fabricated.

Fig. 2 is the basic structure of the prefabricated PV roof panel method.

(iii) Heat insulated PV panel method

a. The PV module design, trial manufacture and performance evaluation were carried out. The module rigidity, heat deformation and cooling tests were also conducted.

b. In an overall demonstration test, module panels were installed on a test house and their the design and execution characteristics were confirmed. A series of performance tests (power generating performance, heat insulation) was started.

c. Heat insulated PV panels (PV area: about 68 m^2) were installed on an overall demonstration house (three-story wooden building, building area: 135 m^2) and its de-

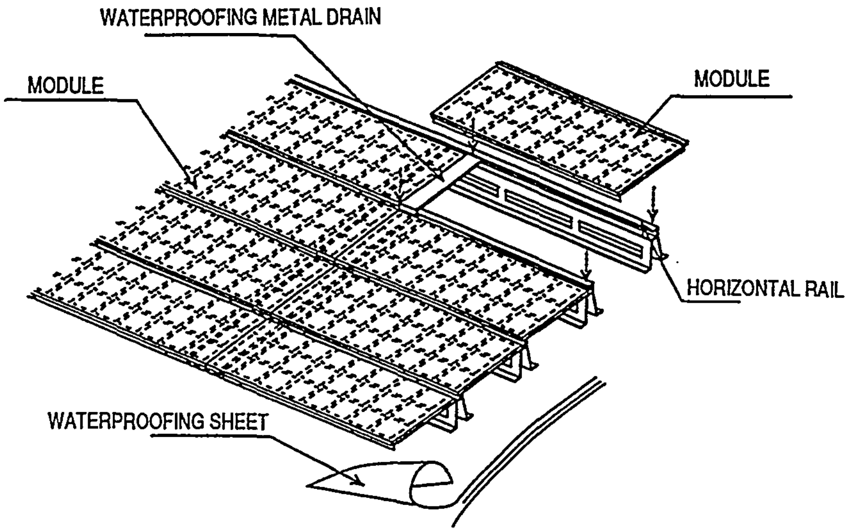


Fig. 1 Schematic Diagram of Exchangeable PV Single Method

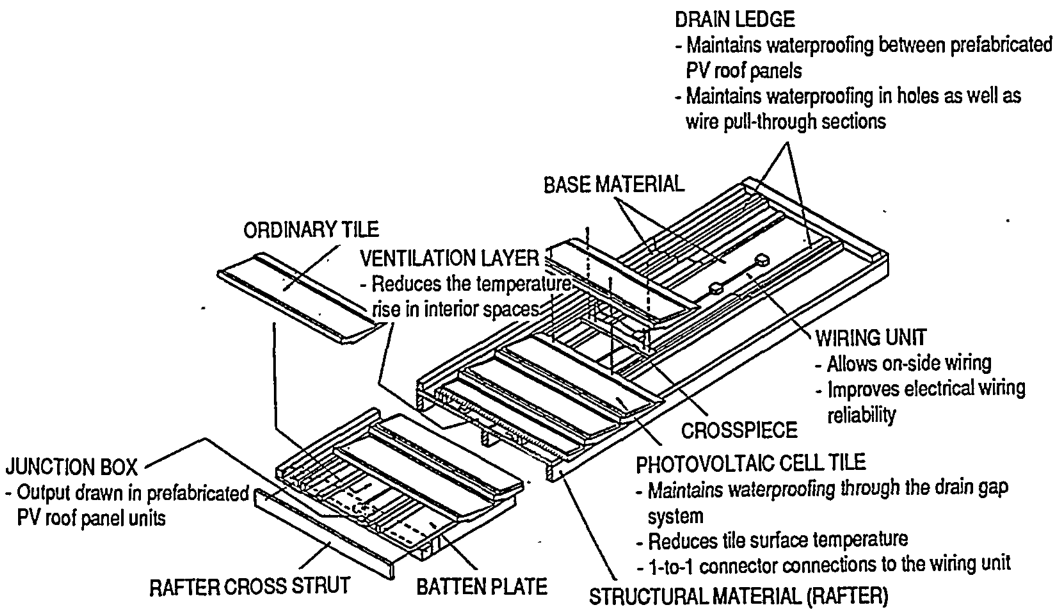


Fig. 2 Basic Structure of Prefabricated PV Roof Panel Method

sign and execution characteristics were confirmed. A series of tests on power generating characteristics and heat insulating performance was started.

Fig. 3 shows the heat insulated PV panel method demonstration test house. Fig. 4 shows the results of measurement of amounts of the generated energy.

(b) PV modules integrated with wall materials

(i) PV glass curtain wall method

a. A market survey was conducted centering on high-rise building wall materials. Engineering processes were examined, taking into account building wall reforming needs in addition to new building demand.

b. Development was carried out on technology for manufacturing a variety of PV cells by changing reflection preventive film forming conditions. A cell sealing method using flame retardant EVA was examined.

c. As part of study on methods of integration with building materials, development was carried out on improvement of endurance, module structure and enlargement of module sizes with trial manufacture of prototypes in each category together with a study on execution methods. Using the simplified demonstration test unit shown in Fig. 5, the design characteristics, execution methods, etc., of PV modules were examined.

(ii) Metal curtain wall method

a. Performance requirements in application as wall materials and problematical points in practical utilization were identified and examined.

b. The PV module and panel development was carried out. Optimization was sought of submodule installation angles and intervals. Using a power generating performance evaluation wall shown in Fig. 6, a series of performance and reliability tests were conducted.

(c) Flexible PV modules for roofing

(i) As application of engineering processes in use today is assumed for solar roofing, the flexible module should be able to be rolled just as easily as current roofing sheets. The flexibility of module component materials was tested and a basic structure of solar roofing was decided. Fig.7 shows the basic construction of solar roofing.

(ii) The examination of a point method for glass sheet holding was promoted, taking into account the effect of shadows, and basic specifications were established. A water spray test was made to check visually for inward leakage of water. The waterproofing proved acceptable.

(iii) As for the energy generated when the use of glazed or tinted glass is specified, study was carried out at different levels of glass transmissivity. Results showed no loss of transmissivity with the use of glazed glass while it dropped to 60–80% with tinted glass.

(3) Future Tasks

(a) PV modules integrated with roofing materials

(i) Exchangeable PV shingle method

a. Through examination of module materials and structures, final confirmation of the reliability of the modules of final specification and development of the module execution and installation methods study will be promoted on execution and installation methods and practical application, and a series of tests using cut models will be

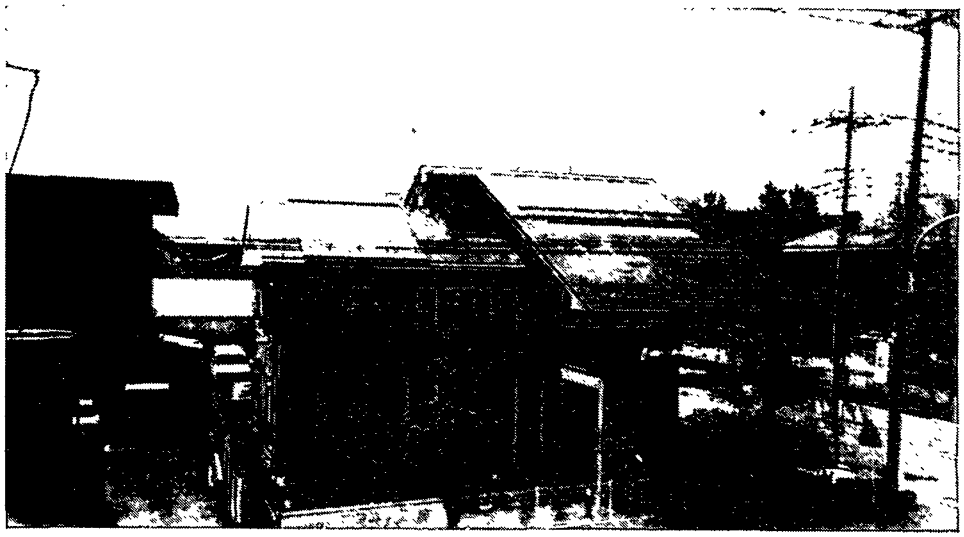


Fig. 3 Heat-Insulated PV Roof Panel Method Demonstration Test House (Hino City, Tokyo)

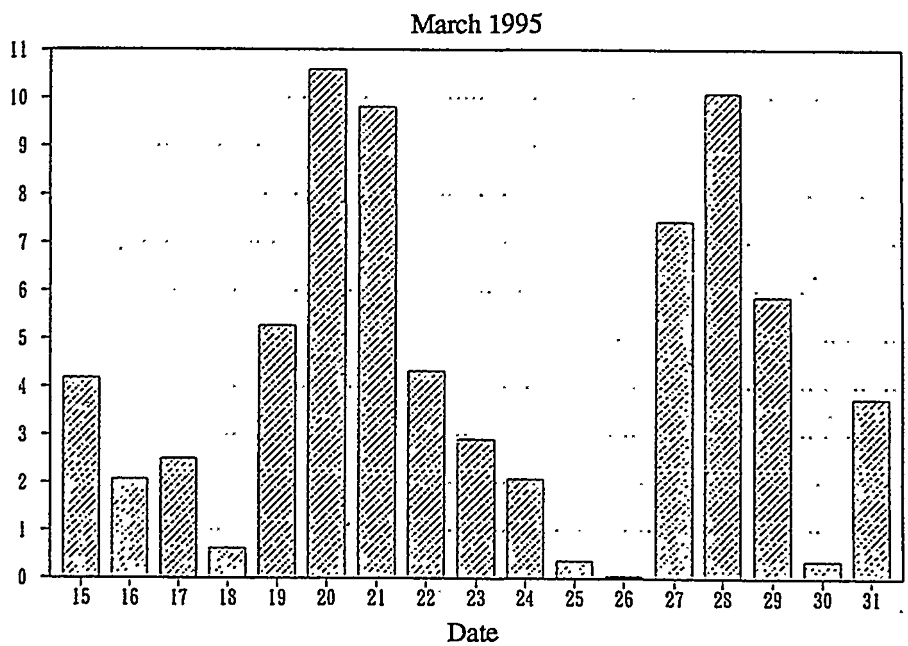


Fig. 4 Generated Power Measurement Results (March 15 - 31, 1995)

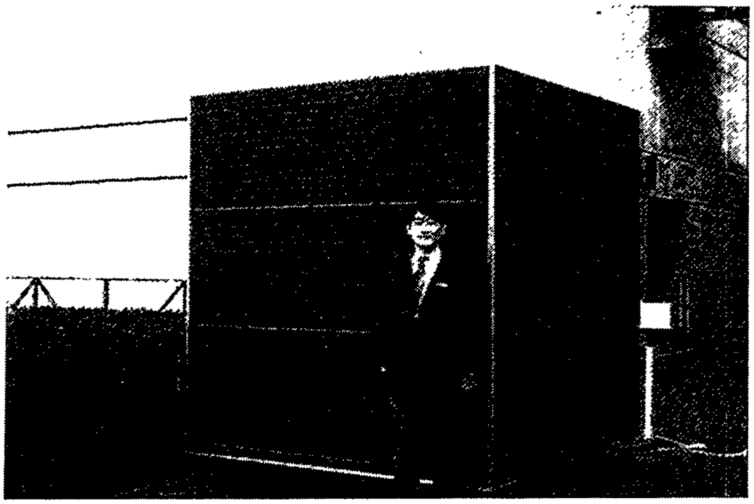


Fig. 5 Simplified Demonstration Test Facilities

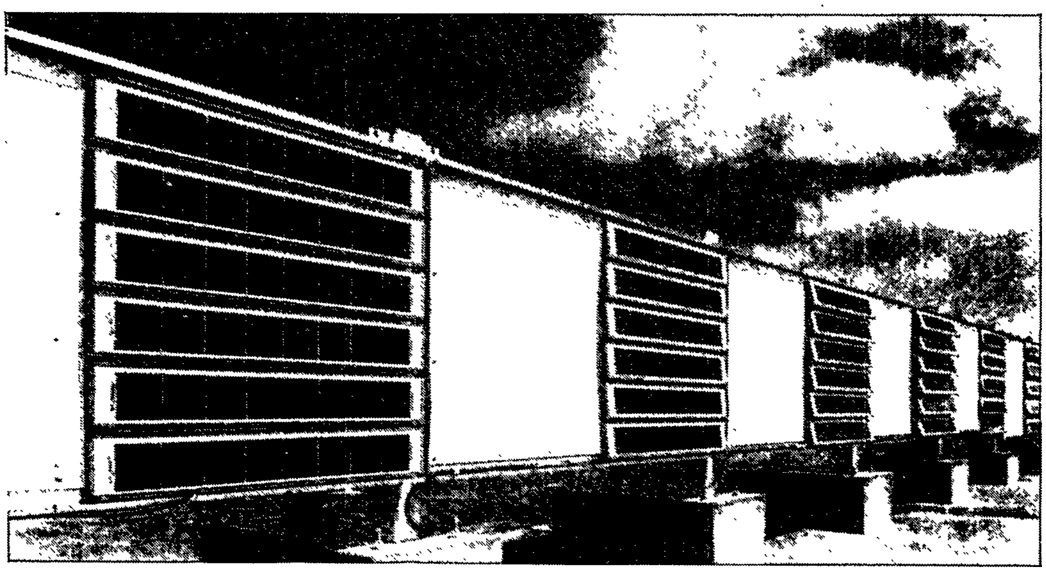


Fig. 6 Test Wall Used in Generation Performance Evaluation

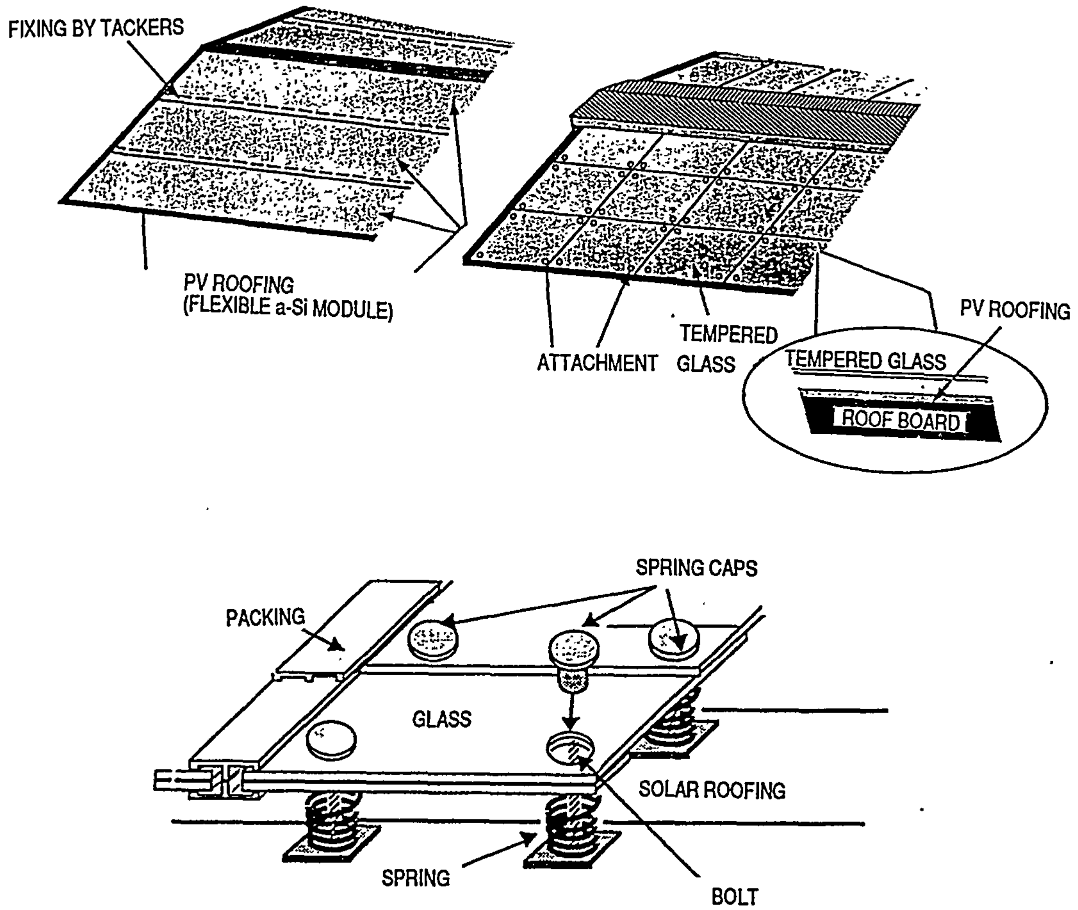


Fig. 7 Basic Structure of Solar Roofing

conducted.

b. A demonstration test and economics evaluation will be made with a model house for overall performance evaluation.

(ii) Prefabricated roof panel method

a. Painted/baked type CdS/CdTe PV modules to double as roof tiles will undergo outdoor deterioration, sealing performance and various reliability tests. Basic issues concerning mass production and practical application will be examined and research on improved design and engineering processes will be carried out.

b. The component members such as solar cell roof tiles, wiring units, etc., and roof panel modules will continue to undergo reliability tests, aiming at a decision on a final structure of PV modules integrated with roofing. In addition, engineering processes to insure favorable fitting characteristics and accuracy of roofing will be carried out and trial execution conducted. A system design built around roofing panels will materialize and system research aiming at demonstration tests will be carried out.

(iii) Heat insulated PV panel method

a. The module specification incorporating the results of final improvement will be completed. In particular, a performance test will be made in association with enlarged solar cells (484 x 872 mm each) and problem-free operation be confirmed.

b. The execution techniques will be completed. Especially, the ridge cover design, fabrication and workability will be confirmed together with study on maintenance methods, and a confirmation test will be carried out.

c. The module roofing of the overall demonstration house will continue to undergo performance evaluation. In addition, a design support system will be developed by improving existing software and a collection of model plans assuming various roof shapes and roofing materials will be prepared.

(b) PV modules integrated with wall materials

(i) PV glass curtain wall method

a. Design characteristics and installation methods will be examined using the simplified demonstration test unit. Based on the results, a demonstration test unit that will be attached to actual buildings will be fabricated. The amount of energy generated and useful forms of its consumption will be studied.

(ii) PV metal curtain wall method

a. Specifications on the submodule structure, component materials, etc., will be set. At the same time research will be carried out to optimize the angle and interval of submodule installation and shape of aluminum substrates.

b. A simulated test wall will be fabricated, design characteristics confirmed and problematical points in execution examined.

c. The module unit performance as a building material will be tested (water tightness, wind resistance, heat elongation, etc.) and wiring and maintenance methods studied.

(c) Flexible PV modules for roofing

(i) As part of flexible PV module manufacturing technology development, techniques for wiring between solar cell tiles, laminating modules for supply in rolls, etc. will be developed.

(ii) For development of technology to insure higher reliability, the environment-resisting characteristics of the trial manufactured solar roofing will be tested, and the improvement of sealing and protective film materials will be promoted.

(iii) For trial manufacture and installation of modules for houses and roofing function technology development, problematical points associated with various roof configurations will be identified, appearance aspects of roof finishing materials studied and waterproofing tests made.

5.2 Development of Various Installation Methods

(1) Objectives and Work Program

(Objectives)

In order to facilitate the introduction of photovoltaic power generation, investigation will made of possible locations of medium- to large-scale installation of solar cells other than on the roofs of personal residences and office buildings, to identify technical opportunities and problems. At the same time low-cost configuration techniques and installation methods suitable for different areas of utilization will be developed.

(Work Program)

(a) Investigation of applicable areas and study on technical problems

(b) Study on installation techniques for photovoltaic arrays

(c) Testing and evaluation of structural design of array racks

(d) Basic design of various promising systems

(e) Performance and cost evaluation

(f) On-site overseas survey

(2) Summary for FY1994

(a) Investigation of applicable areas and study on technical problems

Assuming highways, railroads, dry river banks, public facilities and such like as applicable locations, a comprehensive feasibility study was conducted covering various types of application, installation possibilities, matters to be noted in terms of geographical conditions, compulsory regulations, etc. At the same time concrete types of application and installable wattage were summed up. The results are shown in Table 1. This table shows that about 7,900MW will be usable in locations other than houses and buildings. As instances of overseas application, 18 interesting instances involving remote islands, remote villages, mountain areas, oceans, etc. were investigated.

(b) Study on photovoltaic array installation techniques

Various types of application were represented by models according to types of installation, installation methods and system configurations. These were reduced to basic and simple design conditions, which could be combined to meet specific needs of application. By allowing for special conditions such as the wind velocity coefficient, earthquakes, load, snow load, momentary maximum wind velocity, etc., it was made possible to deal with various types of application uniformly.

(c) Testing and evaluation of structural design of array racks

(i) Wind tunnel test

Wind tunnel test models assuming the use on structure wall surfaces, station platform buildings and highway sound barriers were tested. As a result, conditions of preparing the optimum design in terms of wind load, space between tPV array panels, PV array angles, etc. were grasped.

(ii) Indoor installation tests

Five types of racks in two installation categories (inclined surfaces like faces of slopes and highway noise insulation walls) were fabricated on a trial basis and tested. It was learned that material costs, personnel costs and so on accounted for the majority of rack costs, leaving only little room for cost reduction by increasing production. It was also revealed that adoption of larger and prefabricated panels and advanced construction machinery to reduce the installation cost which would otherwise tend to assume a larger portion of the total cost, and promotion of integration of solar cells and sound barrier materials, etc. should be sought hereafter.

Table 1 Potential Installation Objects and Installable Volume

No.	Installation object	Area of installation object	Installable volume (MW)		
			Potential A	Potential B	Potential C
1	Embankments	2,441 km (68.3 km²)	1,628 (50%)	814 (25%)	407 (12%)
	Riverbeds	105 km²	249 (5%)	100 (2%)	50 (1%)
2	Harbors (facilities)	14.7 km²	140 (20%)	70 (10%)	35 (5%)
	Harbors (parking lots)	0.004 km²	0.17 (100%)	0.09 (50%)	0.03 (20%)
3	Airports (facilities)	1.10 km²	26 (50%)	16 (30%)	8 (15%)
	Airports (parking lots)	1.44 km²	68 (100%)	34 (50%)	13 (20%)
4	Railway stations (JR)	101 km²	1,916 (40%)	958 (20%)	479 (10%)
	Railway stations (private lines)	25.4 km²	484 (40%)	241 (20%)	121 (10%)
5	General roads (guardrails, etc.)	17,212 km (125 km²)	297 (5%)	120 (2%)	59 (1%)
	Highways (on slopes, etc.)	253 km (1.77 km²)	3.37 (4%)	1.69 (2%)	0.75 (1%)
	Freeways (on slopes, etc.)	163 km²	388 (5%)	155 (2%)	77 (1%)
6	Agricultural areas (pasture)	6,608 km²	3,147 (1%)	1,573 (0.5%)	629 (0.2%)
	Agricultural areas (foot-paths and roads)	226 km²	431 (4%)	215 (2%)	108 (1%)
7	Public facilities	1.09 km²	26 (50%)	10 (20%)	5 (10%)
8	Urban parks	146 km²	69 (1%)	35 (0.5%)	0 (0%)
9	Dams (on dam banks)	573 km (3.99 km²)	95 (50%)	48 (25%)	19 (10%)
10	Natural parks (fields, etc.)	11,547 km²	2,749 (0.5%)	1,100 (0.2%)	550 (0.1%)
11	Seashore (sandy beaches)	11,201 km (78.3 km²)	373 (10%)	187 (5%)	75 (2%)
12	Lakes and marshes	943 km (6.59 km²)	157 (50%)	79 (25%)	31 (10%)
13	Schools (facilities)	203 km²	961 (10%)	480 (5%)	192 (2%)
14	Forest	6,711 km²	3,196 (1%)	1,598 (0.5%)	320 (0.1%)
15	Golf courses (facilities)	11.3 km²	216 (40%)	108 (20%)	54 (10%)
	Total	26,149 km²	16,620	7,943	3,233

Notes: 1) Area of installation object: For linear objects, added values of applicable areas are shown in parentheses.
2) Installable volume: Potential A — mild restrictions
Potential B — intermediate restrictions
Potential C — strict restrictions
Each category was evaluated based on the following generation capabilities. Light-receiving angle: 35°; solar altitude: 30° (winter); generation efficiency: 10%; and space factor: 0.53.

Table 2 Various Installation Methods: Applications of Evaluation Systems (Plan)

Array installation pattern			Solar cell	Current collection system	Power source system	Applications	Technical issue
(1) Horizontal surface on the ground	Vertical	Striped	Thin-film	MIC parallel	Grid-connected	Freeways (dousers: integrated type), etc.	Douser modules
(2)	Inclined	Centralized	Crystalline	DC centralized	Grid-connected	Riverbanks, seashore, natural parks, pasture, forest (simplified racks), etc.	Simplified racks
(3) Inclined surface on the ground	Inclined	Dispersed	Crystalline	AC distributed	Grid-connected	Freeways, railways, riverbanks, lake sides (racks on slopes), etc.	Racks on slopes
(4) Walls of structures	Vertical	Striped	Thin-film	MIC parallel	Grid-connected	Freeways, railways (noise barriers: integrated type), etc.	Noise barrier modules
(5)	Inclined	Striped	Crystalline	AC distributed	Grid-connected	Freeways, railways (noise barriers), etc.	Prefabricated racks
(6) Sheds on structures	Inclined	Centralized	Crystalline	DC centralized	Grid-connected	Platforms of railway stations, parking lots (sheds: integrated type), etc.	Building materials integrated modules
(7)	Inclined	Centralized	Crystalline	DC centralized	Grid-connected	Expressways, sightseeing and harbor facilities (sheds: low profile racks), etc.	Low profile racks
(8) Lake surfaces	Inclined	Centralized	Crystalline	DC centralized	Grid-connected	Lake surfaces (floating racks)	Floating racks

Notes
1. Building material-integrated module technique is applicable to (2)-(7).
2. To optimize system, an indoor test on purification capability of (8) was conducted.
3. MIC is an abbreviation of Module Integrated Converter.
4. Other potential applications include long and large bridges (railings) and dams (on dam banks).

(d) Basic design of various promising systems

(i) On-land installation

Interconnection systems of the distributed installation type for application to highways, railroads and so on were considered and their conceptual designs were prepared, including array racks and BOS systems for typical examples as shown in Table 2.

(ii) On-the-water installation

Taking note of promising possibilities for lake water purification, various application instances were investigated and the amounts of electricity required by purification methods were grasped. As part of the study on impacts on environmental conditions, the effect of decreasing water temperature was calculated by covering the test water area surface.

(e) Performance and cost evaluation

Even in applications based on the on-land, self-standing rack concept, a generation cost at the ¥80/kWh level is feasible as things stand today. Further cost savings were recognized as possible, taking into account decreases in solar cell and BOS costs hereafter and installation on existing structures.

(f) On-site overseas survey

A cost range of $6–10 is attained in Europe and the U.S. even today. It was revealed that, centering on array installation, many advanced techniques that we should learn in respect to frameless modules, bonding processes for installation, etc. are being put to practical use there.

(3) Future Tasks

Small evaluation systems will be developed in respect to typical application types for demonstration testing of track designs and installation methods. In addition, a lake water purification system design study will be promoted as a typical instance of on-the-water application.

5.3 Development of Peripheral Devices for Integration of Multiple Functions

(1) Objectives and Work Program

(Objectives)

With a view to simplifying the overall PV system, low-cost, compact and high-efficiency peripheral devices (inverters and interconnection protectors) will be developed which can satisfy various regulations including the technical guidelines for utility interaction of dispersed power generation systems, and will have power converting functions, interconnection protection functions and other necessary functions.

• Cost target: ¥50/W or below (with monthly production of 3,000 units and on an ex-factory basis)

• Efficiency target: 95% or above (at rated output)

• Cubic measure and weight: 0.019m^3 or below, 18kg or below

(Work Program)

(a) Research on main circuit, control and protection

(b) Development of transformer-less inverter

(c) Development of peripheral devices for integration of multiple functions

(2) Summary for FY1994

(a) Research on main circuit, control and protection

From fiscal 1994 study continued on the control and protection functions required of peripheral devices including inverters and interconnection protectors according to the technical guidelines established in March, 1993, for utility interaction of dispersed power generation systems and extension regulations prescribed for facilities in individual homes in general. As a result, the necessary functions of the peripheral devices for integration of multiple functions were examined and decided, paving the way for trial manufacture.

(b) Development of transformer-less inverter

The transformer-less inverter trial manufactured in fiscal 1994 as the central peripheral device for integration of multiple functions was tested, evaluated and improved. The results are summed up below. The main and control circuit configurations of the transformer-less inverter is shown in Fig. 5.3–1.

(i) Converter efficiency

Initially the development target (95.0%) was not attained. But it was met later by adopting an improved type of the general-purpose IGBT as the switching device of the main circuit of the transformer-less inverter.

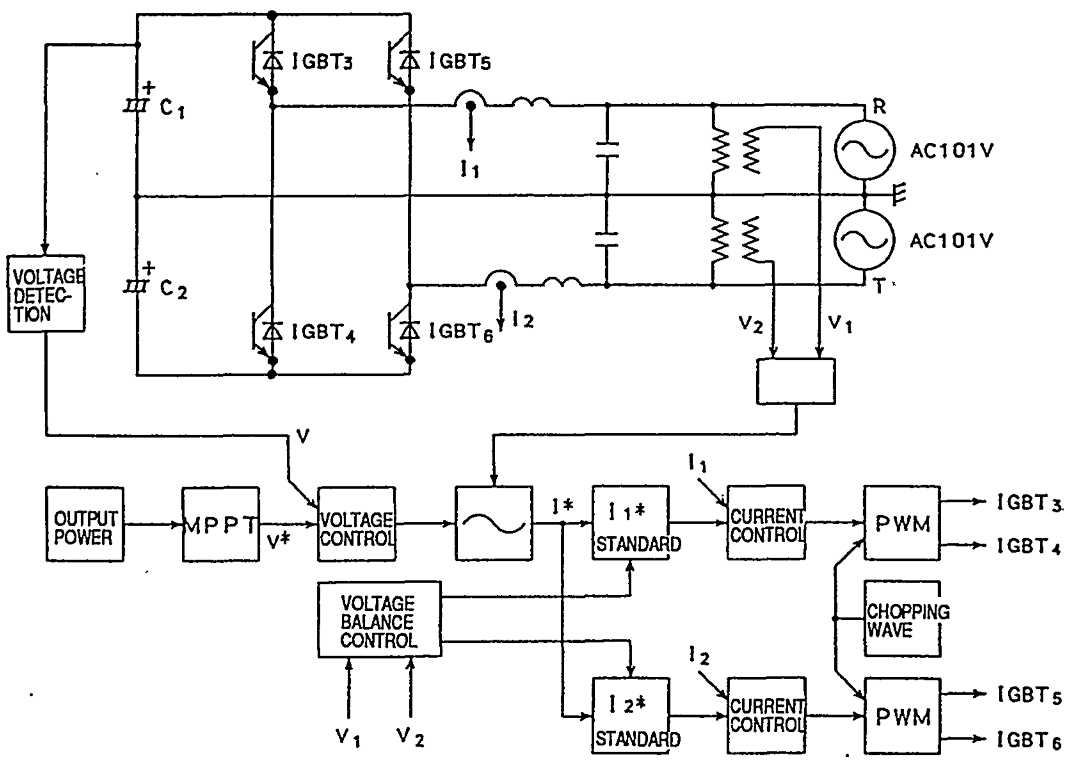


Fig. 5.3-1 Main and Control Circuit Configuration of Transformer-less Inverter

(ii) Output current harmonics distortion

The harmonics outflow current was measured and the overall current distortion of 5% and current distortion of less than 3% in each component current prescribed by the technical guideline for utility interaction of dispersed power generation systems were realized.

(iii) Output DC control

Of the output DC factors the effect of superimposition on the standard was eliminated by inserting a capacitor in series in the signal detecting circuit. Furthermore, a function to detect and compensate for the current detector offset was added. As a result, the development target of less than 0.3% was attained.

(iv) Ground fault DC detection

With the transformer-less method where the neutral wire of the single-phase triple-wire circuit is connected to the solar cell, the direct current resulting from a solar cell ground fault flows through the neutral wire. As the AC leak detector on the interconnection side is not expected to detect this ground fault current, it is necessary to detect it without fail on the inverter side and shut down the path of its flow. For this reason, a DC ground fault detector was installed on the DC input side of the inverter. When the central value of the detection level was set at 75mA, the detection accuracy of ±29.7% realized. This made it possible to insure the detection level of 100mA. This accuracy is comparable with that of AC leak detectors in general.

If necessary, the detection current is able to be set less than 100mA hereafter simply by changing the ratio of current transformation of the converter for detection circuit instruments.

(v) Results of EMI measurement

In the circuit of initial design the value prescribed by VCCI Type 1 was exceeded in a certain frequency region. Improvement by switching the filter to a two-stage type, etc. was confirmed to succeed in satisfying the VCCI Type 1 level requirements.

(c) Development of peripheral devices for integration of multiple functions

A peripheral device for integration of multiple functions having an interconnection protection circuit and protection function periodic inspection circuit built in the transformer-less inverter was fabricated on a trial basis. Fig. 5.3–2 is a photograph of this device. The volume was 0.025 m^3 against the target of 0.019 m^3. This was because a thinner profile was considered more favorable for wall-mounted installations in actual individual homes as reducing the depth would be less intrusive from the standpoint of interior space. The weight of 17 kg was attained against the target of 18 kg.

(3) Future Tasks

As for the necessary functions of the peripheral device for integration of multiple functions, trends in the environmental conditions of household PV systems such as the possible revision of related standards, compulsory regulations, certification test methods, etc. will be confirmed and the review of safety performance, etc. will be examined as necessary. Furthermore, the peripheral apparatus for integration of multiple functions trial manufactured in fiscal 1994 will be put to overall evaluation testing and field testing. The problematical points

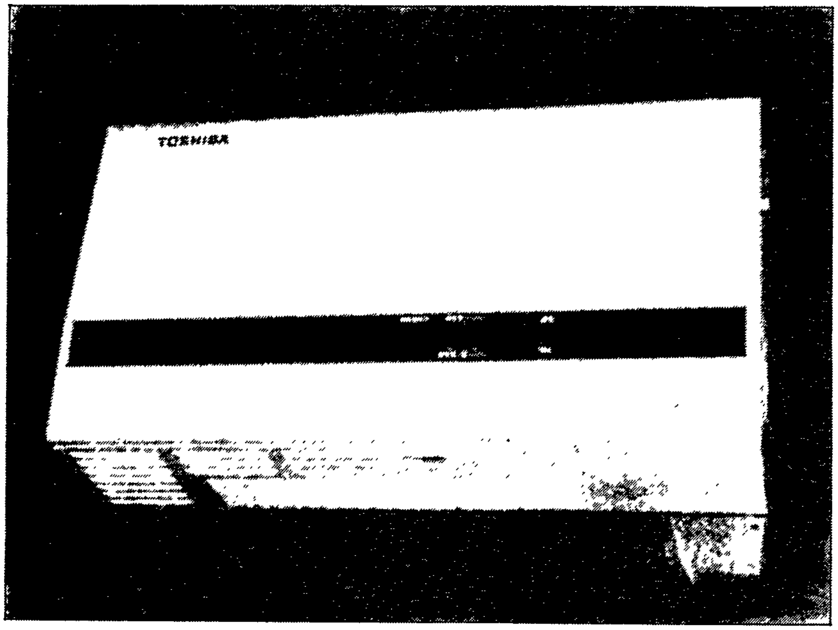


Fig. 5.3-2 External View of Peripheral Device for Integration of Multiple Functions

surfacing there will be corrected while cost analysis and other activities will be carried out.

5.4 Development of Batteries for Photovoltaic Power Generation

5.4.1 Development of Nickel-Hydride Storage Battery for Photovoltaic Power Generation

(1) Objectives and Work Program

(Objectives)

As a peripheral device to constitute part of a photovoltaic power generation system, low-cost sealed nickel-hydride storage batteries will be developed, which would permit high charging/discharging and deep discharging and, moreover, would have a long cycle life.

Battery dimensions: 100Ah (0.1C-rate), 12V

Battery life: 6,000 cycles (at a charging current of 1/3C, a maximum discharging current of 1C and a DOD of 80%)

Cost: ¥70/Wh (0.1C-rate, at an annual output of 200MWh)

(Work Program)

(a) Research on cost reduction of electrode materials

(b) Research on performance improvement (life elongation) of batteries

(2) Summary for FY1994

(a) Cost reduction study for electrode material
  (i) Study on hydrogen storage electrodes (negative electrode)

Of hydrogen storage alloys which could constitute hydrogen storage electrodes (positive electrode) for use in nickel-hydride batteries, $MmNi_{5-x}M_x$, which is an alloy having an AB_5 structure, was taken up in an attempt to reduce the cost of the metallic material for use as M. The compositions of hydrogen storage alloys obtained through past research can be represented by $Mm(Ni\text{-}Co\text{-}Mn\text{-}Al)_5$, in which the cost of the Co metal accounts for a particularly large portion of the cost of the alloys. In view of these findings, alloys in which the Co substitution quantity was reduced or Co was replaced with some other cheaper metals were produced on a trial basis, and the characteristics of these alloys were examined.

As an example, the characteristics of an electrode made of an alloy where Co was replaced with Cu are shown in Fig. 1. When the Co substitution quantity is reduced, the cycle life is evidently shortened. This makes it necessary to keep the Co substitution quantity at more than 0.4 atom. If Ni was used instead of Cu or if the Co quantity was simply reduced, the same results were obtained. This reveals that reducing the Co quantity in the alloy to less than 0.4 atom is difficult in the present circumstances.

The alloy powder is still manufactured by the process shown in Fig. 2. Elimination of heat treatment by improving dies to accept quenching and adoption of gas atomizing to simplify the crushing process were examined and alloys were trial manufactured based on the findings. The characteristics of electrodes made of these alloys were measured. Characteristics equivalent to those attainable with the electrodes of the previous process were obtained. Thus a fair prospect was obtained for less costly production of useful alloys.

Whereas foamed nickel porous bodies (three-dimensionally structured) were previously used to support the electrodes, study was made on an electrode manufacturing process using less expensive thin porous plates (two-dimensionally structured) for electrode supports. As thin porous plates were planar porous bodies, they were interior to the foamed counterparts in holding force and electroconductivity. Binding agents and conductive materials were added to improve their characteristics. The electrode cycle life improved to 5,600 cycles or so, although a slight loss of capacity was observed in comparison with earlier foamed type electrodes. The characteristics thus obtained were almost equal to the target values. This makes it possible to use less costly electrode supports.

(ii) Study on nickel electrodes (positive electrodes)

The characteristics of nickel electrodes supported by less costly thin porous plates were examined. As they were put to an accelerated life test under severe charging and discharging conditions, the loss of service life due to the dislocation of active substances from electrode supporting bodies was observed. This makes it necessary to use electrode supports with a three-dimensional structure and to select powerful binding agents. As a result of examination, PTFE (polyethylene tetrafluoride) proved to excel as the binding agent, creating promising prospects for a longer service life.

(b) Research on performance improvement (life elongation) of batteries

In order to reduce the cell cost, the use of thin porous plates as electrode supports was studied. As they were of a two-dimensional

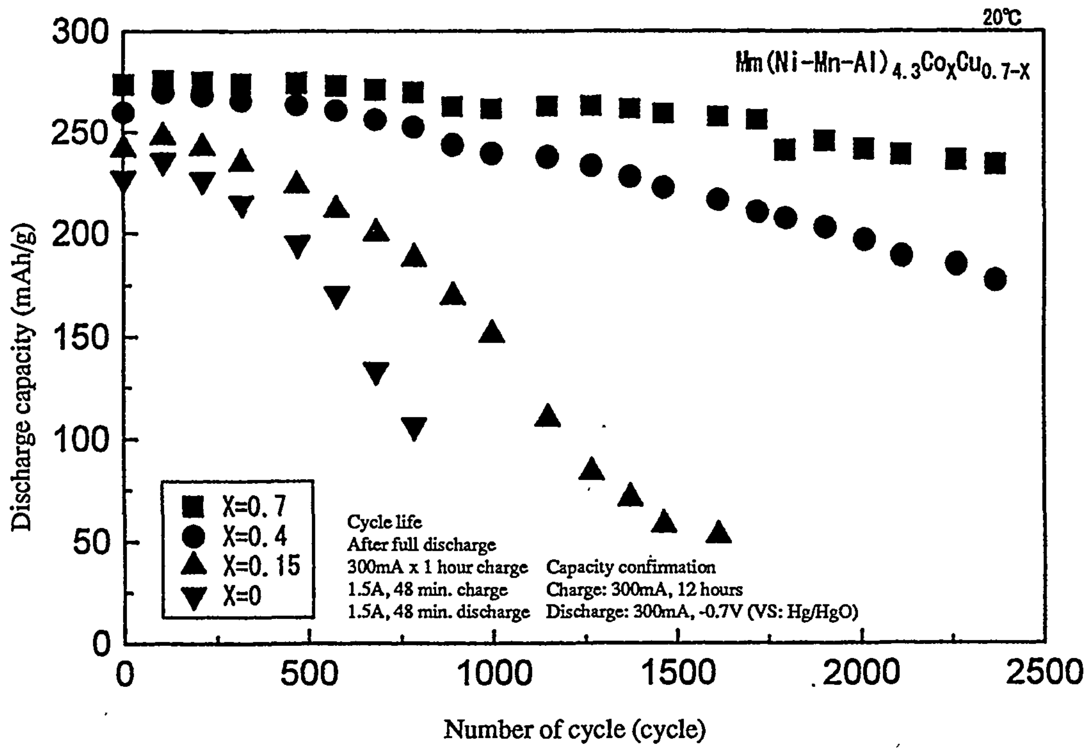


Fig. 1 Effects of Co Quantity Substitution for Cu

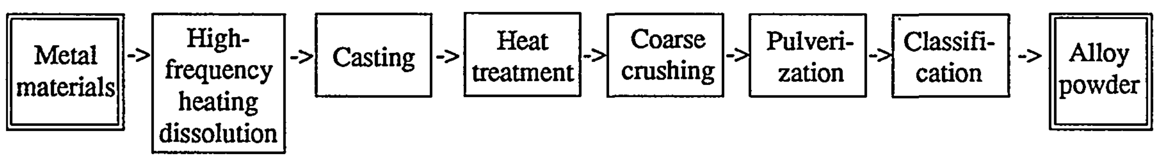


Fig. 2 Alloy Powder Manufacturing Process

structure, however, they posed such problems as difficulty in forming a conductive network, dislocation of active electrode substances, etc. As a result, new electrode supports which were claimed to be comparable to the three-dimensional type were developed by sophisticated machining of thin porous plates. The characteristics (especially the cycle life) of electrode supported by them are undergoing evaluation.

(3) Future Tasks

The hydrogen storage electrode (negative electrode) structuring method will be established in terms of both materials and manufacturing methods and cost reducing possibilities will be identified. As for nickel electrodes (positive electrodes) a life elongation technology will be established for electrodes where cost reduction is considered more feasible. In addition, the manufacturing conditions of cells scaled for practical use will be established, the cell characteristics evaluated and the target follow-through rate determined.

5.4.2 Development of Redox Flow Batteries for Photovoltaic Power Generation

(1) Objectives and Work Program

(Objectives)

As a storage battery device to be applied to a photovoltaic power generation system, technology for practical use of high-power, low-cost batteries will be developed.
Power output: 1.5kW/m^2 of electrode area
Cost: ¥14/Wh (50kW x 50-hour storage capacity, at an annual output of 200MWh).
Battery life: 20 years

(Work Program)

(a) Development of electrolyte manufacturing technology

(b) Development of battery system

(2) Summary for FY1994

(a) Development of electrolyte manufacturing technology

(i) Study on electrolyte manufacturing method

A process was established for manufacturing trivalent and tetravalent electrolytes by reducing, with sulfur vanadium, compounds of high purity from ammonium metavanadate recovered from boilers.

As the reaction conditions of trivalent electrolyte manufacture are severe, reaction bath material selection for industrialization is rather difficult and likely to lead to a cost increase. For this reason, a hydrogen reduction method more advantageous for industrialization of trivalent electrolyte production was studied, basic technology established and an apparatus with a daily manufacturing capacity of 5L completed. A fair prospect is thus obtained for reduction of the electrolyte manufacturing cost on an industrial scale. Fig. 3 compares the two electrolyte manufacturing methods.

(ii) Evaluation of performance and stability of electrolyte

A week-long continuous charging/discharging test was carried out with mini-cells using the vanadium electrolyte thus manufactured and problem-free applicability confirmed. In order to check if the electrolyte manufactured will stay useful for a long time, its properties and stability are under test with an electrolyte performance evaluation apparatus.

(b) Development of battery system

(i) Evaluation using mini-cells

Electrode integrated cells using electroconductive resins were tested and a performance level equal to the one attained with carbon plates was realized. For further improvement of cell performance, the electrode structure was made dual-phased by combining the carbon electrode of high reactivity and carbon electrode of high electroconductivity. This arrangement is expected to contribute to cell cost reduction.

(ii) Fabrication of 2kW batteries

The 2kW batteries fabricated last

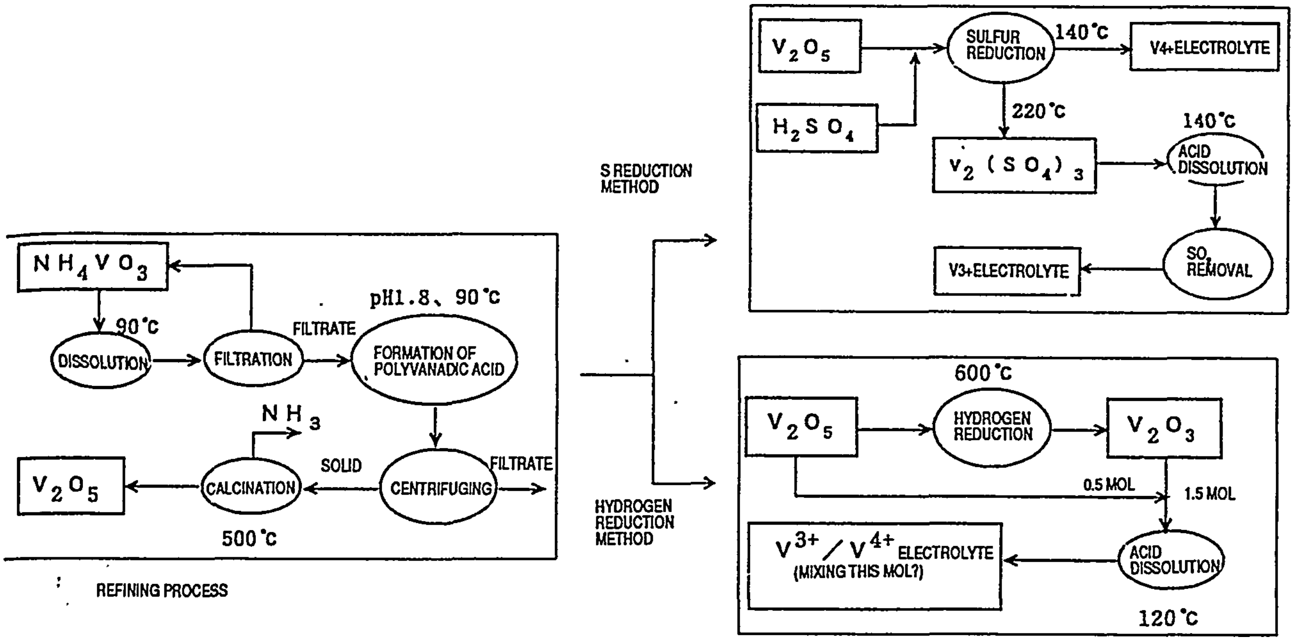


Fig. 3 Comparison of Electrolyte Manufacturing Methods

fiscal year were improved and operated for performance evaluation. The power efficiency of 80%, which was very close to the final target, was attained at a current density of 100mA/cm^2.

(3) Future Tasks

(a) Development of electrolyte manufacturing process

As the vanadium trioxide produced by reducing vanadium pentoxide with hydrogen is slow to dissolve in a sulfuric acid solution, the shapes of crystals and method for prompt dissolution will have to be studied. A key point will also lie in determining the permissible concentration of impurities in raw materials and improving the long-term charging and discharging characteristics and electrolyte stability.

(b) Development of high-power cell stacks

In order to generate high power it is necessary to feed large amounts of electrolyte to cells. This calls for selection of electrode materials of smaller flow resistance and improvement of the stack design. The corrosion resistance, physical strength and other characteristics of membranes have also to be improved.

5.5 Meteorological Analysis for Design of Photovoltaic Power Generation Systems

(1) Objectives and Work Program

(Objectives)

The hourly METPV (Meteorological Test data for Photovoltaic system) for detailed planning and design of photovoltaic power generation application systems will be collected at official meteorological stations (about 150 stations) in Japan and processed.

(Work Program)

(a) Study on METPV selection standard from standpoint of photovoltaic power generation systems

(b) Development of full-sky solar radiation intensity estimation model based on data collected with rotary heliographs

(c) Collection and processing of METPV

(2) Summary for FY1994

(a) Study on METPV selection standard from standpoint of photovoltaic power generation systems

The aim was to identify the most representative year by screening observation data over a long time and to process the data of the year thus selected for input into the photovoltaic power generation system output calculation. Through examination of various meteorological elements, METPV was sought to be set as itemized as shown in Table 1.

The average hourly METPV for a year was prepared by selecting from the past data years having a month or months whose solar radiation intensity stood at or closest to a mean (mean years) and combining the monthly data of the 12 months to compile data for one year. In addition, the years with too much and too little solar radiation intensity were selected based on actual data collected in the summer (May–August) and winter (November–February) and the hourly data in these periods was collected and processed. For representative year selection, Japan was divided into 26 sunlight climate zones as shown in Fig. 4 and a representative year for each zone was selected by analyzing the daily data of the representative 26 stations for the 9-year period from 1986 to 1994, taking into account the monthly mean data and frequency distribution.

(b) Development of full sky solar radiation intensity estimation model based on data collected using rotary heliographs

The official stations engaged in observation of full sky solar radiation intensity are located at 67 stations in Japan. In order to prepare the nationwide METPV it is necessary to estimate the full sky solar rotation intensity from the sunshine duration observed at all of these stations. A model was developed for the purpose. For this development, data was collected at 26 stations representing illumination climate zones in Ja-

Table 1 Standard Meteorological Data to Be Prepared

Meteorological Test Data for Photovoltaic System
Global solar radiation intensity on horizontal surface
Direct solar radiation intensity on horizontal surface
Sky solar radiation intensity on horizontal surface
Solar radiation intensity on inclined surface
Duration of sunshine
Temperature
Wind direction and speed
Depth of snow fall
Depth of snow

pan. Specifically, sunshine duration, solar altitude, snow depth, etc. went into development of this model to estimate the time-integrated full sky solar radiation intensity from the hourly sunshine duration data.

(3) Future Tasks

(a) Study on monthly data linking method

Using the hourly data selected this fiscal year, a technique will be developed for linking the monthly data without incongruence.

(b) Development of METPV

METPV will be developed to cover official meteorological stations located at about 150 stations in Japan.

5.6 Research on Utilization Systems, Etc.

5.6.1 Survey on Specific Purpose Modules

(1) Objectives and Work Program

(Objectives)

In order to facilitate expanded use of photovoltaic power generation, research will be made on low-cost durable new types of modules suitable for different purposes, guidelines regarding module specifications for different applications will be spelled out, and development guidelines and policies will be proposed.

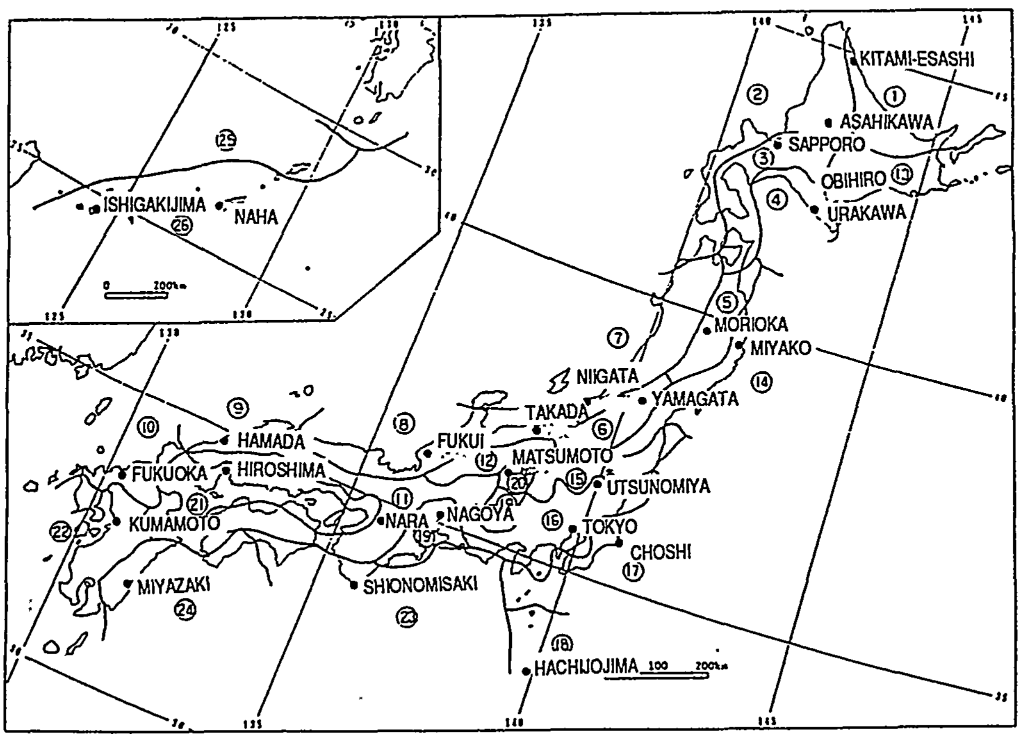


Fig. 4 Location of the 26 Representative Stations

(Work Program)

An expert Working Group on Specific Purpose Modules will be organized to investigate the latest technologies and technical trends concerning the development of specific purpose modules.

(a) Investigation of new types of modules

- Investigation of possible new areas of utilization
- Study on modules suitable for different applications
- Search for new materials and investigation regarding development of materials
- Study on compatibility with different institutional arrangements
- Study on proposed module development plans for different purposes

(b) Investigation of domestic and overseas technical trends

(2) Summary for FY1994

(a) Contents of progress

(i) Feasibility study concerning new fields of utilization

It was learned that large areas including farm land, roads, railroads, public facilities, etc. would be available. As for endurance, it was found necessary to examine the issue from the standpoints of materials and structure, also taking cost into account.

(ii) Study on optimum modules for different applications

Applications were divided into the categories of desert and barren land, coast and ocean, river banks, railroads and roads, mobile systems, shopping arcades, curved surfaces and roofs and others. The structure, manufacturing method, cost and tasks were examined for each. Standardization was necessary from the cost standpoint and modules of larger size were found more advantageous. It was also learned that restrictions were inevitable from the standpoints of strength and harmony with the environment.

(iii) Search for new materials and survey on materials development

It was learned that the use of existing materials for higher endurance would lead to increased costs. It is considered necessary to develop less costly materials that would also deliver the necessary characteristics (water resistance, humidity resistance, flame retardancy, etc.).

(iv) Development plan drafting

The development items, tasks, periods, costs, etc. necessary for development suitable for various applications were estimated. Concrete actions to be taken hereafter for a typical case were examined. The development period will be three to five years. Joint research setups between material makers and solar cell makers are necessary to deal with tasks involving materials development.

(v) Investigation of technological trends

a. 1st World Conference on Photovoltaic Energy Conversion (WCPEC)

As part of the research on specific purpose modules, technological trends presented at WCPEC were investigated.

Reflecting the recently growing interest in photovoltaic power generation, more than 600 papers on results of the latest research were published covering every field from materials to systems. In the module-related field, papers on construction material-integrated modules attracted attention.

b. Photovoltaic Power System Workshop

Starting with system components such as cells, modules, batteries and inverters, the themes covered by PVDAC — that is, system design, execution, operation, maintenance, overseas development support programs and so on — were thoroughly covered.

(3) Future Tasks

The research described was carried out from fiscal 1993 to fiscal 1994.

In this period the current modules were studied and the optimum module structure and necessary materials for various applications were considered in terms of function. A development plan was drafted to sum up the research results.

Seeking an optimum module for each application will lead to a disturbing lack of uniformity in size and different materials will have to be used. From the cost standpoint, grouping and standardization are considered necessary.

Unit structure by standardization will lead to cost reduction through mass production. It is especially necessary to reduce costs while seeking improvement of quality of materials including frame materials. As the application of current materials means higher costs, materials development including that for new materials is strongly urged.

5.6.2 Research on PV Utilization Systems

(1) Objectives and Work Program

(Objectives)

Solutions to various problems that may arise in the surface area development of photovoltaic power generation systems, including those related to aesthetics and regulation by the public authorities, will be studied, and investigation will be made of developmental techniques for two-dimensional systems, such as those regarding efficient utilization of limited space and how the optimal system should be oriented. Furthermore, the functions and specifications needed to adapt various structures and facilities to photovoltaic power generation will be studied, together with the possibility of cost reduction through standardization, and at the same time the impact of surface area development on the utility power supply system, as well as its positive benefits, will be clarified.

(Work Program)

(a) Examination of investigation approach

Approach methods for realizing the basic scenario of two-dimensional photovoltaic power generation system development will be examined.

(b) PV community case study

For cases where photovoltaic power generation is expected to be introduced, specific locations will be selected and evaluated together with investigation and examination.

(c) Preparation of development scenario

A development scenario will be prepared reflecting the results of the case study of (b), above.

(2) Summary for FY1994

(a) Examination of investigation approach

Based on the results of study in fiscal 1993, the surface area development concept was defined to seek a maximum installation area and minimum cost of PV systems, taking into account the aesthetic and environmental protection requirements. In order to realize the basic scenario, study and investigation were carried out in the following order.

(i) Identification of positions and locations for installation (improvement of utilization efficiency).

(ii) Isolating element techniques centering on the array architecture.

(iii) Study on optimization of total systems (making up the core for surface area development).

(iv) PV community case study (specific examination of individual elements).

(v) Examination of the effect and influence of surface area development (examination of installable amounts of area, cost-reducing effect, etc.).

(vi) Identification of problematical points and study on measures for settling them.

(vii) Preparation of a development scenario.

(b) PV community case study

Concrete areas were selected, investigated and examined as to cases assumed.

(i) Housing district type

The Seibu Kitanodai Housing Complex (mostly single family homes) and Tama New Town Suwa Zone (mostly apartment houses) were selected.

PV systems will be installed on roofs, walls and windows of buildings in these districts.

In single family homes the generated wattage will be three to four times as much as consumption while the amounts will be about even in apartment houses.

The environmental, aesthetic and visual aspects are especially important as these are residents' immediate living places.

Safety demands full consideration as the systems will be installed very close to residents.

Judging from the housing plan up to 2000, demand for about 380MW (268MW for single family homes and 114MW for apartment units) is expected to materialize.

(ii) Commercial district type

The Akikawa Shopping Center was selected as a suburban commercial facility of new type. The Brandome Ichiban-Cho Arcade, Sendai, was selected to promote development or activation of an old commercial street with PV system installation.

In the Akikawa Shopping Center PV systems will be installed on rooftops and outer walls of buildings. The PV generated wattage will be about 480kW, accounting for roughly 7% of the total power consumption.

In the Ichiban-Cho Arcade the yearly PV power supply rate will be about 124.2%, assuming the generated wattage of about 150KW for the ceiling opening rate of 50% and lighting at the rate of 4 hr/day.

The suppliable amount of electricity is estimated to be about 41MW for the Akikawa Shopping Center and about 95MW for the Ichiban-Cho Arcade.

(iii) Central urban area type

Ebisu Garden Place, a complex of offices, hotels, housing, cultural facilities, etc., was selected.

In the high-rise building area the

effect of shadows cast by adjacent buildings and so on is unavoidable. The PV system utilization rate will turn out to be quite small if only locations of favorable solar radiation conditions are considered.

PV system installation on the greatest possible degree on outer walls, roof tops, and so on will be able to deliver about 4.6MW for commercial buildings (hotel and office buildings) and about 0.9MW for residential buildings.

The PV power supply rate can be expected to be more than 10% for hotel and office buildings, 20% for high-rise residential buildings of more than 30 stories and more than 30% for residential buildings of 10-plus stories.

The space available for PV system installation in high-rise office buildings in the center of Tokyo alone is such that a yearly generated wattage of about 4.4MW is feasible.

(iv) Industrial district type

Working from the national industrial complex statistics, the Sakura No. 3 Industrial Complex was selected.

PV system application on roofs, walls, parking lots and street lamps of main roads will be able to deliver about 21MW from roof systems, about 6MW from wall systems and about 9 MW from parking lot systems.

The generated wattage depends on the shape and azimuth of roofs. As low and flat buildings make up the majority in this case, the effect on the yearly generated wattage is not pronounced.

The maximum generated wattage will be almost equal to the power consumption on weekdays. Thus the yearly PV power supply rate will be very high, taking into account the cross-currents on holidays.

PV system installability amounting to 3,000,000kW of steam power generation is expected to materialize.

(v) Overall evaluation

Judging from location conditions in Japan, the development of PV systems built into housing and building structures will be approached with the emphasis on surface area for the time being. In this sense the building material-integrated modules under development will be essential. It is also necessary to develop new modules.

Optimization of not only costs but also design aspects is especially important. It is necessary for PV systems to be made attractive to housing technical experts, contractors, distributors, etc.

By examining PV system compatibility with specific buildings and estimating the installable area of PV systems by expanding the compatibility data, quite large values result for all these cases. Collective placement of orders to meet this demand and mass production effect make it very possible to reduce costs by a large margin.

Furthermore, it is necessary to form disaster-response communities where PV systems are installed in schools, gyms and other public buildings as security systems to be called upon at times of such disasters as earthquakes and typhoons.

(c) Preparation of development scenario

It is thought that surface area development for PV systems should be promoted according to the basic scenario shown in the last section. Unlike previous cases in which individuals and corporations installed PV systems in various districts without uniformity, installation of many PV systems in one district means that not PV system makers but housing developers, third-sector corporations for regional redevelopment and the like will take the initiative in PV system development and application.

To promote surface area development for PV systems, some incentives are necessary. For instance, these incentives may be loans at low interest rates for districts seeking PV system installation, tax exemption for promotional bodies, and promotional assistance for the organization of marketing and maintenance networks on a district-by-district basis.

(3) Future Tasks

From the case study assuming specific districts for PV system installation the following tasks were singled out. For the surface area development of photovoltaic power generation it is necessary to accomplish these tasks.

(a) Technology for integration with low-cost building materials such as siding board, ALC and RC slabs, corrugated sheets, etc.

(b) Development of new modules such as those for shopping arcade application.

(c) Development and standardization of execution procedures for installation on balconies, eaves, etc.

(d) Development of daily solar radiation intensity estimation techniques, taking into account the effect of shadows, reflection, etc. in high-rise building areas in the center of larger cities.

(e) Development of DC collection and distribution methods, power quality improvement technology, storage battery use stabilization and application technology, etc.

(f) Development of setups and methods for PV community management and administration.

5.6.3 Evaluation of Photovoltaic Power Generation

(1) Objectives and Work Program

(Objectives)

The value of using photovoltaic power generation to the global environment, the electric power supply and the economy in general, among others, will be assessed in a broad perspective.

(Work Program)

(a) Research on evaluation techniques for energy payback time

Highly reliable calculation techniques will be established for the energy payback time of photovoltaic power generation in its different modes of utilization.

(b) Research on evaluation techniques for environmental contributions

The effects of using photovoltaic power generation to restrain the quantities of generated NOx, SOx and CO_2 will be calculated, and study will be made on the quantification of its environmental contributions including the suppression of acid rain and global warming, savings in the costs of environmental conservation measures, and the safety aspects of the production, use and scrapping of PV cells.

(c) Survey on potential scale of introduction of photovoltaic power generation

The areas available for the installation of PV arrays will be surveyed on a nationwide scale, and the suitable modes of introduction in those areas will be classified, together with the estimation of the possible wattage that can be generated in each area.

(d) Evaluation of contributions to existing power supply systems

The economic impacts of the use of photovoltaic power generation on such aspects as the cost of power generation, load pattern and rate structure will be quantitatively assessed.

(e) Overall evaluation

Photovoltaic power generation will be evaluated in a broad perspective, taking account of its economic and social implications.

(2) Summary for FY1994

(a) Research on evaluation techniques for energy payback time

The energy payback time (EPT) evaluation techniques are broadly divided into those which calculate EPT by adding up the energy inputs in a certain power generation system and those which use the industrial association tables.

A recent survey on the results of research using the industrial association tables of Japan revealed that the EPT values turned out to be somewhat larger than the values found by the add-up method and that the indirect energy inputs could not be ignored. It was also learned that the major portion of the energy inputs tends to be accounted for by certain types of materials. A more precise estimation of costs of these materials was thus found necessary for more accurate calculation of EPT.

EPT differs with the scale of production and type of installation (on-roof or building material-integrated type). With the production scale of 10MW almost directly feasible with the current technology, it is 2.4 years for the on-roof polycrystalline type and 2.1 years for its building material-integrated counterpart. It is 2.1 years and 1.6 years respectively for the amorphous type. EPT is shorter more or less with the amorphous type.

(b) Research on evaluation techniques for environmental contributions

Needless to say, the value of the amount of CO_2 reduced and the CO_2 reduction cost are relative based on the results of comparison with comparable power generation systems. The amount of CO_2 reduced and the CO_2 reduction cost are calculated below against the average power delivered by the typical Japanese electric power supply setup consisting of coal-, petroleum- and natural gas-fired thermal power generation systems.

The amount of CO_2 emission reduced per kWh due to installation of a comparable photovoltaic power generation system was found as follows.

$\Delta(CO_2)$ [g-C/kWh] = (CO_2)fossil − (CO_2)PV — (1)

where

(CO_2)fossil: CO_2 emission physical unit of existing electric power [g-C/kWh]

(CO_2)PV: CO_2 emission physical unit of photovoltaic power generation [g-C/kWh]

Furthermore, assuming the cost increase per kWh where a photovoltaic power generation system replaces a comparable existing thermal power system as the cost of reducing CO_2 by the amount found by (1), the CO_2 emission reduction cost of photovoltaic power generation can be defined as expression (2) below.

$$cCO_2 = (CPV - Cfossil)/\Delta(CO_2) \text{ — (2)}$$

where

- cCO_2: CO_2 emission reduction cost of the photovoltaic power generation system [¥/g-c]
- CPV: Photovoltaic power generation cost [¥/kWh]
- Cfossil: Existing power generation cost [¥/kWh]

As a result, it was learned that even the building material-integrated system using amorphous solar cells of the generation scale of 100 MW/year, which was expected to be least expensive and low in CO_2 emission, was more costly than comparable thermal power generation plants in terms of CO_2 emission reduction.

These results reveal the need to identify the position of photovoltaic power generation systems in society and clarifying the framework for their evaluation in order to consider the extent of their environmental contribution. It is necessary to work out an agreement on the position in society as a whole of photovoltaic power generation systems for evaluation and define clearly the framework for their evaluation.

(c) Survey on potential scale of introduction of photovoltaic power generation

Surveys had been carried out to estimate the potential scale of introduction of solar cells. In fiscal 1993 the techniques used in these surveys were arranged in order. At the same time potential destinations of introduction not covered by previous surveys were singled out. In fiscal 1994 the values based on previous survey results were put in order and the potential scale of introduction of photovoltaic power generation in Japan was roughly calculated. It stood at about 191GWp although restriction-free circumstances were assumed. Compared with the current power generation capacity in Japan the value was concluded to be fairly large.

In addition, to consider the potential scale of introduction abroad, the potential demand for village power supply and water pumping services in developing countries was roughly calculated based on existing data and markets in solar cell-mounted products were also examined.

The results of nonconditional rough calculation show the ideal and final amounts of introduction. Therefore, it is necessary to find the appropriate scale of introduction, taking into account the intentions of the organizations responsible for introduction and institutional and technical factors which may restrict introduction.

(d) Evaluation of contribution to existing power supply systems

(i) Survey on system load patterns

As the evaluation of the contribution of photovoltaic power generation boils down to the evaluation of its consistency with the load patterns of users, distribution lines and power systems, a survey was carried out on the load patterns that could be models for examination.

a. Basic survey on distribution line load pattern

The results of investigation published in the "Development of New Cell Power Storage Systems" of NEDO were used as distribution load data. In this NEDO research a total of 87,246 banks of distribution substations in the four electric power districts of Tokyo, Chubu, Kansai and Shikoku were considered and the daily load curves for one year of monthly averages were developed into models.

As for the household load pattern, there is no published data available and we would like to wait for the results of the "Demonstration Test for Establishment of Household Photovoltaic Power generation Load Leveling Technology and Others," a new NEDO project.

b. Basic survey on system load pattern

In order to promote the evaluation of usefulness of photovoltaic power generation as a system power source, the system load pattern at the peak load and its power source composition ratio and power generation costs were investigated and examined. It was learned that the power generation cost of the system power source as a whole was in the ¥10–11/kWh range. It was about ¥15/kWh or so at most, even when account was taken only of the pumping power and interchange power for demand and supply balance adjustment. For this reason it was learned that not only the simple generation capacity but also new added value potentials making the most of the characteristics as decentralized power sources within a demand district had to be considered in respect to photovoltaic power generation.

(ii) Study on forms of application of photovoltaic power generation

By making the most of the potential hardware capabilities of photovoltaic power generation systems, it was considered possible to develop new value added such as contributing to household and distribution line voltage adjustment, improving the quality of electric power and as backing up power sources against interruption of normal power supply or occurrence of accidents.

The necessary functions for these forms of application were studied. It was learned that building storage batteries of very small capacity in interconnection systems would be very useful.

(iii) Evaluation of the value of photovoltaic power generation

Techniques for evaluating the value of photovoltaic power generation as a system power source were examined. At the same time a survey was carried out on cost trends hereafter and basic cost evaluation made. The results showed that cost situations would be very severe even if the development targets, say, of NEDO were accomplished completely. It was thus learned that, as seen in the instance of Pacific Gas and Electric Co. (PG&E) of the U.S., various meritorious points conceivable from the practicality standpoint would have to be added up, as would the advantages in terms of power transmission and distribution, environmental protection, etc.

These issues will be examined in detail in the coming fiscal year.

(e) Overall evaluation

Of late the external cost is a popular theme of discussion in relation to energy. This external cost means the cost not reflected in the market price but passed on to third parties not directly related to production or to future generations. This concept should definitely be reflected in the evaluation of photovoltaic power generation. In and after fiscal 1993 attention was paid to this external cost and external cost items listed by each researcher were screened and arranged in order by referencing existing documented information. In fiscal 1994 attention was centered on specific calculation techniques and techniques for calculation of the effect on people, etc. were developed.

On the other hand, although there is no reliable instance of an overall and quantitative evaluation of photovoltaic power generation, there are several cases where the energy field or other fields are put to overall evaluation according to multidimensional scales. In this connection, study was made on proper evaluation indexes for multidimensional evaluation. As a result, a monetary index was judged to have high validity.

Based on the above, study on overall evaluation techniques using the external cost was started and the matters to be noted in evaluation — for instance, value added of photovoltaic power generation — were set in order. Including in the external cost category of evaluation the expense of countermeasures against resource conflicts and referring to the usefulness of the power source as a value added item to give a feeling of hope and security in the event of an accident — these were pointed out in particular as matters that should be kept in mind.

(3) Future Tasks

(a) Research on evaluation techniques for energy payback time (EPT)

The sunshine conditions will be investigated by district. The on-roof system outputs will be roughly calculated by district. Then EPT will be calculated on a trial basis using the results of the foregoing and energy input found in fiscal 1994.

(b) Research on evaluation techniques for environmental contribution

Attention will be paid to emissions other than CO_2 and the effect and cost of their reduction by photovoltaic power generation will be roughly calculated. In addition, the life cycle assessment (LCA) of photovoltaic power generation will be carried out for the first time in step with overall evaluation efforts.

(c) Survey on potential scale of introduction of photovoltaic power generation

By incorporating the latest statistics published at home and abroad the results of rough calculation up to fiscal 1994 will be updated. At the same time, processes for meeting the potential demand will be studied.

In addition, the quantitative grasp of restrictive conditions concerning introduction of photovoltaic power generation will be sought and techniques for reflecting them in calculation of the potential scale of introduction will be studied.

(d) Evaluation of contribution to existing power supply systems

The value of photovoltaic power generation as a system power source, its economic aspects, optimum system configuration, etc., will be examined, in an effort to identify the form of application that can make a greater contribution to existing power systems. At the same time, the contribution will be evaluated in specific terms.

(e) Overall evaluation

A photovoltaic power generation external cost system will be developed and an overall evaluation technique reflecting in specific terms the results of (a) through (d) will be established and evaluated.

5.6.4 Research on Large-Scale Energy Supply Systems

(1) Objectives and Work Program

(Objectives)

Optimization of large photovoltaic power generation systems will be studied for application to large-scale energy supply systems. Furthermore, specific types of large photovoltaic power generation systems will be studied.

(Work Program)

(a) Optimization study on large systems

Study will be made on problems in large systems, how the optimal system should be oriented, problems in modules and peripheral devices, problems in construction and maintenance and calculation of system costs.

(b) Optimization of large-scale transfer systems

Study will be made on selection of means of transfer of electric power, calculation of system costs, etc.

(c) Impacts of large systems

Likely environmental and social impacts will be assessed and studied.

(d) Selection of proper sites

The meteorological conditions, social and economic conditions, relations with Japan and other possibilities will be examined.

(e) Development scenario

A scenario for large-scale system development will be prepared based on results of (a) through (d).

(2) Summary for FY1994

(a) Study on optimization of large-scale systems

A rough design was prepared of a model system that would be referenced in actually constructing a large-scale centralized photovoltaic power generation system in a desert area.

The design philosophy was to construct not a single system having a generation capacity of hundreds of thousands of kilowatts but a hierarchy of small-scale unit systems.

As a result of examination, a power generation system of 250 kW x 2 = 500 kW was selected as the smallest unit.

The meteorological conditions of inland areas of China were considered in preparing the racks and engineering designs. As there is no threat of typhoons in these areas, the wind velocity and other conditions assumed were less severe than those applicable in Japan.

In rough cost estimation, account was taken of the personnel expense situation in China. As things stand presently, it was only possible to assume conditions in Japan as to the procurement, etc., of cells and other equipment. Furthermore, the scale merit and so on were not considered. Thus, the results of rough calculation could not be said to be very reliable. They showed, however, that the design would be feasible. It is desirable to calculate rough costs again after collecting information based on a survey of the local economic environment.

(b) Optimization of large-scale transfer system

Overhead AC transmission, overhead DC transmission, superconductive transmission, hydrogen gas pipelines and LH_2 tankers are considered to have good prospects as systems to transfer electric power generated by large-scale photovoltaic power generation stations.

Power system transmission by AC or DC transmission usually makes the most efficient system for electric power transfer. Generally AC transmission is considered to be more economical. As there is a stability limit in the transfer capacity for AC transmission power, however, the electric power that can be transmitted is reduced as the transmission distance increases. The economy of DC transmission increases proportionately.

Superconductive power transmission technology is under development. As it is possible to transmit power at a power density 10 times that of previous transmission methods, it is considered useful especially for transmission of power of more than several gigawatts (GW). If the reliability of conduction and cooling systems proves to be high enough, it will make a promising candidate for large-capacity power transmission.

Systems whereby the electric power generated by thermal, hydraulic or nuclear power stations is converted to hydrogen gas and transferred by pipeline are reported to have an economic equilibrium distance against AC power transmission in the 320–1,000 km range.

LH_2 tankers are the most promising means of ocean transfer of electric power. Converting electric power into LH_2 is handicapped by relatively large energy losses, but its necessity will be most appreciated if the use of hydrogen gas engines spreads to such means of transportation as jet liners and automobiles, not to mention the ocean transfer of electric power.

(c) Impacts of large-scale systems

The impacts of large-scale developments such as those involving power generation plants are broadly divided into three categories: impacts on the air, impacts on the natural environment and impacts on the social environment. Their causes and the concepts for their evaluation were screened and arranged in order.

(i) Impacts on the air

When China is assumed to be the proper site, large-scale photovoltaic power generation, replacing thermal power generation, is expected to contribute to the reduction of pollutants. The amount of discharges of sulfur oxides, etc. per unit of the wattage generated at mostly coal-fired Chinese power stations is very large.

(ii) Impacts on the natural environment

When a desert is assumed to be a site of a large-scale photovoltaic power generation system, the local heat balance, water balance, wind conditions, etc. will be affected. But the negative effect will at least be slow to develop. This can be proven by applying existing evaluation techniques.

On the other hand, the impact of salt deposition demands attention, although it remains to be understood specifically regarding the natural conditions of an actual site.

(iii) Impacts on the social environment

In considering the impact on the social environment it is necessary to assume the process from the construction of a large-scale photovoltaic power generation system to the actual power generation and system management.

The impacts considered important are as follows.

- Employment effect and economic effect associated with construction.
- Contribution to improvement of power situations and industrial development through supply of electric power.

(d) Selection of proper sites

When selecting a proper site for construction of a large-scale photovoltaic power generation system, it is important to consider natural and social conditions and so on that will affect the construction of the system in addition to the scale of the anticipated demand.

In selecting candidate sites for large-scale systems, meteorological conditions, social and economic conditions, relations with Japan, etc. were considered as index factors and China was selected. Furthermore, of the deserts in inland China six were selected as candidate sites.

In order to select proper sites from these six deserts the Analytic Hierarchy Process (AHP) method was adopted. As a result, the following three were concluded to be proper sites on the strength of superior materials availability and electric power transfer capacity and large demand in neighboring areas.

- Hobq Shamo
- MuUs Shamo
- Horgin Shamo

(e) Development scenario

The development scenario aiming at a large-scale energy supply system in a desert in China consists of three steps, taking into account the current situations of photovoltaic power generation and large-scale systems in China: the first step is to install a 500KW PV plant for research, the second step is to build a 10MW demonstration system, and the third step is to construct large-scale systems.

In the first step, research and development will be carried out on an optimum system to operate under unknown conditions a desert will impose. As actual results are almost nonexistent for large-scale systems for deserts, it will be necessary to develop modules, inverter racks, etc. most suitable for the desert environment. The endurance of the system under desert conditions will also be studied. Furthermore, such issues as localization of PV power generation system production and technology transfer will be examined. The Unkakukai Development Pattern-Setting Zone is considered to be the most promising candidate site of the research plant as a result of the "selection of proper sites."

In the second step, a system of minimal scale consisting of several tens of units, for instance, a 10MW scale system, will be built to demonstrate the economy, reliability, etc. of large-scale systems. In this step problematical points in interconnection in large-scale systems will be settled and operation and maintenance techniques will be established.

In the third step, large-scale PV power generation plants of 1GW class will be considered for installation in deserts of inland China and their vicinity, taking into account the growth of electric power demand in China, global environmental issues, possibilities of the growth of PV-related industries into new key industries in China, etc.

(3) Future Tasks

Based on the results of the investigation and research in fiscal 1994, investigation and research in and after fiscal 1995 will center on the following to identify possibilities of large-scale PV power generation systems in a desert environment.

(a) Optimization of large-scale systems

Natural conditions in deserts in inland China will be grasped more accurately and a conceptual design of the demonstration system will be prepared. Furthermore, study will continue on solar cell modules, overall system configuration, methods of linking with existing power networks, etc.

(b) Selection of proper sites

Problematical points in building plants in deserts and tasks will be identified. Comparison will be made with other electric power source development projects and decentralized PV power generation systems. Contribution to environmental protection, etc. will be examined. These will aim at clarifying the technical, economic and social possibilities of large-scale PV power generation systems in a desert environment.

(c) Development scenario

Demonstration system test program drafts will be considered and large-scale PV power generation system promotional measures and system introduction and development will be studied.

5.6.5 Investigation on High Endurance and Low Cost Materials and Structures for Photovoltaic Modules

(1) Objectives and Work Program

(Objectives)

In order to promote the spread of photovoltaic power generation systems by reducing their generation cost to a level consistent with the selling price, solar cell modules that excel in cost aspects or endurance or both are in need of development.

On the other hand, research to date on solar cells has almost entirely centered on improvement of the performance or costs of cells themselves. The number of instances of research on peripheral materials such as window and filling materials of cells or module sealing materials and members is small. If there are such instances, they are not promoted systematically as such. This program aims at systematic investigation on improvement of endurance (target: 30 years) and reduction of cost (plastic materials that will be assured of a service life of 20 years or so) and flame-resistant materials and structures for solar cell modules. The feasibility of the targets of improvement of materials and structures, their combined application, etc. will also be studied.

(Work Program)

(a) Investigation on transparent plastic materials for high-endurance, low-cost photovoltaic modules

Instances of application of transparent materials to solar cells will be investigated to grasp the current state of transparent materials development, characteristics required of them and tasks and problematical points in their application.

In addition, the applicability of reforming technology for transparent plastic materials for solar cells will be considered, leading to feasibility studies and overall consideration of development targets, development methods, etc. for the future.

(b) Investigation on sealing materials for high-endurance, low-cost photovoltaic modules

Instances of photovoltaic module sealing will be investigated to grasp tasks and problematical points in current situations concerning module sealing.

In addition, application possibilities of reforming technologies of sealing materials for solar cells will be considered, leading to feasibility studies and overall consideration of development targets, development methods, etc. in the future.

(2) Summary for FY1994

(a) Investigation on transparent plastic materials for high-endurance, low-cost solar cell modules

(i) Grasp of state of development of transparent plastic materials for solar cell modules, tasks and problematical points

Judging from patents granted or applied for, trends in application of transparent plastic materials center on fluorocarbon resins, PET, acryl and polyimide as surface materials and EVA, silicon and PVB as filling materials.

Synthetic resin applications for which patents are granted or applied for can be summarized as below.

a. Use of fluorocarbon resin-based materials as surface materials

As fluorocarbon resin materials are expensive, transparent resins which are less expensive are used to provide mechanical strength and fluorocarbon resins are coated over the surface for improvement of moisture resistance, etc.

The light transmittance of surface materials is improved using the low index of refraction of fluorocarbon resins.

b. Impregnation of fluorescent materials in resins

This aims to improve the UV resistance of resins and make effective use of previously ineffective sunlight components.

c. Mold structure having cells embedded in transparent resins

The application of transparent resin materials is expected to shorten the module assembly process by a large margin with corresponding improvement of productivity.

d. Molecular structure of resins with specific copolymerized oligomers and their manufacturing methods

Standards on solar cell modules are established in various countries including Japan. International standardization is under study by IEC and much is expected to come from that.

Distinctive features of synthetic reins in current use include, for instance, light weight and high crack resistance. Conversely, their demerits such as poor heat resistance, inadequate surface hardness, moisture permeability, etc. remain to be overcome. It is necessary to complete these and other tasks for application of synthetic resins to photovoltaic modules. Presently glass is used exclusively especially as a surface material. The strongest reason is that synthetic resins deteriorate over time because of their poor light and weather resistance.

Unlike surface materials, filling materials are in direct contact with cells and are expected to protect them. In other words, they have to be able to absorb the mechanical stress developed by deformation of cells undergoing expansion or contraction, depending on temperature, etc.

(ii) State of transparent resin materials development in Japan and abroad

Taking into account optical characteristics, mechanical characteristics, chemical characteristics, environmental resistance, etc., only several types of resins are considered to be feasible for application to solar cell modules. They are polycarbonate resins, metacryl resins, fluorocarbon resins, acryl resins and polyester resins. Various derivatives of these resins are developed and available in many product types. They have merits and demerits but their applicability to specific purposes deserves consideration, including improvement of their quality and performance.

(iii) Study on applicability of reforming technology to transparent resin materials

In order to improve the light resistance characteristics, the use of UV absorbing agents is under study. They are added to or coated on synthetic resins. Efforts are also being made to prevent photodeterioration and improve the conversion efficiency of solar cells by mixing fluorescent materials in synthetic resins or coating them on synthetic resin surfaces.

Synthetic resin materials containing –OH, –CONH and –COOH groups excel in heat resistance. Conversely, the presence of $-CH_3$, $-OCH_3$ and –COOR groups means poor heat resistance. In addition, the higher the degree of copolymerization, crystallization and bridging, the poorer the heat resistance. Double bonds and branching tend to spoil heat resistance. Countermeasures include bridge structure adoption and the addition of phenol, amine, phosphor or sulfur based antioxidants and stabilizing agents. But their effect on transparency still remains an issue in need of settlement.

Glass coating is adopted for surface reinforcement.

In any case, it is difficult to overcome the current problems such as photodeterioration, surface scratches, etc. with only one type of synthetic resin material presently available. Materials compounding in the broad sense of the word is considered inevitable. In this sense the application of reforming technology is important.

(iv) Consideration of feasibility of transparent resin materials for high-endurance, low-cost solar cells

Compounding holds the key to improvement of the performance of synthetic resin materials. Furthermore, prices pose another major issue. Usually more sophisticated compounding means higher prices. Inexpensive engineering processes and module structures have to be sought at the same time.

Based on these results of investigation, specific measures for improvement were considered, aiming at the realization of transparent resin materials for high-endurance, low-cost solar cells.

The improvement measures were based on the three types of structure — previous-structure type (glass replacement), mold-structure type and replaceable-structure type — and summed up as listed below.

a. Improvement 1 based on fluorocarbon resin
b. Improvement 2 based on fluorocarbon resin
c. Improvement based on polyester resin
d. Improvement based on polyurethane resin
e. Improvement based on polycarbonate resin
f. Improvement based on acryl resin
g. Improvement based on PMMA resin
h. Repair type assuming replacement

(b) Investigation on seal materials for high-endurance, low-cost photovoltaic modules

(i) State of development of seal materials and structures for photovoltaic modules and problematical points

Module structures are mostly of super straight type and seal materials used are butyl rubber, almost without exception. There cases where polyurethane is used, but they are exceptional.

Judging from patents applied for, rubber- and resin-based materials seem to be attracting interest as seal materials.

Seal materials are generally divided between the solid type gaskets and the non-solid type offered in liquid or putty form. Rubber elastic materials are usually used to make solid seal materials. Rubber elastic materials are mainly vulcanized rubber and thermoplastic elastomers which are attracting attention these days. In addition, liquefied rubber and powder rubber have been developed.

Rubber elastic materials which excel in Young's modulus and mechanical characteristics such as compression recovery, are preferred as seal materials. Their superior chemical resistance and heat aging resistance are important factors that insure their use for a long time. Their small moisture permeability is another important factor.

According to a seal material test report, silicon- and polyurethane-based materials showed higher moisture permeability, polysulfide-based samples developed pin holes during a boiling test and were likely to let in water while butyl rubber-based materials were free from any particular trouble and showed favorable results.

(ii) Study on applicability of reforming technology to seal materials

Light stabilizing agents are added in some cases to prevent photodeterioration. Unlike transparent materials, it is not necessary to maintain transparency. This permits the use of carbons, silicons and such like. As shielding offers the best means of preventing photodeterioration, carbonblacks are widely used for this purpose. In order to realize higher weather resistance, it is necessary to improve areas related to temperature rather than areas related to light. The following methods are available to improve heat resistance.

a. Increase in crystallinity.
b. Introduction of polar side chain groups.
c. Introduction of aromatics or heteroaromatic rings to principal or side chains.
d. Formation of bridge between molecules.

(iii) Consideration of feasibility of seal materials for high-endurance, low-cost solar cells

As for seal materials, problems in need of urgent settlement are not pointed out so frequently in respect to butyl rubber in current use. One of the reasons for the popular choice of butyl rubber is the low price. For further improvement of performance it is considered important to lower the total cost by making good use of expensive materials. In addition, it is considered desirable to seek a better effect by combining or blending with other materials.

(3) Future Tasks

(a) Fabrication of solar cell modules using various types of resins and evaluation of their endurance

(b) Analysis of deterioration factors of solar cell modules

(c) Establishment of solar cell module endurance evaluation method

5.6.6 Study of Future Scenarios for Diffusing Photovoltaic Power Generation Systems

(1) Objectives and Work Program

(Objectives)

In order to make clear what measures should be adopted in the national policy for promotion of the practical application and spread of photovoltaic power generation systems, the simulation model developed in fiscal 1993 was used to examine by simulation the necessary policy costs, power generation costs and extent of introduction for realizing the targets set forth in "Basic Guidelines for New Energy Introduction." Political measures which were thought to be necessary were then studied.

(Work Program)

A survey was carried out on the following items.

(a) State of execution of support policies concerning photovoltaic power generation

(b) State of dissemination of photovoltaic power generation

(c) Verification of targets set forth in "Basic Guidelines for New Energy Introduction" by simulation of proliferation

(d) Study on support policy scenario considered necessary for realizing targets and related tasks.

(2) Summary for FY1994

(a) Trends concerning photovoltaic power generation and state of diffusion

Various support policies are in force concerning the introduction of photovoltaic power generation to homes and public facilities. In order to realize the targets set forth in the General Guidelines, it is necessary to reinforce these policies.

(b) Evaluation of introduction targets by simulation of the dissemination schemes

By reinforcing the subsidy and other support policies by a large margin from the current level it is possible to realize the targets set forth in the Basic Guidelines. For this purpose the policy costs especially those of achieving the targets set forth for fiscal 2000 will add up to a sizeable sum as the yearly support on the order of hundreds of ¥100 millions is considered necessary. The scale of financial support after fiscal 2000 will get smaller in step with the progress of cost reduction. It will be reduced to zero when the targets set forth for 2010 are attained.

(c) Dissemination support policy scenario

(i) Enlargement of subsidy activities targetting residential houses

In addition to subsidies currently granted to single family homes, financial support for apartment houses and public housing by local governments are considered necessary.

(ii) Introduction into public facilities by governmental agencies

It is desirable to inaugurate promotional policies for spreading photovoltaic power generation in general fields and introducing it into public facilities.

(iii) Introduction support for private enterprises

Measures considered effective in this category include low-interest loan systems, preferential taxation systems, compulsory use of energy that can be recycled by plants and such like that will consume energy above a certain level, etc.

(iv) Support for facility investment

In order to realize the target of 400MW set forth for fiscal 2000 in the New Energy Introduction General Guidelines, it is necessary to reinforce facilities on a large scale at an early period. The state government is expected to show clearly its long-term policy on support hereafter.

(v) Reinforcement of electric power purchase system

Presently the buying and selling costs are equal. This is not based on law. Electric power companies are not bound to buy power, either. Hereafter, it is desirable to establish a system based on law and grant support to electric power companies in one way or another.

(vi) Others

In addition to putting into effect the support policies mentioned above, it is desirable to settle raw material shortage problems, offer related information and enhance education efforts, etc. to realize the targets.

6. Demonstration Research on Photovoltaic Power Generation Systems

(1) Objectives and Work Program

(Objectives)

Technology for the practical application of photovoltaic/diesel hybrid power generation systems will be developed for use as power sources on remote islands.

(Work Program)

(a) Research on system operation control techniques

(b) Research on optimal system configuration

(2) Summary for FY1994

(a) Research on system operation control techniques

(i) Study on diesel generator operation

method

As a result of simulated operation to minimize the supplementary electric energy, the diesel generation system was set to start when the storage battery residual capacity fell to 20% and to stop when it rose to 30%.

In the operation research period from October, 1994 to March, 1995 the system started 160 times, recording the operation time of 293 hours and specific fuel consumption 0.313 l/kWh. The specific fuel consumption was larger than the rated 0.289 l/kWh. This is considered attributable to the high starting frequency relative to the operation time. A feasibility study on reduction of the start frequency and specific fuel consumption is scheduled hereafter.

(ii) Pre-operation inspection

On September 1 and 2, 1994 the system underwent a governmental inspection (pre-operation inspection) and was accepted.

The inspection items were appearance, ground resistance measurement, insulation resistance measurement, dielectric strength, protector test, overall interlock test, control power source loss test, load on/off test, load test (including measurement of voltage harmonics) and actual load test.

(b) Research on optimum system configuration

(i) Adjustment and testing of demonstration system

By combining the solar cell unit (750kW), AC-DC converter (250kW x 3 units), storage battery unit (3,058kWh) and diesel generator (300kW) installed by fiscal 1993 the storage battery charging/discharging test, AC parallel operation test using the DC-AC converter and diesel generator, and others were carried out for overall adjustment and testing of the demonstration system in advance to demonstration operation for general users.

(ii) Analysis of demonstration operation characteristics

a. Actual results of generation

Fig. 1 compares the actual results of generation from October, 1994, to March, 1995, with the planned value. The average load power for the six months was 82.2kW. This was about 93% of the planned 88.2kW, almost meeting the planned value.

b. Array surplus electric energy

In the storage battery overcharging region a voltage increase enlarged the difference from the array maximum output operation voltage as shown in Fig. 2. This led to a drop in generated wattage. As the electric energy in the slashed area in Fig. 2 is naturally able to be led out when the Ah level of the storage battery is low under heavy load, it was taken as the array surplus electric energy. Therefore, if the photovoltaic generated wattage and load are kept in ideal balance, the expected array output is the sum of the actual array output and surplus electric energy. The transmittable electric energy was found by converting this array output to the output on the AC side.

c. Comparison between actual and planned generated wattages

The difference between the actual generated output and the planned value (found by simulation using meteorological data from August, 1992 to July, 1993 at the Miyakojima site) was roughly taken as follows:

• An analysis of the array output data revealed that the actual output would be 90% of the value found by simulation because the solar cell conversion efficiency correction factor was not considered in simulation.

• The inclined surface solar radiation

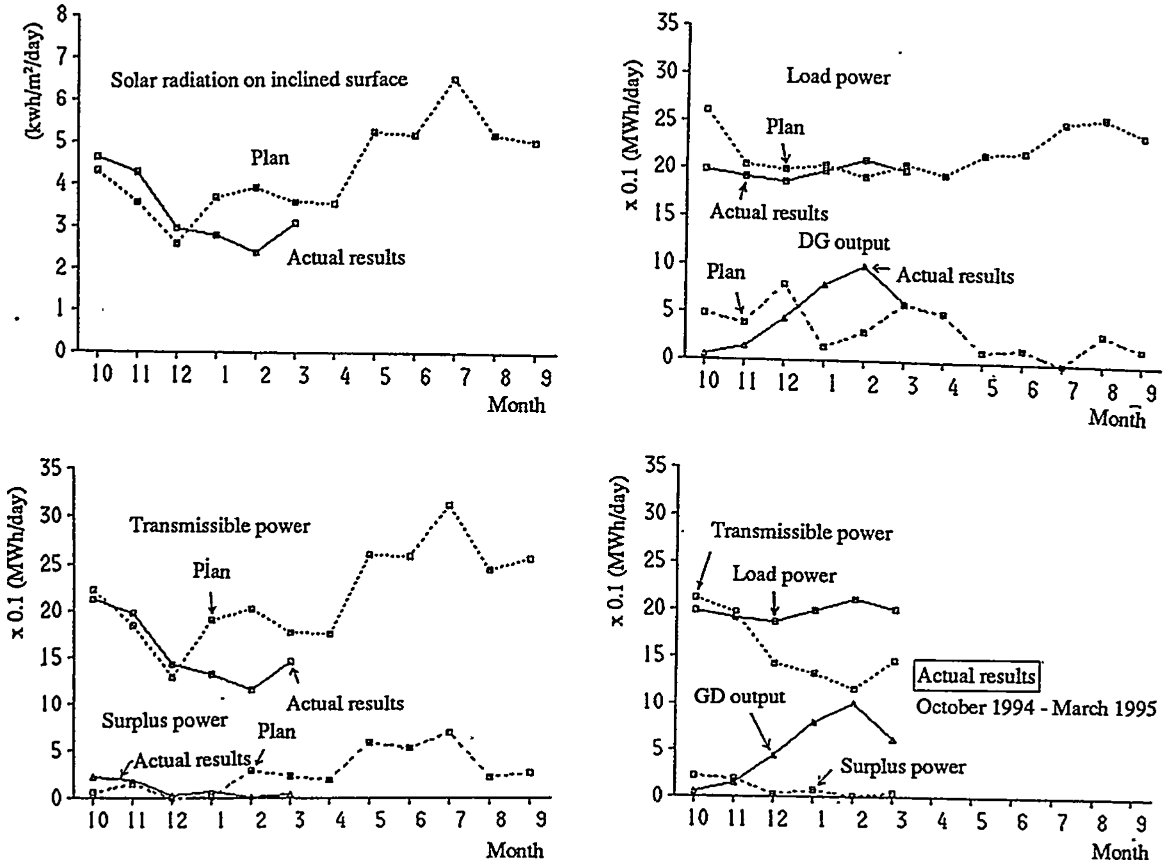


Fig. 1 Comparison Between Actual Results and Planned Values of Power Generation

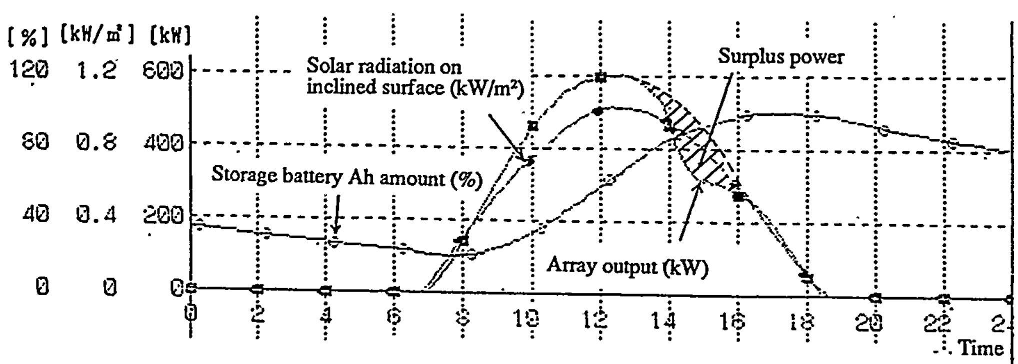


Fig. 2 Array Surplus Power

intensity was about 7% less than the planned value. Together with the preceding effect this led to a drop of 14% or so in the generated wattage that could be transmitted.

d. Array output characteristics

The solar cell conversion efficiency correction factor KP for the six months was 0.738.

$KP = WS/(HA \times PAS/GS)$

WS: Actual array generated wattage [kWh]

HA: Inclined surface solar radiation intensity [kWh/m^2]

PAS: Array total [kW] (750.3kW)

GS: Standard solar radiation intensity (1kW/m^2)

The coefficients making up this compensation coefficient were estimated by calculation based on the operation data, etc. It was found that the temperature correction coefficient 0.94 x line loss correction coefficient 0.99 x load matching correction coefficient 0.91 x nonlinear response fluctuation correction coefficient 0.96 x other correction coefficient 0.96 = approximately 0.73.

e. Storage battery characteristics

Uniform charging (overcharging) using the array surplus power is carried out in this system. The Wh efficiency in all regions including the storage battery overcharging region (Ah > 90%) is about 87% on average (the larger the monthly surplus generated output, the worse the storage battery efficiency tends to be). But the Wh efficiency in the Ah $\leq$ 90% region is a high 90% on average.

(3) Future Tasks

Independent operation assuming general users will be demonstrated and actual operating characteristics analyzed. Through research on operation using the demonstration system, the technologies aiming at the following will be established.

(a) Construction of a hybrid system able to supply electric power economically and stably by realizing optimum supplementary operation.

(b) AC parallel operation technology for photovoltaic and diesel power generation including the inverter control techniques for diesel generator parallel-in or parallel-off during inverter operation, optimum supplementary operation methods for different types of generators, etc.

(c) Parallel inverter operation techniques for independent operation and small power system protection and control methods will be established.

7. International Cooperative Demonstrative Research on Photovoltaic Power Generation Systems

7.1 Accelerated Demonstration Research Utilizing Highland Weather Conditions (Nepal)

(1) Objectives and Work Program

(Objectives)

The wide temperature fluctuation between day and night in the highlands of Nepal is utilized to operate water pumping systems powered by a photovoltaic power generation system. Deterioration in the efficiency of solar cells and their materials and variations in peripheral devices over time will be checked with a view to improving the reliability of the power generation systems.

(Work Program)

(a) Operational research on prototype system

(b) Design, fabrication and installation of demonstration type system

(2) Summary for FY1994

(a) Operational research on prototype system

Table 1 shows the PV-generated wattage and pumped-up water volume.

As the fine silt in the pumped-up water reduced the pumping-up capacity, the pump was replaced at the end of May. As the dynamic water level of the well was about –30 m and stable, the pump type was changed from the medium-head, medium-capacity type to a low-head, large-capacity type. As the riser pipe connection at the bottom developed cracks due to vibration caused by erosion in the pump impeller, the pump was not connected at the bottom but a blocking plug was put in. Two of the new pumps were installed to take over the previous operation with three pumps.

As the power supplied to the pumps was almost unchanged while the pumped-up water volume increased by 10% or so, the new pump configuration was proven to be a better choice for the well.

In the middle of March, another pump was connected at the bottom and normal operation with three pumps resumed and the operational research continues to this day.

(b) Design, fabrication and installation of demonstration type system

This system was built within the site where a reservoir facility called BODE-R was installed owned by NWSC (Nepal Water Supply Corporation) in the Bode zone in the northeast area of the Kathmandu valley.

The photovoltaic array capacity of this system is 40kW. Two general-purpose, high-head submerged pumps have been placed in the well. By changing the array combination according to solar irradiation level the system is designed to operate effi-

Table 1 Wattage Generated and Pumped-Up Water Volume (Nepal)

	Month / Year	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Yearly mean
Horizontal global irradiation ($kW/m^2/day$)	FY1994	5.23	5.50	5.35	5.00	4.86	4.40	4.70	3.66	3.19	2.87	3.42	4.63	4.40
	FY1993	4.86	5.01	4.91	4.26	3.85	4.03	4.55	3.37	2.98	2.80	3.69	4.44	4.06
30° inclined global irradiation ($kWh/m^2/day$)	FY1994	5.17	5.01	4.71	4.51	4.64	4.62	5.71	5.08	4.65	3.91	4.28	5.18	4.78
	FY1993	4.64	4.49	4.27	3.80	3.61	4.11	5.47	4.45	4.33	3.97	4.83	4.99	4.41
PV-generated wattage (kWh/day)	FY1994	16.1	15.8	14.8	13.9	14.1	13.9	17.1	16.2	15.6	13.1	13.9	17.0	15.1
	FY1993	13.3	15.8	14.7	14.1	12.9	14.5	19.6	16.5	16.9	14.5	17.6	16.0	15.5
Pumped-up water volume (m^3/day)	FY1994	39.4	31.4	44.7	41.5	41.8	40.6	46.1	43.8	41.7	34.9	35.6	40.6	40.1
	FY1993	39.0	49.3	40.6	36.1	34.1	36.5	49.1	44.2	45.5	39.0	38.2	40.0	40.9

ciently even at lower solar irradiation intensity.

(3) Future Tasks

Partly aided by the water and power shortages in the Kathmandu basin, the prototype system is proving to have high reliability. The form of utilization of large-scale PV generation systems like this system as a public facility has been established. Expectations are also high for the system as the power source for water service systems for agricultural areas.

The political situation in Nepal is presently unstable. Working with a good counterpart and in a stable political environment are important factors for smooth execution of international projects.

7.2 Demonstration Research on Movable Power Generation Systems

(1) Objectives and Work Program

(Objectives)

Because the Mongolian social system is one in which people traditionally do not reside in permanent settlements, demonstration research will be undertaken in that country using portable power generation systems which can be integrated into their nomadic lifestyle. This will be done with a view to reducing the size and weight and improving the portability and reliability of photovoltaic power generation systems including peripheral items such as batteries and inverters.

(Work Program)

(a) Field surveys

(b) Operational research

(c) Design, fabrication and installation of systems

(2) Summary for FY1994

(a) Field surveys

Opinions were exchanged with the Institute of Renewable Energy (NEDO's Mongolian counterpart) of the Mongolian Ministry of Fuel and Energy to determine the rough specifications and the installation locations for the fiscal 1994 systems, and the method of evaluating the operational data was also studied.

(b) Operational research

Table 1 shows the yearly averages and totals of the system operation data. Favorable solar radiation data for a long term is recorded. The operation data shows that there are so many fine days and so few rainy or cloudy days in Mongolia, making for solar radiation conditions incomparably better than those in Japan. The load utilization time zones center on mornings and nights. The load utilization time is especially long at night and generated wattages are correspondingly large.

(c) Design and fabrication of systems

Reduction of the size and weight and the improvement of the portability and reliability of the systems were attempted by ameliorating the systems of fiscal 1993. The systems of fiscal 1992, 1993 and 1994 are compared in Table 2 to highlight the points

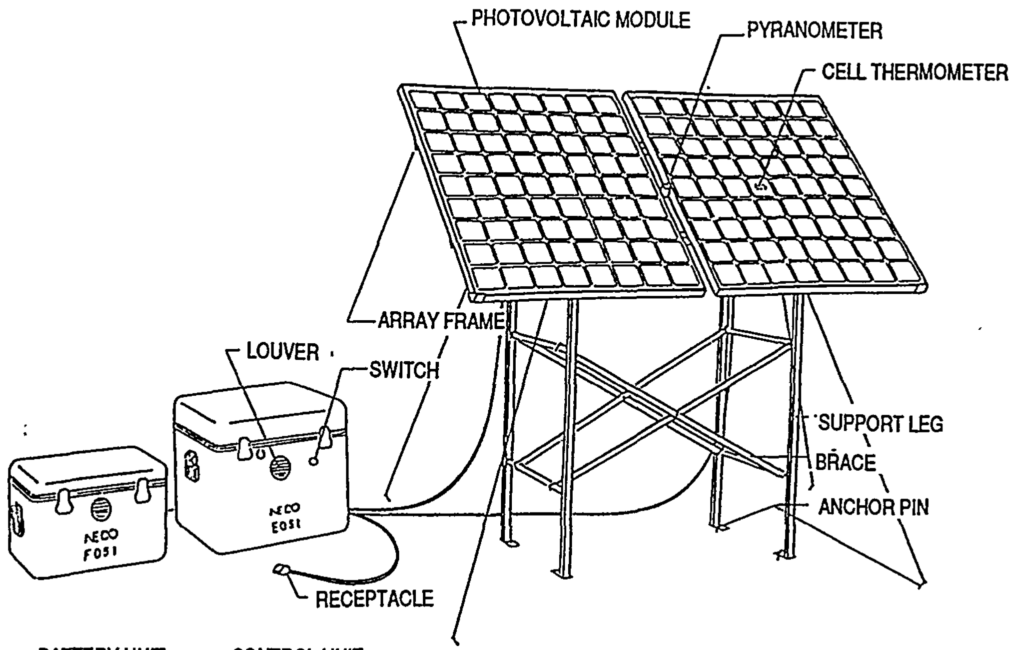
Table 1 Yearly Means and Accumulated Values of System Operation Data (Mongolia)

System No.	C003	C005	C007	C012	C021	C026	C027	C040	Mean	Accumulation
Solar radiation intensity										
(Mean) kWh/m²/day	5.47	5.29	6.15	5.73	5.14	5.51	5.50	5.69	5.57 kWh/m²/day	
(Accumulation)kWh/m²	564.45	1200.35	1129.29	1076.23	946.29	1117.43	953.37	733.84		7721.25 kWh/m²
Available solar radiation intensity										
(Mean) kWh/m²/day	5.22	3.62	5.22	3.42	4.18	3.45	4.83	4.07	4.19 kWh/m²/day	
(Accumulation)kWh/m²	545.19	808.75	935.23	661.16	768.78	715.06	837.31	535.94		5807.42 kWh/m²
PV output (Mean) kWh/day	0.70	0.46	0.68	0.55	0.50	0.50	0.45	0.59	0.547 kWh/day	
(Accumulation) kWh	74.24	101.33	125.88	107.47	92.24	102.75	78.66	76.75		759.31 kWh
Inv. output (Mean) kWh/day	0.31	0.24	0.36	0.28	0.22	0.27	0.17	0.31	0.272 kWh/day	
(Accumulation) kWh	33.54	54.09	66.45	55.56	39.76	57.26	29.02	41.04		376.72 kWh
Storage battery voltage (Mean) V	22.59	25.49	21.29	24.89	25.51	25.68	23.71	25.35	24.44 V	
Cell temperature (Mean) °C	-0.87	2.55	15.02	16.22	0.07	-1.03	-0.73	-6.65	3.64 °C	
Unit internal temperature										
(Mean) °C	16.51	16.69	30.17	22.35	19.24	17.23	17.24	19.13	19.93 °C	
Solar radiation energy utilizing rate										
%	94.79	68.54	85.31	59.59	81.93	62.80	88.02	73.58	75.21 %	
Solar cell conversion rate %	7.73	7.70	7.60	9.31	7.01	8.52	5.51	8.40	7.62 %	
Self-supply rate %	43.98	53.30	52.91	50.39	42.42	52.71	36.91	53.49	49.61 %	
System efficiency %	3.41	4.14	4.00	4.67	2.99	4.45	2.02	4.50	3.78 %	
Overall efficiency %	3.26	2.75	3.44	2.86	2.47	2.91	1.76	3.32	2.84 %	
Number of available days Days	101	224	183	186	184	204	173	132		1387 days

Notes
* Mean values were calculated by using the number of available days.
* Available solar radiation intensity was calculated by subtracting solar radiation intensity at the time of overcharge of storage batteries, which makes no contribution to charge, from solar radiation intensity.
* Solar radiation utilization rate = Available solar radiation intensity / Solar radiation intensity
* Self-supply rate = Inv. output / PV output
* System efficiency = Inv. output / Available solar radiation intensity
* Overall efficiency = Inv. output / Solar radiation intensity

Table 2 System Comparison and Improvements

Components		FY1992 type	FY1993 type	Points of improvement	FY1994 type	Points of improvement
Solar cell units	(1) Photovoltaic panel	51W module x 4 sheets 445(L) x 985(W) x 36/ 1 sheet (H) 5.9kg x 4 sheets 23.6kg	102W module x 2 sheets 868(L) x 988(W) x 52/ 1 sheet (H) 11.2kg x 2 sheets 22.4kg	*Connectors and wiring have been reduced, and the unit is easier to handle because the photovoltaic panel has been divided into two parts. This was done at the request of the Mongolian nomadic people.	102W module x 2 sheets 869(L) x 988(W) x 52/1 sheet(H) 11.2kg x 2 sheets 22.4kg	Some parts were replaced (some round pipes were replaced by square ones) to reduce weight, increase stability during assembly and improve processability.
	(2) Frame and leg parts	1,100(L) x 750(W) x 1,930(H) 17.3kg	920(L) x 550(W) x 1,600(H) 11.1kg	*Modification for compactness to follow the change of photovoltaic panels.	920(L) x 550(W) x 1600(H) 9.5kg	
	Sub-total	40.9kg	33.5kg	(–7.4kg)	31.9kg	(-1.6kg)
Battery unit		Battery: 12V-100AH x 2 476(L) x 426(W) x 555(H) 65kg	Battery: 12V-70AH x 2 415(L) x 315(W) x 320(H) 40.1kg	*Capacity of the battery was decreased to reduce its size and to improve portability, because solar radiation in Mongolia was greater than expected. (–24.9kg)	Battery: 12V-70AH x 2 415(L) x 315(W) x 320(H) 40.1kg	Unchanged.
Control unit * Charge controller * Inverter * Equipped with data logger		476(L) x 426(W) x 555(H) 43kg	470(L) x 420(W) x 465(H) 41.7kg	*To improve operatability, meters and breakers were set in upper section of the unit. (–1.3kg)	470(L) x 420(W) x 465(H) 35.6kg	Efficiency improvement and weight reduction of the inverter were pursued. A DC12V output terminal for DC radio was added at the request of the Mongolian nomadic people. (-6.1kg)
Total		148.9kg	115.3kg	(–33.6kg)	107.6kg	(-7.7kg)



of improvement.

(3) Future Tasks

Optimization of the system capacity will be studied on the basis of system operation data and meteorological observation data.

7.3 Demonstration Research on Photovoltaic Power Generation System for Battery Charging Stations (Thailand)

(1) Objectives and Work Program

(Objectives)

Utilizing the social systems in Thailand in which car batteries charged by diesel generators are brought home to supply power to electrical appliances, attempts will be made to improve the performance of photovoltaic power generation systems for use in battery charging stations including photovoltaic modules and charge control units.

(Work Program)

(a) Operational research on 4kW prototype system

(b) Design, fabrication, installation and start of operation of a 40kW demonstration system

(2) Summary for FY1994

(a) Operational research on 4kW prototype system

Operational research was carried out on the 4kW prototype system constructed in fiscal 1992 in Karnchanaburi Province, situated about 200km west northwest of

Bangkok.

This system was designed to charge 16 batteries (110Ah 20 hour rate) in about one day with a 4kW PV generation system. 147 households of the test village were divided into 10 groups and a setup was established for charging in rotation for each group every 10 days. The load was limited only to 20W fluorescent lamps in order to grasp changes in battery conditions with time more precisely.

Table 1 shows the operation data of the prototype system. As the meteorological observation system became disordered, data was partially lost. In the table the data for November was not obtainable and the data in and after December remains to be collected.

As the battery cannot be fully charged on days of lower solar radiation intensity, the charging interval has to be adjusted. Favorable operation continues to this day as users keep in touch with each other to facilitate smooth operation.

(b) Design, fabrication, installation and start of operation of a 40kW demonstration system

The demonstration system was built on the Koh Yao Yai Island, Phang-nga Province in the southern part of Thailand. The solar cell capacity of this system is 40kW and its service is limited to 500 households in order to insure full charging even at lower solar radiation intensity in the rainy season. These households were divided into 10 groups and 50 automotive batteries (12V-120Ah) were specified for charging every day. Judging from the results of prototype system operation, the solar cell array output voltage was set at about 250V in order to reduce the line loss. As a controller to supply power to the 12V batteries from this voltage, an inverter-battery charger combination was designed. The DC power from the PV generation system is converted to rectangular waves of 113–184V, 200–300Hz by the inverter and fed to 10 battery chargers through a distributor. This inverter-battery charger combination provides optimum operation point control of the solar cell output according to load. This eases the system utilization rate loss. Building this system as a 12V system is not realistic as 10 times the wire requirements of this design as well as sophisticated terminal arrangements would be needed. Charging with a DC/DC converter not using the inverter and battery charger has almost the same efficiency, but the inverter-battery charger combination was selected on the strength of easy current control against battery overcharging, equipment

Table 1 Prototype System Operation Data (Thailand)

	Month / Year	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Yearly mean
Solar radiation intensity on horizontal surface (kWh/m²/day)	FY1994	5.96	4.65	3.59	3.21	3.21	4.19	4.59						
	FY1993	5.71	4.70	4.77	4.13	3.62	4.00	3.20	4.41	4.10	4.05	4.62	4.46	4.31
PV-generated wattage (kWh/day)	FY1994	12.3	9.1	8.1	7.6	7.1	9.9	11.8	9.3	10.3	11.0			
	FY1992	13.4	11.6	11.1	10.3	9.2	9.0	7.6	11.3	12.7	10.8	11.0	10.7	10.7

Table 2 Energy Loss

		PV side						
		Temperature rise	Soiling	P max deviation	Line loss		Other (control equipment)	Overall system efficiency
Case I	Loss	6.8%	5.0%	2.0%	17.5%	8 mm², 70m Vpm=23.1, I pm=3.05 1S 8 p	15.5%	60.5%
	Efficiency	93.2%	88.5%	86.7%	71.6%		60.5%	
Case I'	Loss	6.8%	5.0%	2.0%	2.1%	8 mm² x 8.70m Vpm=23.1, I pm=3.05 1S 8 p	15.5%	71.6%
	Efficiency	93.2%	88.5%	86.7%	84.8%		71.6%	
Case II	Loss	6.8%	5.0%	5.0%	1.6%	8 mm², 86m Vpm=17.4, I pm=3.05 15S 7 p	INV 5% / AC/C 10%	70.6%
Case A	Efficiency	93.2%	88.5%	84.1%	82.7%		78.5% / 70.6%	
Case II	Loss	6.8%	5.0%	5.0%	1.6%	8 mm², 86m Vpm=17.4, I pm=3.05 15S 7 p	DC/DC 13%	71.9%
Case B	Efficiency	93.2%	88.5%	84.1%	82.7%		71.9%	

Case I: Same system design as prototype (12V system).
Case I': Same system design as prototype, with heavier cables used to reduce line loss (12V system).
Case II Case A: Increased voltage by joining several PVs in series, and charged by an inverter and a charger.
Case II Case B: Increased voltage by joining several PVs in series, and charged by a DC/DC converter.

cooling, etc. and the ability to withstand relatively a rough installation environment. The results of rough calculation of the energy loss are shown in Table 2.

As for battery management, batteries for two days (100 units) fully charged are kept in the charge station for days of low solar radiation intensity. By supplying them, the rotation service interval was adjusted while a liaison setup was established to put off the battery carry-in date of the next group so that fully-charged batteries would always readily available for users.

The PV systems are installed in the center of the four test villages where the counterpart (DEDP) representatives are always stationed for maintenance and management. They also give guidance to users as necessary.

(3) Future Tasks

Favorable operation is being established with the prototype system. There is demand for application to loads other than fluorescent lamps, say, televisions. To service a load other than fluorescent lamps it is necessary to give instructions on operation methods to deal with the increased load.

Furthermore, PEA (the local electric power company) is building a diesel power plant on Koh Yao Yai Island where the demonstration system is installed. PEA plans to supply power only during a part of the day. It is necessary to pay attention to PEA's distribution plans.

7.4 Accelerated Demonstration Research Utilizing Tropical Conditions (Malaysia)

(1) Objectives and Work Program

(Objectives)

In view of the characteristic of the power generation efficiency of photovoltaic systems to decline as the temperature solar cell modules rises, photovoltaic power generation systems will be operated under actual load in the tropical climate of Malaysia, and various cooling effects, among other factors, will be investigated with an eye to improving the efficiency of photovoltaic power generation.

(Work Program)

(a) Operational research of 10kW prototype photovoltaic power generation system

(b) Investigation and selection of site for construction of 100kW actual-type photovoltaic power generation system

(c) Design and fabrication of 100kW actual-type photovoltaic power generation system

(d) Operational research on 100kW actual-type photovoltaic power generation system

(2) Summary for FY1994

(a) Operational research on 10kW prototype photovoltaic power generation system

In order to confirm the cooling effect operational research was carried out on a passive method using the natural cooling effect and active cooling by spraying water.

As for the passive method, the difference in temperature among modules installed on graveled, water and glass land surfaces was measured under same meteorological conditions in order to examine the effect (due to the difference in heat radiation from land surfaces) of array installation surface conditions on the module temperature. The difference was too small to be significant. This is considered attributable to the cooling effect of the constant natural wind flow at an average velocity of more than 2.0 m/s.

The intermittent water spray operation was carried out as described below to examine the active cooling effect. Taking into account the application to practical systems, an interval operation test was made by turning on and off the water spray every 10 seconds to economize on the volume of module cooling water and determine a spray method. Table 1 shows the active cooling operating conditions and extent of the drop in temperature. The results of interval operations are shown in Fig. 1.

(b) Investigation and selection of site for construction of 100kW actual-type photovoltaic power generation system

Table 1 Conditions and Temperature Lapse in Active Cooling Operation

	30 second interval	60 second interval	120 second interval
Quantity of water	5.8 l/min.	2.5 l/min.	1.1 l/min.
Temperature lapse	15 - 20°C	15 - 20°C	15 - 20°C

Unelectrified villages consisting of 100–150 dwellings that would use electric power while meeting sunshine conditions, accessibility requirements, installation area conditions, etc., were investigated jointly with Sabah Electric Power Board (SEB) of Malaysia. Twelve districts were examined and Marak Parak (about 140 dwellings and 500 people), Kota Marudu in the northern part of Sabah Province was finally selected as the test village. The villages investigated are shown in Fig. 2.

(c) Design and fabrication of 100kW actual-type photovoltaic power generation system

A 100kW practical photovoltaic power generation system was designed and the following component units were designed and fabricated.

- Power conditioner: 50kVA
- System control panel
- Load controller: 22kW/300V x 2 sets
- Data recording system: CADAC-100CH, measuring point total: 72CH

(3) Future Tasks

(a) Operational research on prototype photovoltaic power generation system

This operational research will be continued from last fiscal year and data will be collected and analyzed.

(b) Design and fabrication of practical photovoltaic power generation system

Solar cells and storage batteries will be fabricated for the practical system.

(c) Actual-type photovoltaic power

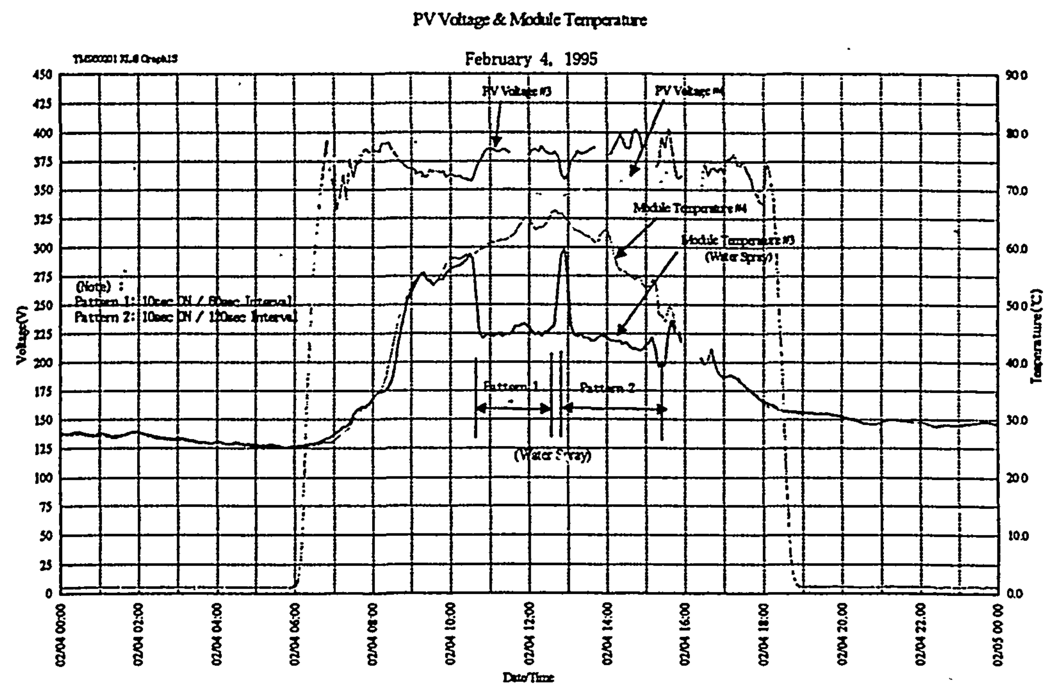


Fig. 1 Results of Cooling Operation by Interval Spray

Fig. 2 Construction Survey Points of Actual Type Photovoltaic Power Generation System

generation system construction and operational research

The site development work, delivery and installation of equipment will be carried out and operational research will follow.

8. Development of a Production System for Compound Semiconductors for Solar Cells

(1) Objectives and Work Program

Aiming at a new breakthrough in photovoltaic power generation technology, a gradient heating furnace, a mirror heating furnace, an isothermal heating furnace, all needed for the production of high-quality substrate crystals of compound semiconductors for solar cells in the microgravity environment of outer space, and related systems pertaining to indispensable functions for the operation of these furnaces (structural and heat control systems, electric power systems and data processing systems) will be developed.

(2) Summary for FY1994

(a) Program management

Program management including progress management, configuration management, etc. was carried out for three types of electric furnaces and mission operation and control systems in step with the progress of development of the space flyer unit (called SFU hereafter).

(b) Maintenance design (Part 6)

The maintenance design work continued regarding the proto-flight models (called PFMs hereafter) of electric furnaces and related systems. In addition, the support work for a series of function confirmation tests and maintenance, inspection, etc. up to the launching were carried out.

(c) Preparation for space environment utilization experiments

The experiment conditions for space environment experiments were finally confirmed coordinated. The operation manual for execution of experiments with electric furnaces was also prepared.

(d) Maintenance and management of mission operation and control systems

The maintenance and management of mission operation and control systems for PFM operation in an orbit were carried out.

(e) Maintenance and inspection of assembly and testing systems

The periodic maintenance and inspection were carried out on the assembly and testing systems required for PFM function confirmation tests, etc.

(f) Preparation for mission operation

Adjustment and other preparatory work were carried out between NASA and Sagamihara Operation Center on the operation of the SFU after launching and its recovery by a Space Shuttle and the operation manual was prepared. Training including practice was carried out for smooth intercommunication in the recovery phase with earth control stations. The manual on ground work after the recovery of the SFU was also prepared.

(g) Mission operation

After the overall test the PFM was carried to the Tanegashima Space Center of NASDA. It was launched with an HII rocket on March 18 and started operation. As for space material experiments, the post-launching, pre-experiment check was completed on the electric furnaces, etc.

(h) Activities of resident office in U.S. in FY1994

At the resident office in the U.S. interface coordination was carried out concerning the electric furnaces and related system operations, mission operation and control systems and use of a NASA Space Shuttle (for SFU recovery).

(3) Future Tasks

After the space experiments with the electric furnaces and related systems aboard the SFU by the end of August, 1995, the SFU will be recovered using a Space Shuttle. After the post-recovery ground work in the U.S. the SFU will be sent back to Japan by sea around February, 1996. Then the samples manufactured in a microgravity state in space and systems developed and operated for the mission will undergo analysis, evaluation, etc.

II

Development
of
Solar Energy System Technologies for Industrial Use

Aiming at spreading the use of solar systems in the sectors of industry where much heat is consumed and sophisticated heat management as well as a great variety of thermal processes from low to high temperature ranges are required, research on elemental technologies to make up systems, development of advanced heat process systems to convert the heat collected with heat collectors to heat in temperature ranges in popular demand, research on passive solar systems centering on light modulating materials, etc. will be promoted.

In addition, as part of the "Cooperative Research on Appropriate Technology," a pillar of the New Sunshine Program of the Ministry of International Trade and Industry, technologies developed under the previous Sunshine Programs and others and recognized to offer a fair prospect of practical application will be actively transferred to developing countries to establish themselves there in order to contribute to the easing of energy and environmental restrictions on a global scale. For this purpose the joint technology development of solar thermal application systems will be promoted.

1. Study of Elemental Technologies

1.1 Research on Chemical Energy Conversion Technologies

(1) Objectives and Work Program

With a view to the effective utilization of solar energy, technology will be developed for steady heat supply by using chemical heat pumps to increase the temperature of low-level thermal energy.

Target performance:

Recovery of heat of 150°C or more at the supplied heat temperature of 80°C; 30% process heat efficiency

Basic technology will be established and demonstrated for 2-propanol/acetone/hydrogen-based chemical heat pumps.

Demonstrated capacity: 1 x 10^5kcal/h class

(2) Summary for FY1994

For this heat pump the bench-scale testing apparatus was modified and put to demonstration tests. In addition studies were carried out on practicability and thermal efficiency improvement.

(a) Modification of bench-scale testing apparatus

In order to carry out a demonstration test in continuous operation for many hours, a system for central control of evaporator temperature, dehydrogenation reaction temperature, hydrogenation reaction pressure, etc. was installed.

(b) Demonstration test

As shown in Fig. 1, 100-hour continuous stable operation was successfully concluded with the bench-scale testing apparatus.

(i) Catalyst performance

No deterioration of catalysts was observed and stable performance was maintained during the continuous operation.

(ii) Undesired reactant density

As shown in Figs. 2 and 3, the densities of undesired reactants such as methane,

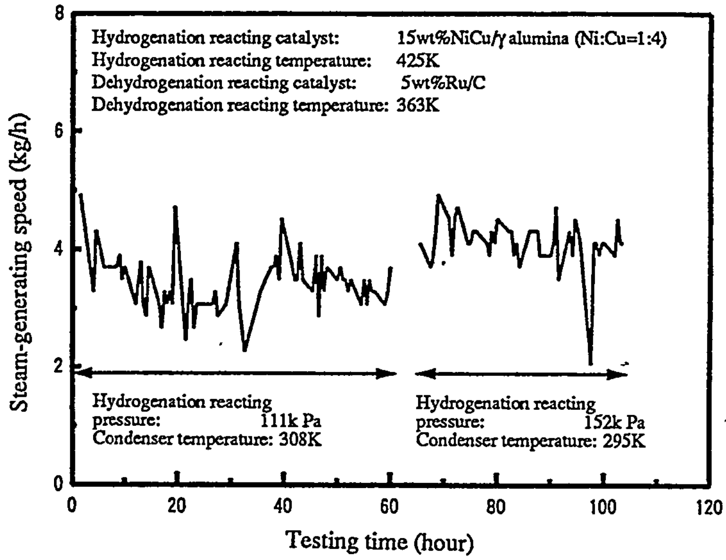


Fig. 1 Steam-Generating Speed in Bench Scale Testing Apparatus

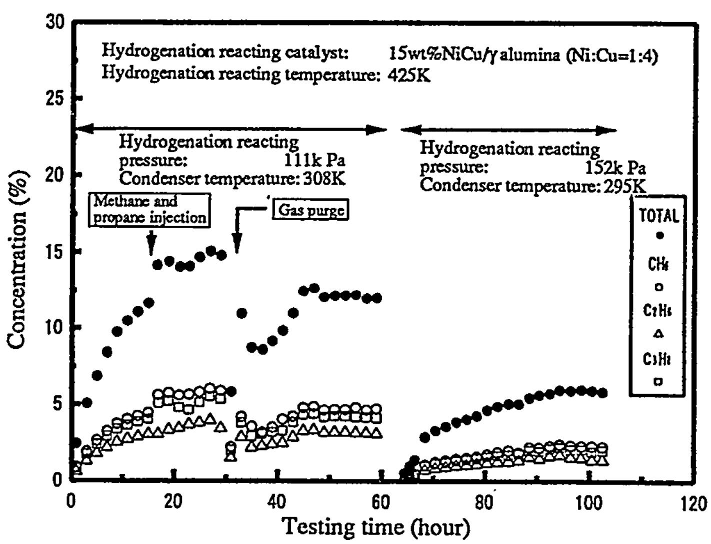


Fig. 2 Changes in Concentration of Gaseous Reactants Other Than Objectives (Hydrogenation Reactor Exit Gases)

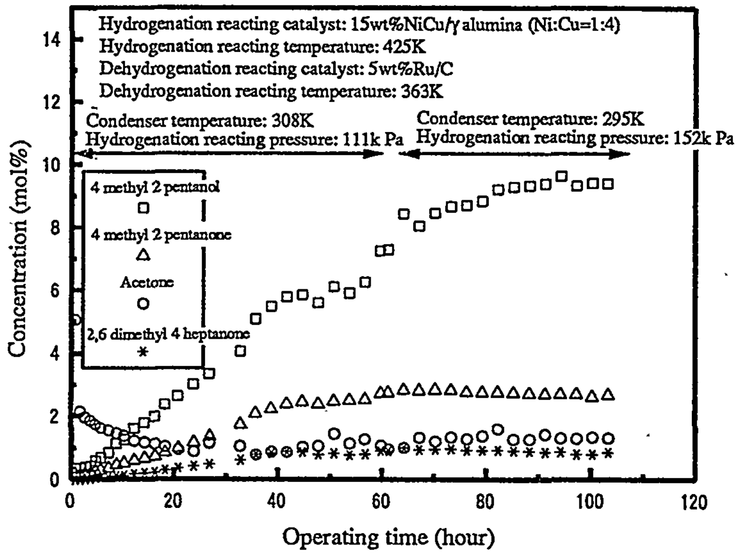


Fig. 3 Change in Concentration of Liquid Reactants Other Than Objectives (Dehydrogenation Reacting Tank Liquid)

ethane, propane, 4-methyl 2-pentanon and 4-methyl 2-pentanol within the system did not rise above certain levels. It was thus learned that they did not stand in the way of continuous operation.

(iii) Quantity of heat recovered

The quantity of heat recovered was about 2,100 kcal/h at steam temperature of 160°C. The scale of demonstration plants is usually 1/100 or less of that of practical plants. The data collected is fully reliable as design data for 1 x 10^5 kcal/h systems fit for practical application.

(iv) Temperature level

The generation of steam 150°C and 200°C was confirmed from hot water of 80°C and 95°C, respectively.

(v) Heat efficiency

The thermal efficiency in the bench-scale test was 10%. But in a series of reaction conversion experiments using hydrogen-absorbing alloys experimentally, data was obtained to insure realization of the process's thermal efficiency at 30%.

(c) Study on practical application

The economy and other aspects of systems combined with solar collectors were evaluated. Possibilities of outperforming steam boilers in running costs are recognized but initial costs are 10 times as high. As there are possibilities of improvement in step with the progress of elemental technologies hereafter, it is necessary to consider them.

(d) Study on improvement of thermal efficiency

As a results of experiments with apparatuses using hydrogen-absorbing alloys, data exceeding the target acetone density (60%) at the dehydrogenation reactor outlet was obtained. It was thus learned that the thermal efficiency target would be met by application of hydrogen-absorbing alloys.

(3) Future Tasks

This research succeeded in demonstrating a chemical heat pump using catalytic reaction for the first time in the world. Hereafter it is necessary to establish an operation control method compatible with intermittent (ON-OFF) supply of heat, aiming at operation smoothly responding to changes in solar radiation intensity. Specifically, operation control by installing hydrogen and acetone storage tanks and converting thermal energy to chemical energy for storage and recycling will have to be studied. Reaction catalysts and reactors will have to be optimized, too. In order to improve the economic aspects of operation for practical application, it is necessary to develop hydrogen-absorbing alloys as new materials as well as new liquid film type processes.

2. Development of an Advanced Heat Process Type Solar Energy System

2.1 Development of a High-Efficiency Refrigeration System Using Solar Heat

(1) Objectives and Work Program

As part of the development project aiming at effective utilization of solar heat, a stand-alone type refrigeration system utilizing the heat of the reaction between hydrogen-absorbing alloys and hydrogen gas will be developed, using solar heat in the medium temperature range (130–150°C) and intended to meet needs for various refrigerating heat levels centering on the –10°C temperature level.

Capacity of refrigerating heat generation:
1,500 kcal/hr or above

Temperature of refrigerating heat to be reached: –10°C or below

(2) Summary for FY1994

(a) Research on refrigeration materials

At the temperature levels (–10°C or below and normal temperature) required for solar heat stand-alone refrigeration technology (–10°C or below), development of new types of hydrogen-absorbing alloys excelling in hydrogenation equilibrium characteristic and reaction rate was attempted, and new hydrogen-absorbing alloys of refrigeration temperature levels appropriate for further refrigeration (–30°C to –40°C) was also developed.

As for high-temperature alloys required for regeneration at the solar heat temperature level, the relationship between compositions and hydrogenation equilibrium characteristics of $LaNi_{5-x-y}Mn_xAl_y$ alloys was examined carefully. The results made it possible to simulate P-T-C characteristic curves for any composition. This is shown in Fig. 4.

As for low-temperature alloys required at the refrigerating temperature level, the multi-composition possibilities of Ti-Zr-Mn-V-based alloys were studied. The Al replacement for Mn was recognized to reduce hysteresis and Cu replacement to flatten the plateau region. As these replacing elements have little influence on the equilibrium hydrogen pressure, controlling the equilibrium hydrogen pressure by V replacement is considered possible also for Ti-Zr-Mn-V-M-based alloys containing them. With Ti-Zr-Mn-V-Al-Cu alloys Al and Cu replaced simultaneously for Mn the plateau flattening effect of Cu was not recognized but the hysteresis reducing effect of Al was maintained.

Based on these results, La-Ni-Mn-Al alloys compatible with alloy designs having the hydrogenation equilibrium characteris-

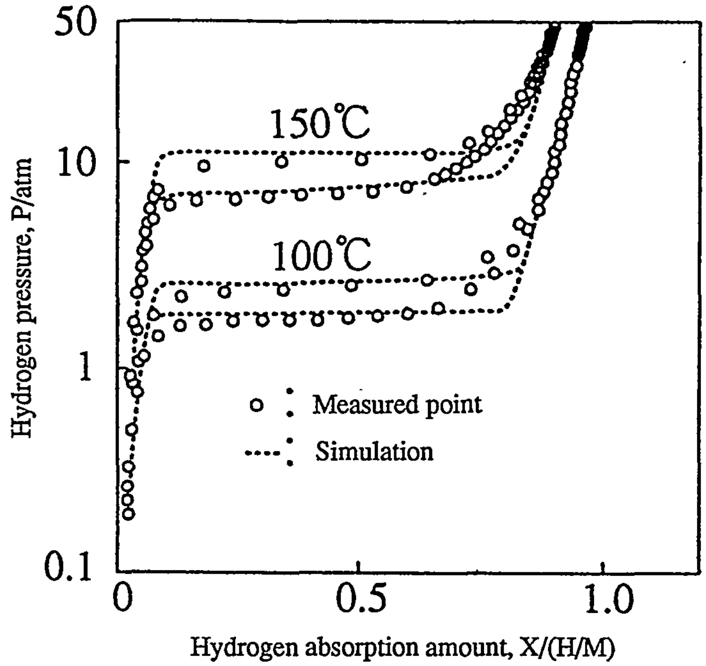


Fig. 4 P-C-T Characteristics Curves of $LaNi_{4.50}Mn_{0.25}Al_{0.25}$ Alloys

tics fit for use as high-temperature alloys at the solar heat regeneration temperature and La-Y-Ni-Mn alloys as low-temperature alloys because of their stable hydrogenation equilibrium characteristics and reaction rate were selected provisionally as laboratory-scale refrigerator alloys to produce refrigerating heat of −10°C. Furthermore, by alloy characteristics simulation it was recognized to be possible to produce the cold heat of −10°C by air/water cooling at the solar heat regeneration temperature of 140°C level.

(b) Research on refrigeration unit fabrication technology

As part of high-performance heat exchanger development, the relationship between volume expansion at hydrogen absorption of hydrogen-absorbing alloys and internally generated pressure (vessel wall distortion) was examined. It was learned that the vessel wall distortion abruptly increased as hydrogen absorbed over 1.1wt%. As this was thought to have a large effect on heat exchangers in alloy layers, it turned out to be necessary to adopt a method for structurally avoiding internal pressure rises or to provide reaction rate control by controlling the refrigeration cycle operation.

For air/water cooling technology development the effect of fin configuration on heat transmission performance was examined. The overall heat transfer coefficient of slit fin-equipped air-water cooling heat exchangers stood at 50 W/(m^2K) (front wind velocity: 1 m/s). The performance improved about 1.5 times over that of the smooth-finned unit of fiscal 1993.

In addition, a laboratory-scale prototype was designed, fabricated and operated (intermittent operation). In intermittent operation the regeneration process used a 140°C heat source and air heat source of 26°C. The refrigerating process used an air heating source of 28°C. The cold heat temperature produced varies with duration of the refrigerating process. It was learned to be possible to achieve less than –10°C at a duration of 15–20 minutes.

(3) Future Tasks

In refrigerating material research hydrogen absorbing alloys centering on Ti-based types having super-reversibility required for a stand-alone refrigeration system (less than –20°C) using solar radiation will be developed. In the refrigeration unit fabrication, field development will center on high-performance heat exchanging technology for refrigeration and regeneration for solar stand-alone refrigeration systems (less than –20°C) and element technology of air-water cold heat exchanging.

3. Research on Passive Solar Systems

3.1 Research and Development of Light Modulating Materials, Etc. (Research and Development of Advanced Glazing)

(1) Objectives and Work Program

Light modulating glass, which would effectively utilize solar energy and contribute to energy substitution for air conditioning and lighting purposes, will be developed. Light modulating glass can be used in the outer wall openings of buildings, will be sufficiently durable for practical purposes and excel in optical characteristics.

Durability: 10 years or more in outdoor use

Cycle life: 10^5 cycles or more

Size: 600mm or more in width

Visible light transmittance: Capable of continuously modulating light in a transmittance variation rate of 50% or more

(2) Summary for FY1994

(a) Durability and cycle life

Light modulating devices configurated as shown in Fig. 5 were fabricated on a trial basis to different sizes (5 x 5cm, 10 x 30cm, 30 x 60cm and 40 x 60cm) and their basic characteristics such as appearance, response characteristics, optical characteristics, etc. were measured. The small samples (5 x 5cm) were put to optical characteristics evaluation and the range of change in visible light transmittance proved to be larger than the target of more than 50% as shown in Table 1. As for component materials, the reduction coloring type WO_3 and oxidation coloring type counter-electrode material NiO were found useful as electrochromic materials. As electrolytic materials, hydrate oxides of the proton conduction type SbO_x were found useful. Details of film forming conditions and their optimization, prevention of peeling and hazing, coloring-decoloring reaction reversibility, etc. were studied. Fair prospects were obtained for developing light modulating elements that would provide stable operation under solar radiation for roughly 10 years. The accelerated deterioration test was carried out only on the small sample. Hereafter a real-time actual exposure test on the actual-sized sample (40 x 60cm) will have to be made to study the size effect on deterioration.

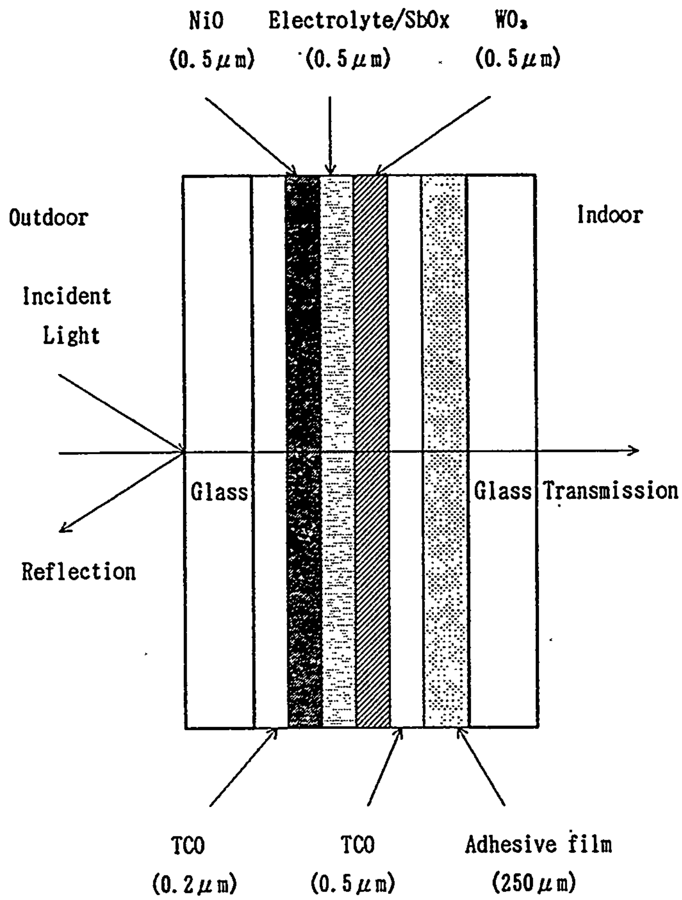


Fig. 5 Cross Section of Light Modulating Glass

Table 1 Optical Characteristics of Light Modulating Glass

Driving mode	Visible radiation transmissivity	Visible radiation reflectance	Solar radiation transmissivity	Solar radiation reflectance
Colorless mode	72.6	10.3	54.9	14.8
Intermediate mode	32.8	7.2	21.5	13.1
Colored mode	17.6	7.6	10.7	12.7

(b) Element formation and enlargement

A large light modulating element (40 x 60cm) trial manufacturing process was developed and its various characteristics evaluated together with research on film composition details. Specifically, a large element film forming process with a high-speed film forming unit was developed. At the same time a substrate grinding/cleaning unit was installed and used to examine electric shorting attributable to dust and pin holes. The edges of the 40 x 60cm sample turned brown due to incomplete decoloring but fair prospects were obtained for settling this problem by optimizing film forming conditions of various component materials.

(c) Peripheral techniques regarding light modulating glass

Techniques for installation of larger sheets of light modulating glass for windows and so on were established by improving sealing methods and materials, assembly methods and so on. As for electric circuits, it was learned that adequate endurance was feasible with DC 1.5V drive units. This contributed to simplification of circuits.

(3) Future Tasks

The trend in light modulating element characteristics will be grasped and practical tests, etc., assuming application as functional window glass will be carried out. The substrate surface properties which are related to increasing the yield of elements immediately after film formation and foreign substances that may cause shorting troubles will be analyzed and examined. The results will go into examination of large light modulating glass manufacturing techniques and preparation of conceptual designs of manufacturing processes. Furthermore, basic specifications will be set through examination and improvement of peripheral techniques in window applications and overall evaluation of light modulating glass in window use will be conducted by integrating element technologies.

4. Survey and Research on Solar Systems

4.1 Survey and Research on Technology for Solar Cities

(1) Objectives and Work Program

The effectiveness and economy of solar technology applicable to existing buildings, etc. and energy-saving technology (retrofit technology) will be evaluated to decide on a kind of retrofit technology appropriate for use in Japan. How its economic aspects should be considered, as they hold the key to its practical application, what should be done, and how, to spread it and how retrofit technology research should be promoted will also be examined.

(2) Summary for FY1994

Economic contributions that would be made in the form of energy saving, energy-cost saving, cost recovery, etc. if retrofit technology were introduced in Japan were studied together with research on applicability of retrofit technology.

Retrofit technology appropriate for use in Japan has emphasis placed on the reduction of costs and thus is not necessarily the same as retrofit technology whose applicability is studied in the U.S. and Europe.

Retrofit techniques whose costs are considered recoverable in Japan are those applicable to windows (laminated glass, light modulating glass and low radiation-factor glass), solar collector technology (solar collectors for hot water services, air-solar collectors) and transparent heat insulating materials.

In Japan, where reconstruction takes place more frequently than renovation, retrofit technology will not stop at existing buildings but will increasingly involve new building applications. This is unique in that costs are recoverable more easily.

Retrofit technology in Japan depends largely on regional characteristics. The retrofit technology in the U.S. and Europe is difficult to apply in Japan in certain aspects, but it is considered fully useful in Hokkaido, the northernmost island of mainland Japan, whose meteorological conditions are similar to those of the northern Europe. Another point to note is that the applicability differs with the regional energy demand and energy prices.

As Japan is mostly a hot and humid place the demand for comfortable air temperature and humidity environment is appreciably high. Japanese-type retrofit technology has to provide comfort in air conditioning applications, not stopping at the saving of energy.

Furthermore, retrofit technology by itself is not so effective, making it difficult to insure its economy. In order to make up for this aspect, combined application of various retrofit techniques are conceivable. It is learned that this approach will reduce costs of execution and increase the possibility of improving the overall economics.

(3) Future Tasks

To spread retrofit techniques it is necessary to shorten the cost recovery time by further reducing costs. It is also necessary to consider the contribution to the reduction of the environmental load and to the improvement of comfort as well as the anticipated effect from the standpoint of life cycle assessment (LCA).

4.2 Surveys and Research on a Snow Melting System Through the Efficient Use of Solar Energy

(1) Objectives and Work Program

Study and proposal will be made regarding snow melting systems, for which utilization of solar energy is expected to prove efficient and find extensive use, through surveys and research on the trends of technological development of snow melting systems for buildings in heavy snow cover areas.

(2) Summary for FY1994

The basic concept on snow melting systems for popular use was defined as (1) to minimize consumption of nonrenewable energy, (2) to use energy sources having less impact on the environment, (3) to aim at systems that would melt snow around buildings efficiently while increasing the interior comfort of building and (4) to reduce initial and running costs as much as possible.

The development targets of snow melting systems for popular use were set not to melt the snow cover on roofs completely but to keep the snow cover a maximum of 20–30cm deep for heat insulation of the roof area as a whole, to use surplus energy, if any, for hot water supply and heating within buildings, to make the maximum use of solar radiation during the winter and to develop heat collectors of favorable response and heat storage facilities that would work throughout the season.

Based on these targets, research and proliferation programs concerning efficient snow melting systems were examined and two types were proposed as model systems for popular use. One aimed to develop heat collectors integrated with roof building materials and wall members for construction of eco-homes of high heat insulation and energy-saving performance. In this way the solar radiation would be collected all over wall surfaces and the heat would be led to the attic for overall roof heating while the roof itself would be a heat radiating body to melt snow. Research on metal outer wall materials and their mass production techniques, development of high-efficiency members that would provide a spacer function, development of urethane panels that would excel in heat insulating characteristics and durability, etc. — these were set as development tasks in the element technology category, aiming at collectors to double as building materials.

The other type proposed would send the heat collected to a storage tank and use it in the winter for snow melting, etc. For this purpose it is necessary to develop heat storing vessels that would excel in heat insulating performance while satisfying the heat storing requirements throughout the season and matching the scale of buildings. The element technology development tasks selected for these purposes were the heat storage tank structure, heat storage tank materials of high heat insulating performance, heat storage tanks of proper scale, etc.

(3) Future Tasks

In order to promote the spread of snow melting systems for popular use, it is necessary to estimate trends in element techniques, energy-saving capabilities and economic aspects together with examination of trends in development of technologies. Of these the detailed study on economic aspects and estimation of their trends there are considered especially important.

5. International Joint Projects for Technological Development of Solar Energy Utilization Systems

(1) Objectives and Work Program

Technological development will be undertaken in cooperation with other countries particularly rich in solar energy to establish as "appropriate technologies" matching their respective environmental conditions such technologies for solar energy utilization developed under the Sunshine Program as already have reasonable prospects for practical application. At the same time, human resources to engage in such efforts will be developed to extensively promote the utilization of solar energy and to support the capabilities of these countries to address energy-saving needs and solve environmental problems.

(2) Summary for FY1994

(a) Design of model timber drying plant

Based on the conceptual design of the model timber drying plant prepared in fiscal

1993, further investigation and research were carried out. A detailed design of a model timber drying plant assuming practical application in Indonesia on a commercial basis was prepared jointly with Indonesian technical personnel. The basic system and sketch of the plant are shown in Figs. 6 and 7, respectively.

(b) Feasibility study on model timber drying plant

Based on the model plant design, the construction cost, running cost, etc. were estimated in meetings with Indonesian technical personnel and through detailed joint investigation in Indonesia. Based on the results, a feasibility study was carried out. The environmental effect associated with installation of the model timber drying plant was examined jointly with Indonesian technical personnel.

As a result, the model timber drying plant under study was concluded to be a system whose spread in Indonesia would be fully feasible technically. As for economy, it falls behind previous systems which use waste timber as the fuel at no charge. But taking into account the possible change in timber drying business in the future, that is, supply of the fuel for pay in step with promotion of the more effective use of waste timber, the system under study may possibly spread over previous systems. The system under study is thus considered to be one that is advantageous in economic aspects and embodying environment-friendly technology, offering fair prospects for spreading in Indonesia.

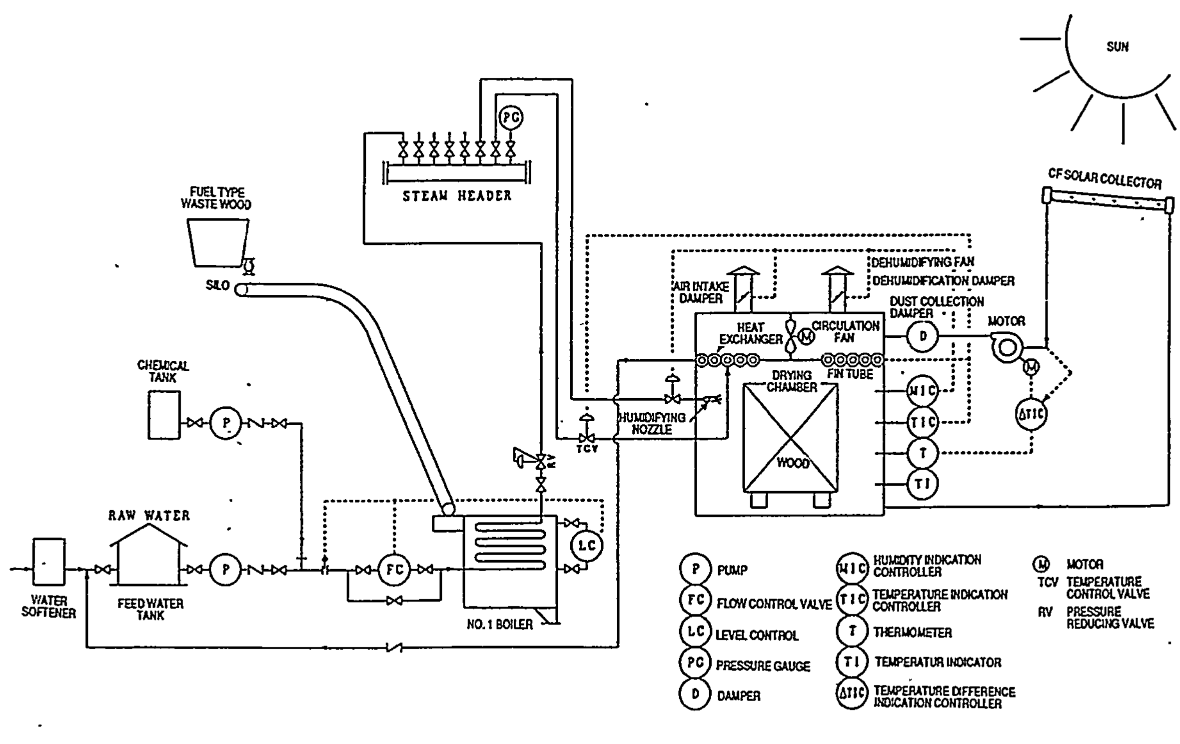


Fig. 6 Basic System of Solar Heat Timber Dehydration

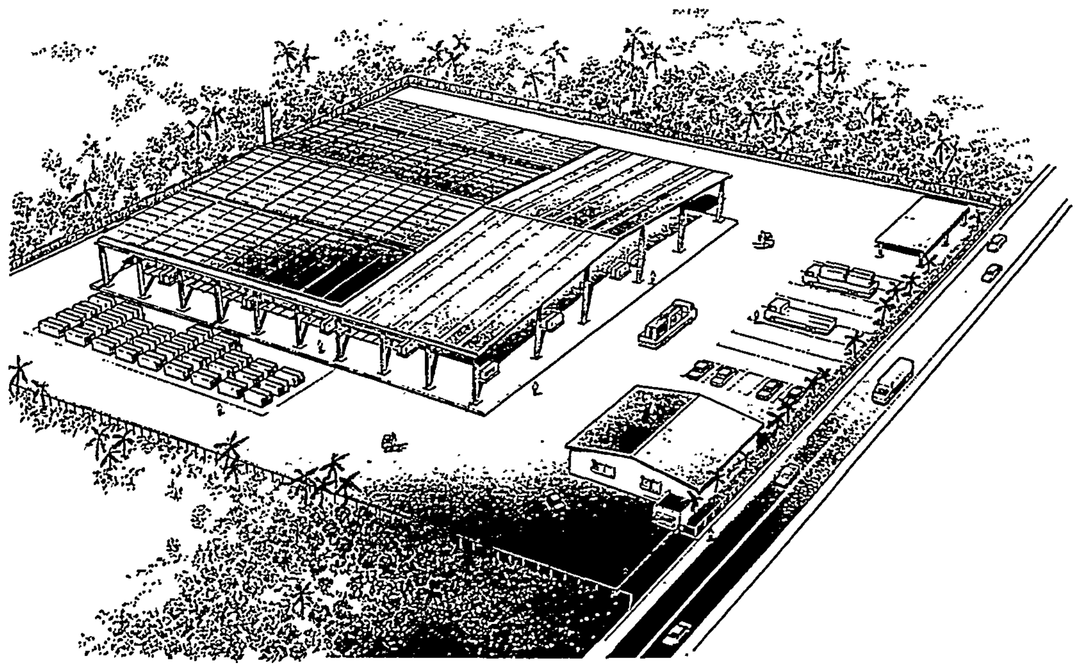


Fig. 7 Bird's-Eye View of Timber Dehydration Model Plant

(c) Design and feasibility study on model plant of cacao drying system

In order to probe the possibilities of developing the results of the design and feasibility study on the model timber drying plant into systems applicable to other products, the design work and feasibility study on a cacao drying system were carried out jointly with the Indonesian counterpart. Blow, circulating and circulating and heat storing types were examined. Of these the circulating type is considered most economical. Its basic system configuration and plant sketch are shown in Figs. 8 and 9, respectively.

As a result, it was concluded that the system would be fully feasible technically in Indonesia but that it would nonetheless fall behind previous drying plants in economic aspects. It is thus considered necessary to examine again the possibilities of the system's spreading through overall evaluation of its environmental load-suppressing effect and economy.

(d) Indonesian technical personnel training

Training of Indonesian technical personnel who would take part in the joint work to develop solar heat dehydration systems was carried out in Japan and Indonesia.

(3) Future Tasks

A pilot plant will be designed jointly with Indonesia. The local availability, etc. of equipment and materials for construction of the plant will be investigated and analyzed. Based on the results, the necessary equipment and materials will be ordered, procured and transported for machining, fabrication, etc. in Indonesia. The training of Indonesian technical personnel will continue in Japan and Indonesia.

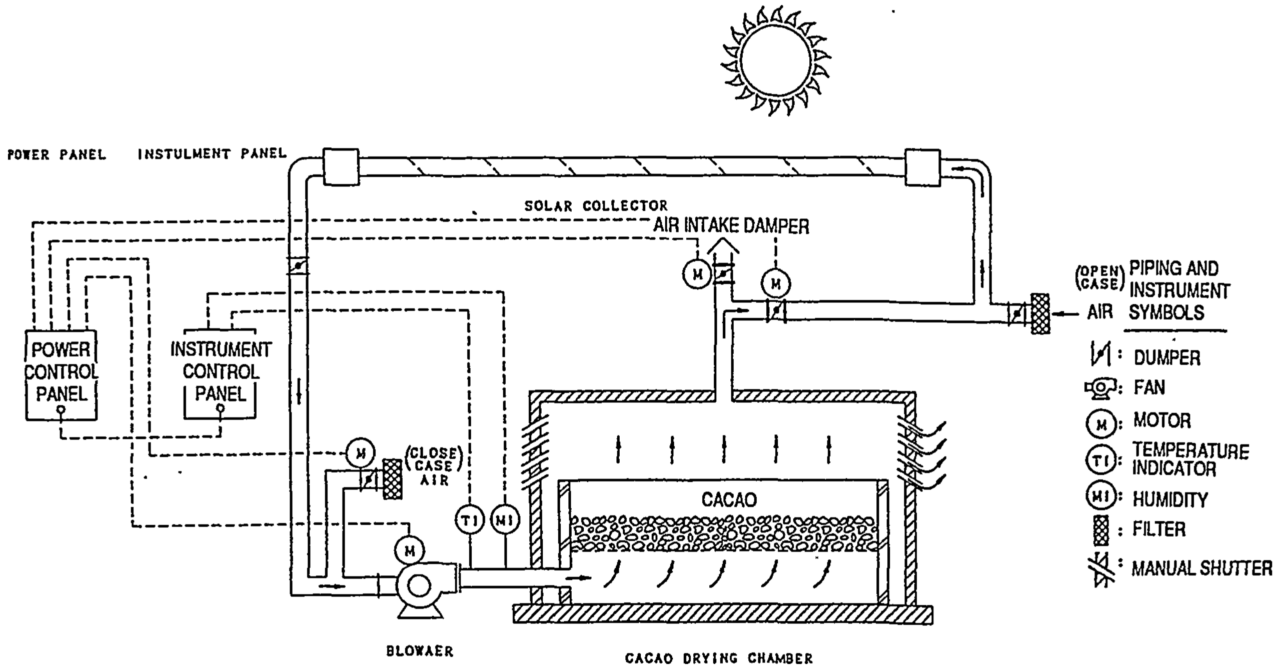


Fig. 8 Basic System of Solar Heat Cacao Dehydration

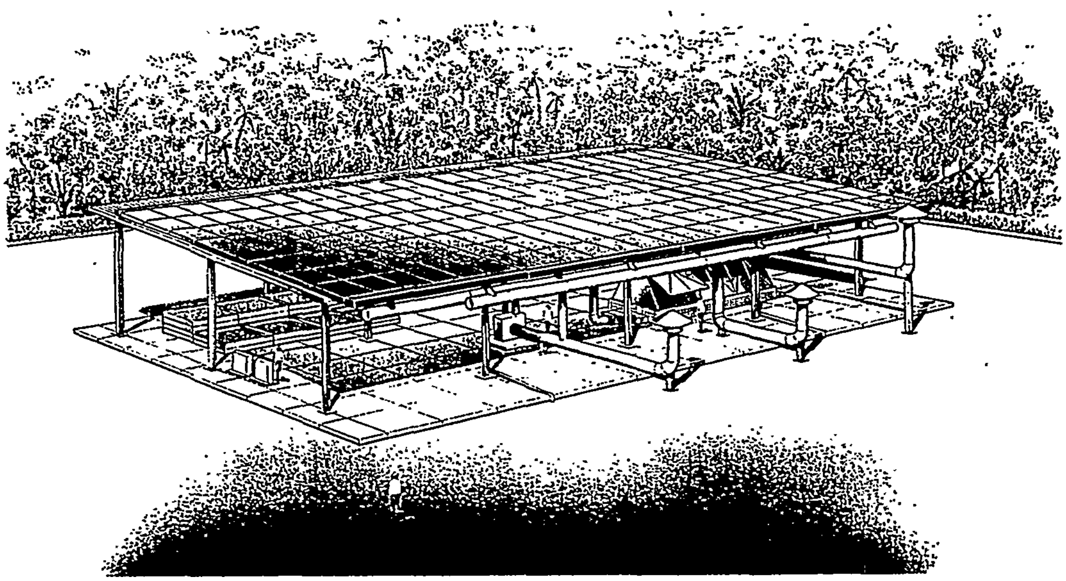


Fig. 9 Bird's-Eye View of Cacao Dehydration Model Plant

III

Projects for International Cooperation

(1) Objectives and Work Program

Acceleration of the introduction of photovoltaic power generation requires development of a favorable environment for introduction as well as encouragement of technological development efforts on a worldwide scale. In this connection, NEDO will engage in the collection of information regarding the IEA photovoltaic power generation program and IEA solar heating and cooling programs and in the technical Summit project as multilateral cooperation activities for solar energy utilization.

Further, as bilateral cooperation projects, Japan-Australia solar energy technical cooperation will be continued under the framework of cooperation between the Australian Department of Primary Industries and Energy and the Japanese Agency of Industrial Science and Technology concerning the development of photovoltaic power generation systems, and solar energy technical cooperation will also be carried on between Japan and France under the agreement for scientific and technological cooperation between the Government of Japan and the Government of the Republic of France, and between Japan and the United States under the arrangement between the United States Department of Energy and the Japanese Agency of Industrial Science and Technology in the area of solar energy. In addition to these, there will be implemented technical surveys and information exchange regarding solar energy between Japan and Spain, together with technical surveys in other countries where solar energy technologies are developed, such as Germany and Italy.

(2) Summary for FY1994

(a) Multilateral cooperation regarding solar energy

(i) Collection of information regarding the IEA photovoltaic power generation program

This fiscal year Japanese delegates attended executive committee meetings held in April and November, 1994, Task I exert meetings in June and December, Task II expert meetings in October, 1994 and March, 1995, Task III expert meetings in April and December, 1994, Task VI workshop in July, 1994 and Task VI expert meetings in March, 1995.

(ii) Collection of information regarding IEA Solar Heating, Cooling and Hot Water Supply Programs

Japanese delegates attended the 35th and 36th meetings of the executive committee held in Turkey in May 1994 and Finland in October 1994, respectively, and collected information. At the meetings, the progress of work on each task and future policies were discussed.

Japanese delegates also attended experts' meetings of Task XVIII held in Norway and France in June 1994 and January 1995, respectively, and collected information. Japan served as secretariat for the experts' meeting of Task XVI held in Tokyo in November 1993, and also collected information during the meeting.

(iii) Summit Working Group's cooperative project for photovoltaic power generation

No particular consultative session was held this fiscal year, but the third international handed-round PEP measurement is now under way by two separate groups respectively responsible for the establishment of the World Photovoltaic Cell Standards (WPVS) and for the comparison of measurements regarding new types of solar cells.

(b) Japan-Australia solar energy technical cooperation

(i) Performance evaluation of Japanese and Australian solar cells

Solar cell performance evaluation tests are under way, scheduled for completion at the end of 1995. With a view to successful implementation of these tests, the progress of research in this fiscal year was surveyed, information was exchanged, and the implementation of tests was inspected at the field test sites for new technology solar cell modules (three sites in Innisfail, Alice Springs and Clayton).

The small-sized double-layer tandem-structured amorphous solar cell modules supplied in fiscal 1993 to examine changes in spectral sensitivity characteristics started undergoing the field test at the Alice Springs site.

The amorphous solar cell modules withdrawn in fiscal 1993 as a result of the site change and curtailment for field test site rationalization were brought back to Japan, put to the evaluation test and the results were compiled into a report.

(ii) Remote area power supply system (RAPPS)

Based on the results of consultation with DPIE and CSIRO, the battery life evaluation test has been under way on the Japanese side since fiscal 1992.

As a result of the meeting in November, 1994, the consultation concerning the transfer to Phase II was put off.

(c) Japan-France technical cooperation regarding solar energy

No consultations were held this fiscal year.

(d) Japan-U.S. technical cooperation regarding solar energy

Japanese delegates attended the 1st WCPEC meeting held in Hawaii in December, 1994 and exchanged information on trends in technological development, etc. concerning photovoltaic power generation.

(e) Japan-Spain technical cooperation regarding solar energy

No consultations were held this fiscal year.

(f) Technical surveys concerning solar energy technology

As part of the survey related to the "Research and Development on Building Materials-Integrating Modules," ECOFYS was entrusted with a survey in September, 1994.

An inspection tour was made of single-family homes and apartment houses where building material-integrated modules were installed, with a visit to BDA, the building materials testing institution, to learn about testing devices, etc. Next, the Lousanne Federal Politechnique University, Switzerland, was visited for inspection of sites where solar cell modules were built into roofs and facades together with a survey on photovoltaic power generation programs. In Germany, energy self-sufficient solar houses, the 1;000 Roof Top Program, high-efficiency solar cell manufacturing technology, etc. were studied at the Braunhoffer Solar Energy System Research Institute. This was followed by inspection of the PV facades and PV shades PST installed in the Bavarian Environment Ministry building together with a visit to PST to learn about its amorphous silicon solar cell production line capable of producing cells in sufficient quantities to generate 1MW a year.

Japanese delegates attended the Solar Energy Practical Application Policy Conference held in Indonesia in January, 1995 and examined the solar energy introduction policies and programs of the country.

(3) Future Plans

International technical cooperation regarding the utilization of solar energy will be continued.

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CHAPTER 2

DEVELOPMENT
OF
GEOTHERMAL RESOURCES

DEVELOPMENT
OF
GEOTHERMAL RESOURCES

Contents

I

Geothermal Development Promotion Survey Project

1. Geothermal Development Promotion Survey Project

1.1 Objectives and Work Program

(1) Objectives and Positioning of the Promotion Surveys

Japan is one of the few countries in the world with a large amount of volcanic activity and is thus fortunate to have geothermal energy resources. Geothermal energy is advantageous not only because it is domestically available, but also because it is clean and environmentally benign due to minimal resultant CO_2 emissions. Furthermore, geothermal energy can be used as a heat source for multiple purposes in local communities. With the total resource volume that can be developed at current technology levels calculated at 25 million kW, great expectations are being placed on the development and utilization of this energy source.

Developing geothermal energy requires selecting promising geothermal areas, conducting reconnaissance and detailed surveys of these areas, focusing efforts on the development sites, and constructing power generating stations. Especially in the reconnaissance survey stage, there are substantial risks and large fund requirements because:

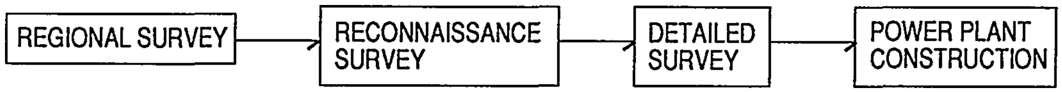
- Information is scarce, and many kinds of surface surveys are required.
- It is necessary to drill many exploratory wells.
- There are cases in which enormous efforts do not lead to actual development.

Currently, Japan's geothermal power generation is limited to about 440,000kW at 14 locations. Even if the power stations now being planned are added, total geothermal power generation will amount to only about 500,000kW. Such a small volume of geothermal power generation is largely due to the great risks involved and substantial fund requirements.

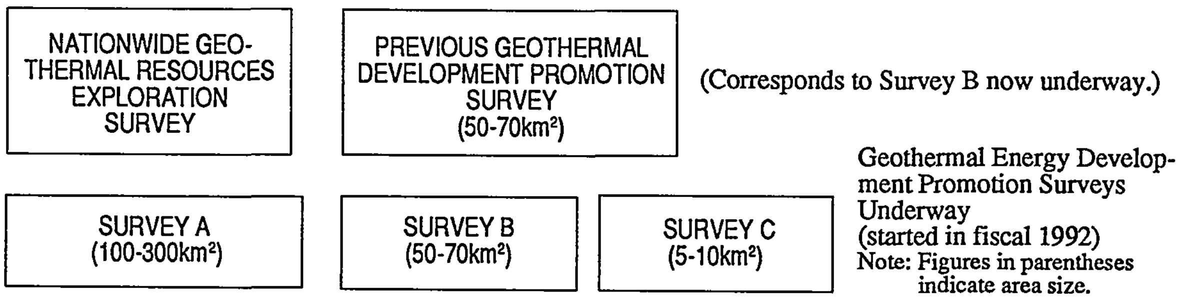
This promotion survey project aims to stimulate and promote geothermal development through NEDO's initiation of reconnaissance surveys and reduction of exploration risks for private-sector corporations.

At present, the projects are being conducted under three programs — Surveys A, B and C — with different survey ranges and contents which consider the degree of promise and the existing data. The positioning of the three programs in the process of geothermal development is shown in the following chart.

(Geothermal Energy Development Process)



(NEDO Geothermal Energy Survey)



(2) Standard Program of the Geothermal Development Promotion Surveys

(a) Standard program (Survey A)

Regarding regions where data is lacking, mainly surface surveys of large areas will be carried out, and the possible existence of high-temperature geothermal energy will be studied. The survey areas will range from 100km^2 to 300km^2. The survey period will be three years for each area, in principle. After the completion of the three-year survey, an overall evaluation will be made to examine the necessity of subsequent surveys (Surveys B and C). The standard program is shown below.

Survey Items and Survey Schedule (Survey A)

Survey Item	1st Year	2nd Year	3rd Year
(1) Geothermal reservoir possibilty survey			
(a) Ground surveys			
• Geological survey			
• Geochemical survey			
• Geophysical exploration			
(b) Well survey			
• Heat hole (400m class x 6 wells)			
• Exploratory well (1,000m class x 3 wells)			
(2) Integrated evaluation			

(b) Standard program (Survey B)

Survey B is for an area ranging from $50km^2$ to $70km^2$. It is designed to investigate the existence of geothermal resources and evaluate the environmental impact of geothermal development for three years in each area, in principle. The standard program for each year is shown below.

(c) Standard program (Survey C)

Survey C includes drilling production-size wells and long-term discharge tests, in addition to the contents of Surveys A and B, in promising geothermal development areas of $5km^2$ to $10km^2$. Beyond confirming geothermal reservoirs, as the previous promotion surveys did, Survey C will perform geothermal resource evaluation and conduct feasibility studies. At the same time, the environmental impact of geothermal energy development will be studied. The survey period will be four years for each area, in principle. The purpose of the survey is to significantly reduce private-sector corporations' exploration risk and, through the effective execution of the survey, to shorten the development time.

An optimum survey plan will be prepared, with adequate thought given to regional characteristics of the areas to be surveyed, existing survey data, and survey expenses. An example of the standard program is shown below.

(d) Judgment on the continuation of the surveys

In view of each year's Survey A, B and C results, the content of the next fiscal year's surveys will be prepared. Judgment on whether or not to proceed with the third year

Survey Items and Survey Schedule (Survey B)

Survey Item	1st Year	2nd Year	3rd Year
(1) Survey of geothermal resources			
(a) Surface survey			
• Geological survey			
• Geochemical survey			
• Geophysical exploration			
(b) Slim hole drilling			
• Heat hole (400m class x 3 wells)			
• Exploratory well (1,000m class x 2 wells)			
• Exploratory well (1,500m class x 3 wells)			
• Reinjection well (1,000m class x 1 well)			
(2) Environmental survey			
Variation and other surveys of atmosphere, water quality and hot spring water			
(3) Integrated evaluation			

Survey Items and Survey Schedule (Survey C)

Survey Item	1st Year	2nd Year	3rd Year	4th Year
(1) Surveys to evaluate geothermal resources				
(a) Detailed survey				
Geological survey, geochemical survey, geophysical exploration				
(b) Well survey				
• Exploratory well (2,000m class x 2 wells)				
• Precise exploratory well (2,000m class x 2 wells)				
• Production well (2,000m class x 2 wells)				
• Reinjection well (1,000m class x 2 wells)				
(c) Geothermal resource evaluation				
Long-term production test, geothermal reservoir evaluation				
(2) Environmental survey				
Variation and other surveys of atmosphere, water quality and hot spring water				
(3) Integrated evaluation				

of surveys will be based on the results of the surveys up to the end of the second fiscal year.

(3) Survey Regions

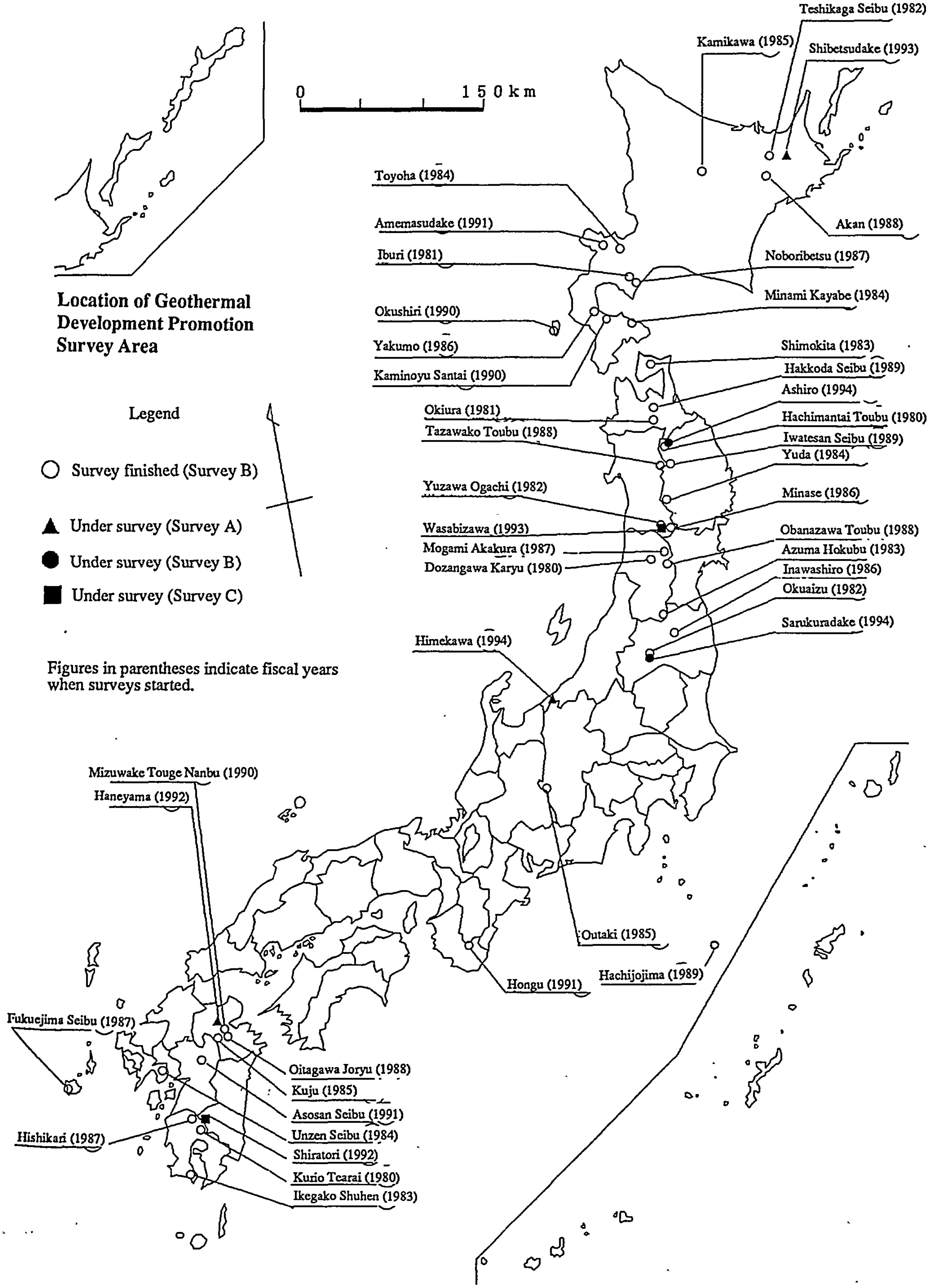
The geothermal development promotion survey has been carried out since 1980. The survey has been undertaken in 45 regions, and has been completed in 38 of these. Survey B is currently under way in only one region — Amemasudake, where the survey was begun in fiscal 1991.

Regarding Survey A, the field survey in the Haneyama area (Oita Prefecture) was completed, and an overall analysis and summary are currently under way. Field surveys are proceeding in the Shibetsu Dake area (Hokkaido) under the third-year program and in the Himekawa area (Niigata and Nagano Prefectures) under the second year program.

Field surveys of Survey B were undertaken in the Ashiro area (Iwate Prefecture) and the Sarukura Dake area (Fukushima Prefecture).

Field surveys of Survey C are going on in the Shiratori area (Miyazaki Prefecture), which entered the fourth year, and in the Wasabizawa area (Akita Prefecture) in its third-year phase.

The map below shows the locations of the past and present geothermal development promotion surveys, with the years of survey commencement also shown.



Location of Geothermal Development Promotion Survey Area

(4) Outline of Survey Results

(a) Survey items

The survey items for the regions where the survey has been completed are shown in the following tables.

General Table of Survey Items: Geothermal development promotion surveys (1)

Survey Area (Prefecture) (Area size) (Year of survey)	Ground Survey Items			Well Drilling		Successful Discharge Test Wells, Etc.
	Geological survey (area surveyed)	Geochemical survey (number of points)	Geophysical prospecting (number of points, length of lines)	Heat hole (depth m x number of wells)	Exploration well (depth m x number of wells)	
1. Hachimantai Tobu Iwate 70 km^2 1980-81	Map compilation, alteration zone survey (30 km^2)	Soil gas & 1m heat hole(150)	AFMT method (40)		400 x 1, 500 x 1 700 x 1, 800 x 1 1,000 x 2, 1,200 x 1 1,350 x 1, 1,500 x 1	N55-HT-2
2. Dozangawa Karyu Yamagata 60 km^2 1980-81	Map compilation		Ground magnetic (410)	200m x 8	1,000 x 2, 1,200 x 1 1,500 x 1, 1,600 x 1 1,800 x 1	
3. Kurino-Tearai Kagoshima 40 km^2 1980-81	Map compilation		Seismic reflection 4 lines: 8.5 km		500 x 1, 1,200 x 3 1,320 x 1, 1,500 x 1 1,800 x 2	N55-KT-5 N55-KT-8
4. Iburi Hokkaido 70 km^2 1981-82	Map compilation		Dipole mapping (326) Seismic reflection 2 lines: 8.5 km		1,000 x 2 1,500 x 4 1,800 x 1	
5. Okiura Aomori 70 km^2 1981-82	Map compilation		Schlumberger 2 lines: 23.25 km		500 x 2, 700 x 1 1,000 x 2, 1,200 x 2 1,500 x 2	N56-OU-4
6. Teshikaga Seibu Hokkaido 70 km^2 1982-83 1981-82	Map compilation	Hg.CO_2 geo-temperature at 1m depths (267)	Dipole mapping (318) AFMT (51)		1,000 x 3 1,500 x 2 1,800 x 1	
7. Yuzawa-Ogachi Akita 70 km^2 1982-83	Map compilation	Hg.CO_2 geo-temperature at 1m depths (210)	Dipole mapping (303) ELFMT (138)		350 x 1, 500 x 1 1,000 x 2, 1,030 x 1 1,200 x 1, 1,500 x 1 1,800 x 1	N57-YO-3
8. Okuaizu Fukushima 70 km^2 1982-83	Map compilation	Hg.CO_2 geo-temperature at 1m depths (276)	SP (1,996) AFMT (50)	(290m - 490m) x6	1,000 x 4, 1,300 x 1 1,500 x 2	N57-OA-4 N58-OA-6

General Table of Survey Items: Geothermal development promotion surveys (2)

Survey Area (Prefecture) (Area size) (Year of survey)	Ground Survey Items			Well Drilling		Successful Discharge Test Wells, Etc.
	Geological survey (area surveyed)	Geochemical survey (number of points)	Geophysical prospecting (number of points, length of lines)	Heat hole (depth m x number of wells)	Exploration well (depth m x number of wells)	
9. Shimokita Aomori 70 km² 1983-84	Map compilation	Hg.CO_2 geo-temperature at 1m depths (260)	SP (1,490) AFMT (70)		400 x 1, 1,000 x 1 1,200 x 1, 1,490 x 1 1,500 x 2, 1,700 x 1	N59-Sk-6
10. Azuma Hokubu Yamagata 70 km² 1983-84	Geological survey, alteration zone survey (70 km²)	Hg.CO_2 geo-temperature at 1m depths (201)	ELFMT (143)	400m x 5	600 x 1, 1,000 x 1 1,150 x 1, 1,289 x 1 1,300 x 1, 1,470 x 1 1,500 x 1	
11. Ikedako Shuhen Kagoshima 55 km² 1983-84	Map compilation	Hg.CO_2 geo-temperature at 1m depths (225)	TDEM (80)		1,000 x 2 1,500 x 3 1,700 x 1	
12. Toyoha Hokkaido 70 km² 1984-86	Geological survey, alteration zone survey (70 km²)	Hg.CO_2 geo-temperature at 1m depths (222)	Schlumberger 3 lines, 22.5 km TDEM (82) Mise-à-la-masse (144)	400m x 2	500 x 2 1,000 x 3 1,300 x 2 1,500 x 2	N59-TH-2 N60-TH-5 N61-TH-6 N61-TH-8
13. Minamikayabe Hokkaido 70 km² 1984-86	Geological survey, alteration zone survey (70 km²)	Hg.CO_2 geo-temperature at 1m depths (233)	Schlumberger 3 lines, 24.25 km AFMT (40) Mise-à-la-masse (208), Gravity prospecting (220)	400m x 3	1,000 x 2 1,200 x 1 1,500 x 2 1,700 x 2	N59-MK-2 N61-MK-6
14. Yuda Iwate 70 km² 1984-86	Geological survey, alteration zone survey (70 km²)	Hg.CO_2 geo-temperature at 1m depths (233)	Schlumberger 1 line, 16.75 km AFMT (70)	400m x 3	1,000 x 2 1,500 x 4	
15. Unzen Seibu Nagasaki 50 km² 1984-86	Geological survey, alteration zone survey (50 km²)	Hg.CO_2 geo-temperature at 1m depths (291)	Schlumberger 4 lines, 27.25 km, CSAMT (155) Mise-à-la-masse (275) SP (1,160), Gravity prospecting (506)	400m x 3	1,000 x 1 1,030 x 1 1,242 x 1 1,500 x 4	N61-UZ-7
16. Kamikawa Hokkaido 80 km² 1985-87	Geological survey, alteration zone survey (80 km²)	Hg.CO_2 geo-temperature at 1m depths (231) Multi-component gas (479)	SP (1,230) TDEM (40) Mise-à-la-masse (138)	400m x 3	1,000 x 4 1,249 x 1 1,500 x 1 1,600 x 1	
17. Outaki Nagano 70 km² 1985-86	Geological survey, alteration zone survey (70 km²)	Hg.CO_2 geo-temperature at 1m depths (202)	Schlumberger 3 lines, 25.25 km CSAMT (152) SP (1,101)	400m x 3	500 x 1 1,000 x 1 1,200 x 2 1,290 x 1	

General Table of Survey Items:
Geothermal development promotion surveys (3)

Survey Area (Prefecture) (Area size) (Year of survey)	Ground Survey Items			Well Drilling		Successful Discharge Test Wells, Etc.
	Geological survey (area surveyed)	Geochemical survey (number of points)	Geophysical prospecting (number of points, length of lines)	Heat hole (depth m x number of wells)	Exploration well (depth m x number of wells)	
18. Kuju Oita 70 km^2 1985-87	Geological survey, alteration zone survey (70 km^2)	Hg.CO_2 geo-temperature at 1m depths (273)	Schlumberger 4 lines, 23.50 km CSAMT (145) Mise-à-la-masse (156), SP (1,083)	400m x 3	847 x 1 911 x 1 1,000 x 2 1,331 x 1 1,700 x 2	
19. Yakumo Hokkaido 70 km^2 1986-88	Geological survey, alteration zone survey (70 km^2)	Hg.CO_2 geo-temperature at 1m depths (204)	Schlumberger 3 lines, 23.75 km TDEM (69) Seismic reflection 2 lines, 8.02 km Gravity (235)	400m x 3	1,000 x 2 1,200 x 1 1,300 x 1 1,500 x 2 1,700 x 1	
20. Minase Akita 70 km^2 1986-88	Geological survey, alteration zone survey (70 km^2)	Hg.CO_2 geo-temperature at 1m depths (232)	Schlumberger 6 lines, 57.0 km MT (58) SP (1,419)	400m x 3	700 x 1 1,000 x 2 1,200 x 1 1,500 x 4	N63-MS-4 N63-MS-6
21. Inawashiro Fukushima 70 km^2 1986-88	Geological survey, alteration zone survey (70 km^2)	Hg.CO_2 geo-temperature at 1m depths (222)	Schlumberger 2 lines, 20.0 km MT (40) SP (1,100)	400m x 3	1,000 x 3 1,300 x 1 1,500 x 3	
22. Noboribetsu Hokkaido 75 km^2 1987-89	Geological survey, alteration zone survey (75 km^2)		Schlumberger 3 lines, 29.0 km MT mthod (60) Mise-à-la-masse (160)	500m x 2	1,000 x 2 1,387 x 1 1,500 x 2 1,520 x 1	
23. Mogami-Akakura Yamagata 70 km^2 1987-88	Geological survey, alteration zone survey (75 km^2)	Hg.CO_2 geo-temperature at 1m depths (200)	CSAMT (98) MT (85)	400m x 3	1,000 x 2 1,300 x 1 1,500 x 1	
24. Fukuejima Seibu Nagasaki 75 km^2 1987-88	Geological survey, alteration zone survey (75 km^2)	Hg.CO_2 geo-temperature at 1m depths (216)	CSAMT (151) Gravity (459)	400m x 3	1,000 x 2 1,300 x 1 1,500 x 1	
25. Hishikari Kagoshima 50 km^2 1987-89	Geological survey, alteration zone survey (50 km^2)	Hg.CO_2 geo-temperature at 1m depths (153)	Schlumberger lines, 28.25 km TDEM (82) Gravity (1,160)	400m x 3	1,000 x 3 1,200 x 1 1,500 x 3	
26. Akan Hokkaido 65 km^2 1988-90	Geological survey, alteration zone survey (75 km^2)	Hg.CO_2 geo-temperature at 1m depths (234)	CSAMT (100) High-density CSAMT (208) MT (38) Mise-à-la-masse (160), Gravity (959)	400m x 3	1,000 x 2 1,200 x 2 1,500 x 2 1,700 x 1 (reinjection well) 451 x 1	N2-AK-7

General Table of Survey Items:
Geothermal development promotion surveys (4)

Survey Area (Prefecture) (Area size) (Year of survey)	Ground Survey Items			Well Drilling		Successful Discharge Test Wells, Etc.
	Geological survey (area surveyed)	Geochemical survey (number of points)	Geophysical prospecting (number of points, length of lines)	Heat hole (depth m x number of wells)	Exploration well (depth m x number of wells)	
27. Tazawako Tobu Akita 65 km² 1988-90	Geological survey, alteration zone survey (65 km²)	Hg.CO_2 geo-temperature at 1m depths (185)	Schlumberger 3 lines, 31.5 km MT (70) Mise-à-la-masse (160) Gravity (233)		1,000 x 4 1,500 x 4	
28. Obanazawa Tobu Yamagata 65 km² 1988-89	Geological survey, alteration zone survey (65 km²)	Hg.CO_2 geo-temperature at 1m depths (174)	Schlumberger 3 lines, 27.5 km TDEM (80)	400m x 7	1,000 x 1 1,360 x 1 1,703 x 1	
29. Oitagawa Joryu Oita 70 km² 1988-89	Geological survey, alteration zone survey (70 km²)	Hg.CO_2 geo-temperature at 1m depths (250)	Schlumberger 2 lines, 16.0 km MT (55) EMAP, 2 lines: 16.0 km	400m x 3	866 x 1 1,000 x 1 1,504 x 1 1,703 x 1	
30. Hakkoda Seibu Aomori 55 km² 1989-91	Geological survey, alteration zone survey (55 km²)	Hg.CO_2 geo-tem–perature at 1m depths (163)	Schlumberger 2 lines, 24.0 km MT (98)		1,000 x 4 1,500 x 3 1,564 x 1	M3-HD-7
31. Iwatesan Seibu Iwate 60 km² 1989-91	Geological survey, alteration zone survey (60 km²)	Hg.CO_2 geo-tem–perature at 1m depths (180)	Schlumberger 5 lines, 60.0 km Mise-à-la-masse(150) SP (1,174) High-density CSAMT (205) High-precision MT (56)		1,000 x 3 1,200 x 3 1,500 x 1 1,700 x 1	N1-IT-2
32. Hachijojima Tokyo 70 km² 1989-91	Geological survey, alteration zone survey (60 km²)	Hg.CO_2 geo-tem–perature at 1m depths (155) Multi-component gas (545)	Mise-à-la-masse (160) TDEM (81) Seismic reflection, offshore 261.2 km in-land 5.6 km		510 x 1 1,000 x 3 1,200 x 1 1,300 x 1 1,500 x 2	N2-HJ-5

General Table of Survey Items:
Geothermal development promotion surveys (5)

Survey Area (Prefecture) (Area size) (Year of survey)	Ground Survey Items			Well Drilling		Successful Discharge Test Wells, Etc.
	Geological survey (area surveyed)	Geochemical survey (number of points)	Geophysical prospecting (number of points, length of lines)	Heat hole (depth m x number of wells)	Exploration well (depth m x number of wells)	
33. Okushiri Hokkaido 70 km² 1990-1992	Geological survey, alteration zone survey (60 km²)	Hg, CO_2, geo-temperature at 1m depths (133)	Gravity (403) TDEM (82)	400 x 2	1,200 x 5 1,500 x 1	N4-OS-5
34. Kaminoyu-Santai Hokkaido 70 km² 1990-1992	Geological survey, alteration zone survey (60 km²)	Hg, CO_2, geo-temperature at 1m depths (120)	Gravity (360) High-precision MT (88) Schlumberger 3 lines, 22 km	400 x 3	1,000 x 2 1,200 x 1 1,500 x 2 1,800 x 2	N3-KS-3 N4-KS-6
35. Mizuwaketoge Nanbu Oita 80km² 1990-1992	Geological survey, alteration zone survey (70 km²)	Hg, CO_2, geo-temperature at 1m depths (180) Natural alpha-ray (681) High-density mercury (273)	Gravity (360) High-precision MT (85) Schlumberger 3 lines, 28 km Mise-a-la-masse (254) Fluid potential (30)		1,000 x 3 1,200 x 1 1,300 x 1 1,500 x 1 1,700 x 1 2,000 x 1	N2-MW-2
36. Amemasu-dake Hokkaido 70 km² 1991-1993	Geological survey, alteration zone survey (119 km²)	Hg, CO_2, geo-temperature at 1m depths (130) Multi-component gas (416) Fluid geochemical	Gravity (408) MT (69) Schlumberger 1 line, 10 km	400 x 6	1,000 x 1 1,300 x 2 1,485 x 1 1,500 x 1	
37. Hongu Wakayama 70 km² 1991-1992	Geological survey, alteration zone survey (60 km²)	Hg, CO_2, geo-temperature at 1m depths (155)	Gravity (446) CSAMT (150)	200 x 7 400 x 3	1,000 x 2	
38. Asosan Seibu Kumamoto 70 km² 1991-1993	Geological survey, alteration zone survey (70 km²)	Hg, CO_2, geo-temperature at 1m depths (103) Fluid geochemical	High-precision MT (52) Schlumberger 5 lines, 30 km	400 x 3	1,000 x 1 1,200 x 3 1,700 x 2 1,800 x 1	

(b) Survey results

The maximum temperature and outline of the results for the 38 regions where the survey has been completed are shown in the following table.

Summaries of Geothermal Development Promotion Survey Results (1)

Area	Prefcture	Max. temp. (°C)	Well where max. temp. recorded	Summary of results
Hachimantai Tobu	Iwate	218	HT-3	Centering around HT-2, high-temperature areas of more than 200°C have been ascertained in a wide region extending to Toushichi hot spring.
Dozangawa Karyu	Yamagata	247	DZ-6	High-temperature areas of more than 200°C have been ascertained around Hijiori Basin (caldera) and Ishidaki hot spring.
Kurino-Tearai	Kagoshima	298	KT-8	Centering around KT-5 and -8, high-temperatrue areas of more than 200°C are widespread.
Iburi	Hokkaido	271	IB-5	High-temperature areas of more than 200°C are distributed around Karurusu hot spring.
Okiura	Aomori	167	OU-8	There is a tendency for temperature to increase in the eastern part of the area.
Teshikaga Seibu	Hokkaido	140	TS-2	Thermal gradient rises sharply beneath the lower Neogene.
Yuzawa-Ogachi	Akita	291	YO-7	High-temperature areas, centering around Mt. Yamabushidake and the Uenotai area, have been ascertained. Survey C is under way in Wasabizawa.
Okuaizu	Fukushima	286	OA-6	High-temperature areas are distributed primarily southwest of OA-6. Geothermal power plant under construction at Yanaizu Nishiyama.
Shimokita	Aomori	228	SK-6	High-temperature areas of more than 200°C have been ascertained in the area stretching from Satougadaira to Akagawa Shimofuro hot spring.
Azuma Hokubu	Yamagata	263	AZ-7	There are high-temperature areas in the southeastern direction of the surveyed area.
Ikedako Shuhen	Kagoshima	147	ID-3	There are high-temperature areas in the eastern central area.
Toyoha	Hokkaido	309	TH-2	Centering around TH-2 and -4, high-temperature areas are distributed along Yunosawa swamp in the NW-SE direction.
Minamikayabe	Hokkaido	184	MK-6	Centering around MK-6, high-temperature areas are distributed in the whole eastern area of Mt. Nakitsura.
Yuda	Iwate	159	YD-2	High-temperature areas are distributed around Yunokawa and Yumoto hot springs.

Summaries of Geothermal Development Promotion Survey Results (2)

Area	Prefecture	Max. temp. (°C)	Well where max. temp. recorded	Summary of results
Unzen Seibu	Nagasaki	248	UZ-1	Centering around Unzen hot spring, high-temperature areas are distributed in the NW direction
Kamikawa	Hokkaido	241	KK-5	High-temperature areas have been ascertained upstream Shiramizu River in the SE part of the surveyed area.
Outaki	Nagano	64	OT-1	High-temperature areas have been ascertained in the NW part of the area.
Kuju	Oita	206	KJ-7	No high-temperature anomalies have been ascertained in the surveyed area.
Yakumo	Hokkaido	232	YK-6	High-temperature areas are distributed from YK-5 to YK-6 and Y-3 in the EW direction.
Minase	Akita	290	MS-6	High-temperature areas are distributed around Ketakuranuma in the SW part and Ooyu in the eastern part of the area.
Inawashiro	Fukushima	227	IN-3	High-temperature areas have been ascertained in the eastern part of the surveyed area.
Noboribetsu	Hokkaido	250	NB-5	High-temperature hot water exists and geothermal potential is high.
Mogami-Akakura	Yamagata	97	MA-3	High-temperature areas are restricted to around Akakura hot spring, and overall geothermal potential is not high.
Fukuejima Seibu	Nagasaki	81	FS-3	High-temperature areas are restricted to around Arakawa hot spring, and the scale is small.
Hishikari	Kagoshima	118	HK-6	High-temperature required for geothermal power generation does not exist, so geothermal potential is low.
Akan	Hokkaido	292	AK-7	Following three geothermal development areas are promising: (1) Meakan-Akan hot spring, (2) Shiramizu River (upstream) and (3) Oakan hot spring.
Tazawako Tobu	Akita	289	TZ-4	Promising area extends from the eastern part of Nyuto hot spring to Mt. Yumori, Mt. Sasamori and Mt. Komagadake.
Obanazawa Tobu	Yamagata	142	OB-2	High-temperature areas center around the Ginzan hot spring.
Oitagawa Joryu	Oita	103	OI-3	High-temperature areas tend to spread from the SW part of the surveyed area to outside.
Hakkoda Seibu	Aomori	219	HD-8	Promising area extends from Sukayu and Jogakura hot springs to the North Hakkoda volcanoes.

Summaries of Geothermal Development Promotion Survey Results (3)

Area	Prefecture	Max. temp. (°C)	Well where max. temp. recorded	Summary of results
Iwatesan Seibu	Iwate	316	IT-8	High-temperature areas extend in EN directions, and promising area stretches from upstream Omatsukurasawa and Yunosawa rivers.
Hachijojima	Tokyo	316	HJ-7	High-temperature, high-pressure geothermal reservoir distributed in southern Higashiyama makes the area promising. Companies have started development of the area.
Okushiri	Hokkaido	181	OS-5	There is a promising area mid- to upstream of the Horonai River.
Kaminoyu-Santai	Hokkaido	197	KS-7	Geothermal sources with temperatures of nearly 200°C are ascertained to exist at great depths of KS-6 and KS-7.
Mizuwaketoge Nanbu	Oita	243	MW-9	High-temperature area in the Terayuka area has been ascertained and companies have started to develop the area. There is also a geothermal reservoir southeast of Yamashitanoike.
Amemasudake	Hokkaido	205	AM-4	High-temperature areas of 200°C or more are restricted to the SE part of the surveyed area.
Hongu	Wakayama	105	HG-2	High-temperature required for geothermal power generation does not exist, so the area's geothermal potential is low.
Asosan Seibu	Kumamoto	217	AS-6	Promising areas are restricted to around surface indication area.

(c) Maximum temperature classification

The temperature-based classification of the regions where the survey has been completed is shown below.

Areas Grouped by Maximum Temperature

Confirmed temperatures	Number of areas	Areas
200°C or higher	24	Hachimantai Tobu, Dozangawa Karyu, Kurino Tearai, Iburi, Yuzawa Ogachi, Okuaizu, Shimokita, Azuma Hokubu, Toyoha, Unzen Tobu, Kamikawa, Kuju, Yakumo, Minase, Inawashiro, Noboribetsu, Akan, Tazawako Tobu, Iwatesan Seibu, Hakkoda Seibu, Hachijojima, Mizuwaketoge Nanbu, Amemasudake, Asosan Seibu
180-200°C	3	Minamikayabe, Okushiri, Kaminoyu Santai
150-180°C	2	Okiura, Yuda
100-150°C	6	Teshikaga Seibu, Ikedako Shuhen, Hishikari, Obanazawa Tobu, Oitagawa Joryu, Hongu
Under 100°C	3	Outaki, Mogami Akakura, Fukuezima Seibu
Total	38	

(d) Discharge tests

In discharge tests, flow tests were conducted at the following 24 wells in the regions shown in the table below.

List of Discharge Test Results in Geothermal Development Promotion Survey

Area	Prefecture	Well Names	Depth[1) (m)	Temperature[2) (°C)	Test Date	Steam Rate[3) (t/h)	Hot Water[3) (t/h)
Hachimantai Tobu	Iwate	N55-HT-2	1,200	213.0	Sept. 8, 1982	0.02	0.2
Kurino-Tearai	Kagoshima	N55-KT-5 N55-KT-8	1,200 1,800	281.9 298.4	Feb. 12, 1982 Oct. 3, 1982	6.0 18.0	1.8 33.0
Okiura	Aomori	N56-OU-4	700	148.7	July 26, 1983	0.6	12.0
Yuzawa-Ogachi	Akita	N57-YO-3	1,200	241.9	Oct. 16, 1983	11.6	5.5
Okuaizu	Fukushima	N58-OA-6 N57-OA-4	1,500 1,300	286.3 266.5	Dec. 22, 1983 Jan. 10, 1984	0.6 7.0	0.6 5.0
Shimokita	Aomori	N59-SK-6	1,700	228.6	June 29, 1985	3.4	9.3

List of Discharge Test Results in Geothermal Development Promotion Survey (continued)

Area	Prefecture	Well Names	Depth[1) (m)]	Tempera-ture[2)] (°C)	Test Date	Steam Rate[3)] (t/h)	Hot Water[3)] (t/h)
Toyoha	Hokkaido	N60-TH-5 N61-TH-8 N61-TH-6 N59-TH-2	1,000 500 1,000 1,500	237.3 172.2 266.5 309.0	Nov. 11, 1986 Aug. 1, 1987 Aug. 6, 1987 Aug. 8, 1987	0.7 8.5 6.0 3.6	5.4 6.5 26.1 0
Minamikayabe	Hokkaido	N59-MK-2 N61-MK-6	1,200 1,700	177.5 184.2	May 10, 1987 May 26, 1987	0.5 1.3	3.8 8.3
Unzen Seibu	Nagasaki	N61-UZ-7	1,500	243.3	June 2, 1987	5.0	19.5
Minase	Akita	N63-MS-6	1,500	281.3	Sept. 1, 1989	6.7	13.3
Akan	Hokkaido	N2-AK-7	1,500	292.0	Oct. 23, 1991	4.8	0.4
Hakkoda Seibu	Aomori	N2-HD-7	1,500	196.8	Oct. 17, 1992	1.2	12.6
Iwatesan Seibu	Iwate	N1-IT-2	1,000	223.0	Oct. 31, 1990	0.5	1.8
Hachijojima	Tokyo	N2-HJ-5	510	245.8	Apr. 12, 1991	5.7	0.9
Okushiri	Hokkaido	N4-OS-5	1,500	180.9	Mar. 16, 1994	2.9	25.9
Kaminoyu Santai	Hokkaido	N3-KS-3 N4-KS-6	1,500 1,800	121.3 196.1	Nov. 16, 1992 June 13, 1993	0.5 2.4	19.3 15.2
Mizuwaketoge Nanbu	Oita	N2-MW-2	1,000	199.1	Feb. 25, 1993	3.0	17.3

Notes 1. Drilled depth
2. Maximum temperature in the well
3. Rate after separator. In principle, at the time of minimum well pressure of characteristics tests.

1.2 Summary for FY1994

Surveys were carried out in a total of seven regions: two regions where Survey A or C entered the third year, two regions where Surveys A or Survey C entered the second year and three regions where Survey A or B was started. An outline of the survey results in these regions is as follows:

(1) Third-Year Area (Survey Started in FY1992)

(a) Haneyama area (about 300 km² covering parts of Kusu-machi and Kokonoe-machi, Survey A)

(i) Summary of survey area

This is an area adjacent to the north-western side of the Mizuwake-touge Nambu area. In the northern part of the area, the Beppu-Kita fault, which is a part of the Matsuyama-Imari fault, extends in the E-W direction, with its southern side depressed structurally. There is a geothermal zone stretching between Noya and Mizuwake-touge, while Haneyama, with its prominent N-W faults, is located in the southwestern part of the area.

(ii) Contents and results of the survey

With the heat flow survey (900 m x 1, 64°C) completed, exploratory wells (1,400 m x 1, 1,600 m x 1) were drilled at the Noya area, a promising geothermal resource location in the southeastern part of the survey area.

(b) Shiratori area (about 7.5 km^2 in Ebino City, Miyazaki Prefecture, Survey C)

(i) Summary of survey area

This area is situated on the northwestern slope of Mt. Shiratori in the Kirishima volcanic range. In the northern part of the area are the Shiratori hot springs with fumaroles. Hot points with temperatures of more than 200°C were confirmed at depths of more than 1,000 m.

(ii) Contents and results of the survey

During fiscal 1994, the drilling of two 2,000-class exploratory wells was completed. It was learned that for ST-2, the highest temperature at a depth of 1,030 m is 201°C, and for ST-1, the highest temperature at a depth of 2,000 m is 203°C. The drilling of another exploratory well (ST-3), begun in December 1994, is continuing.

As for the geological structure, the basement consists of the Shimanto formations of the Mesozoic and Palaeogenic eras. The formations comprise, from the deeper layer, the Quaternary Kirishima welded tuff, Ebino formation, Kakuto andesite rocks and Kirishima volcanic rocks. Most of the area is extensively covered with old Shiratori lava formed in the later part of the Pleistocene period. From the results of various surface surveys, the presence of lineaments and faults in the NW-SE and NE-SW directions was inferred. The Shiratori hot springs are of the acidic SO_4 type, and it is predicted that the springs were formed from ground water heated by the steam from a deep, high-temperature reservoir.

(2) Second-Year Areas (Survey Started in FY1993)

(a) Shibetsudake area (about 300 km^2 covering Nakashibetsu-cho and Shibetsu-cho, Survey A)

(i) Summary of survey area

This area, located in the eastern part of Hokkaido, belongs to the Chishima volcanic zone. The area includes the Shibetsu and Musa volcanoes, which are located on the Akan-Shiretoko volcanic range stretching in the NE-SW direction. There are such hot springs as Yoroushi (85°C), Kawakita (42°C) and Yunosawa (42°C) in this area.

(ii) Contents and results of survey

During fiscal 1994, three heat flow wells (T-1, 2 and 3) were drilled based on results of surface surveys. Consequently, well-bottom temperatures of 92°C, 75°C and 62°C were ascertained at a depth of 800 m in each well. In fiscal 1995, drilling of a 1,800-m class exploratory well is planned in the Musadake area, and that of a 1,200-m class exploratory well is scheduled for the Yoroushi area.

The geological structure of this area is characterized by uplift belts/faults/flexure/layer inclination, with prominent faults of NE-SW and NW-SE directions. Promising geothermal fields are considered to exist in two areas — the Musadake area in the northeastern part of the region and the Yoroushi area in its southwestern part.

(b) Wasabizawa Region (About 8 km^2 in

Yuzawa City and Ogachi-Machi, Akita Prefecture, Survey C)

(i) Summary of survey area

The area is located close to the center of the Yuzawa-Ogachi region in which a geothermal development promotion survey was carried out in fiscal 1982-83. It is located about 6 km southwest of Kaminotai Geothermal Power Plant. During the previous survey, it was confirmed through successful discharge tests at the N58YO-3 well, where a steam flow rate of 11.3 t/h and hot water flow rate of 5.1 t/h were registered, that a high-temperature reservoir exists in the granodiorite that forms the basement. The current survey aims to more accurately determine the expanse of the reservoir within the basement and thereby reduce some of the initial risks of development.

(ii) Contents and results of survey

During fiscal 1994, geological/alteration zone/fracture-type reservoir surveys, a fluid geochemical survey, gravity survey, electromagnetic exploration (CSAMT, MT method) and drilling of two exploratory wells (WZ-2, 3) were implemented.

Regarding geological structure, the basement is composed of granite and green schist formed in the Tertiary period, and the Doroyu layer, Otoriyazawa layer, Minasegawa layer (all formed in the Neogene period) and Takamatsudake sedimentary rocks (Quaternary period) are piled from below. As for faults, NW-direction faults, such as the Wasabizawa fault and the Doroyu fault, are prominent. The discontinuity lines accompanying resistivity basements can be roughly grouped into NW and NE lines, and due to faults in which these discontinuity lines are reflected, basement rocks are considered to be depressed in an easterly direction.

According to the distribution of alteration zones and an abnormally high mercury density, the reservoir was shown to stretch from YO-3 to the northwest.

In the exploratory well drilling, WZ-2 showed a temperature of 285°C at the well bottom 1,500 m, a steam flow rate of 4 t/h, and a hot water flow rate of 8 t/h. The drilling of WZ-3 is now in progress.

For fiscal 1995, the drilling of two 1,500-class exploratory wells and one 1,000-m class medium-diameter reinjection well are planned.

(3) First-Year Areas (Survey Started in FY1994)

(a) Himekawa area (about 170 km² in Itoigawa City, Niigata Prefecture, and Hakuba-mura, Nagano Prefecture, Survey A)

(i) Summary of survey area

This area is located in the Itoigawa-Shizuoka tectonic line. Because volcanic rock newly erupted from the Shirouma Oike Volcano are widely scattered in the southwestern part of the region, there is a possibility that a heat source exists deep underground. In such an underground area, it is presumed that Mesozoic and Paleozoic strata and granite formations are convoluted in a complex way.

(ii) Contents and results of survey

Geological/alteration zone surveys, gravity survey, electromagnetic exploration (CSAMT method), geochemical survey of soil gas, and a hot spring water survey were conducted in fiscal 1994. As a result, the following points became clear: 1) a NE-SW granite formation intrudes into the southwestern part of the area, 2) there are N-S direction lineaments in the area, and 3) there is an extremely low resistivity zone just below Fubukidake.

During fiscal 1995, two 900-m class heat flow wells and one 600-m class heat flow well are scheduled to be drilled, while a fumarolic gas survey is also planned to be implemented.

(b) Ashiro area (about 12 km^2 covering Ashiro-machi, Ninohe-gun, Iwate Prefecture, Survey B)

(i) Summary of survey area

This area was, the target area of a geothermal development promotion survey carried out in fiscal 1980 and 1981. The existence of a high-temperature reservoir zone in Onuma, Sumikawa and Komonomori, located to the north of the E-W volcanic range that includes the Hachimantai volcano, has been confirmed. There presumably is a sufficient possibility that a promising geothermal field is located in this area, because it is situated to the east of the aforementioned locations.

(ii) Contents and results of survey

In fiscal 1994, it was decided to carry out further surveys in this area, and preparations were made to conduct surface survey and environmental effect survey.

(c) Sarukuradake area (about 14 km^2 in Yanaizu-machi, Kawanuma-gun, Fukushima Prefecture, Survey B)

(i) Summary of survey area

This area corresponds to the southern rim of the Okuaizu area, the site of a geothermal development promotion survey conducted in fiscal 1982 and 1983. During that survey, the existence of a dominant high-temperature reservoir was confirmed, and the confirmation led to geothermal development at the Yanaizu Nishiyama Geothermal Power Generating Plant (its operation was started in May 1995; rated capacity of 65 MW). In consideration of this, the existence of a high-temperature reservoir in this area is believed probable.

(ii) Contents and results of survey

During fiscal 1994, it was decided to carry out further surveys in this area, and two exploratory wells were drilled.

2. Feasibility Test of Small-Scale Binary Cycle Geothermal Power Generation Systems

2.1 Objectives and Work Program

The geothermal resources currently utilized for power generation in Japan are limited to high-temperature steam. Hot water which is produced in large quantities together with steam is reinjected without being used. Low- and medium-temperature hydrothermal resources exist in vast quantities throughout the nation, but their utilization is by no means adequate.

The objectives of this project are to develop a "geothermal binary power generation system" to generate power with hot water of 80°C to 150°C as the heat source. The ultimate aim of these activities is to promote the propagation of the system.

The contents of the work program are to perform the research for the spread and practical utilization of the small to medium-sized binary power generation system, including an economic evaluation and research on infrastructure to be introduced, to manufacture the system equipment and to field test the system.

Table 1 Outline of Survey Plan

Item / Fiscal Year	1991	1992	1993	1994	1995	1996	1997
1. Research for diffusion and practical use							
2. Development of a 100 kW-class geothermal binary cycle generating plant							
• Study of the 100 kW-class generating plant							
• Development of the 100 kW-class generating plant							
• Improvement of the systems							
3. Development of a 500 kW-class binary cycle generating plant							
• Study of the 500 kW-class generating plant							
• Development of the 500 kW-class generating plant							

2.2 Summary for FY1994

(1) Studies for Propagation and Practical Use

A system to evaluate economic factors was developed, and the power generation unit cost was calculated on a trial basis. A survey and study were carried out regarding practical use and the basis for introduction.

(2) Development of a Small-Scale Geothermal Binary Power Generation Systems

System equipment was transported and installed. (The status of the installation is shown in Photo 1.) Subsequently, after trial operation and adjustment, pre-use tests were successfully passed on January 20, 1995, and demonstration operation began. Operating hours in fiscal 1994 totaled 1,386 hours, and generated power totaled 155,156 kWh.

(3) Development of a Medium-Scale Geothermal Binary Power Generation System

Preparations for filing an application with the Government, detailed development of the system and manufacturing of some equipment (parts of a turbine/generator as well as a condenser and a remaining-heat-used evaporator) were implemented during the fiscal year.

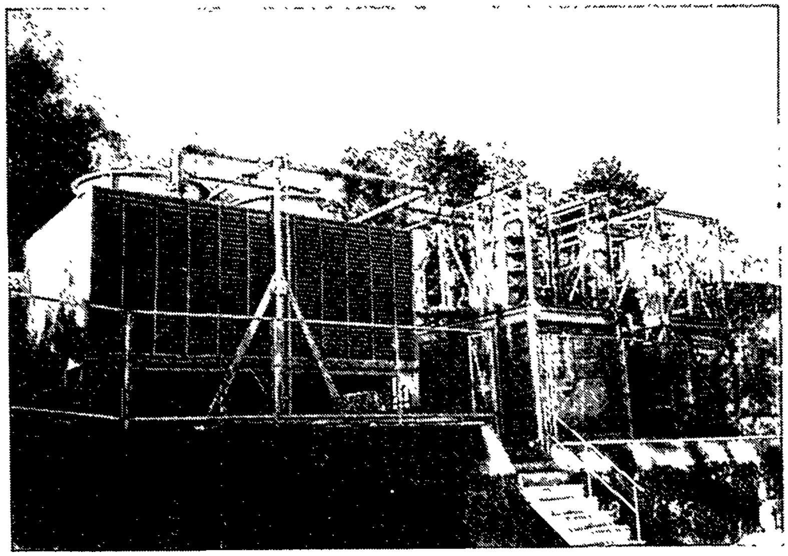


Photo 1 100 kW-class Geothermal Binary Cycle Generating Plant Construction (From left, cooling tower, turbine and generation unit and heat exchanger unit)

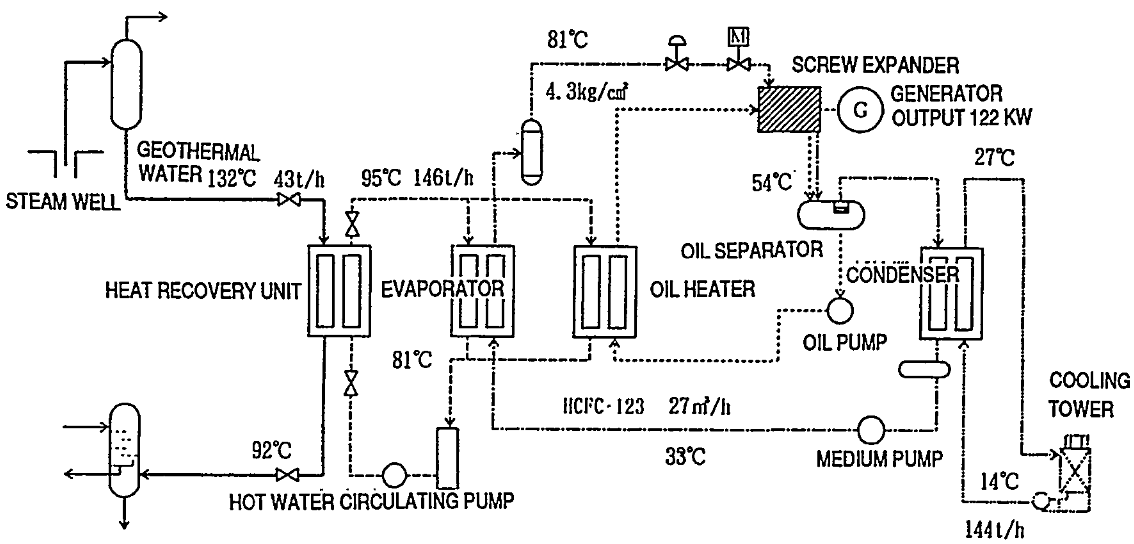


Fig. 1 100 kW-class Generating Plant Heat Balance Diagram (planned value)

N96-02-0184

CHAPTER 3

DEVELOPMENT
OF
TECHNOLOGIES FOR UTILIZING
GEOTHERMAL ENERGY

DEVELOPMENT
OF
TECHNOLOGIES FOR UTILIZING
GEOTHERMAL ENERGY

Contents

I

Confirmation Study of the Effectiveness of Prospecting Techniques for Deep Geothermal Resources

1. Development of Exploration Techniques for Fracture-Type Geothermal Reservoirs

1.1 Objectives and Work Program

(1) Objectives

In a geothermal reservoir, the flow of resources is greatly dominated by fractures within the reservoir. Taking note of new prospecting techniques considered effective for highly precise exploration of fractures, we will develop the technology to apply them to geothermal prospecting.

(2) Work Programs

(a) Development of exploration methods using seismic waves

The development of several techniques will be implemented, including high resolution seismic reflection methods, which detect detailed underground fracture structures through seismic waves generated by shocks given to the ground surface; vertical seismic profiling (VSP), which directly detects fracture structures by creating seismic waves at the ground surface and receiving them within a well; and seismic tomography, which generates and receives seismic waves between two wells and produces images of the geographic condition between the wells. Geothermal-application downhole instruments for use with these survey techniques and core analysis equipment will also be improved.

1.2 Summary for FY1994

(1) Development of Exploration Methods Using Seismic Waves

Because the application of these methods to the geothermal areas became possible by fiscal 1993, their verification tests were started in a geothermal development area in fiscal 1994. During the fiscal year, the Kakkonda area (Iwate Prefecture) was chosen as the test field, because it is a representative area where small fractures form geothermal reservoirs in a network pattern. The high resolution reflection method and VSP were implemented in this field.

(a) High resolution seismic reflection method

A reflection measurement of about 9 km was set on a road running along the Kakkonda valley, and the data from about 600 vibration generation points were obtained based on the use of four vibrators. Vibration receivers were installed at 10 m intervals, while vibrations were generated at 20 m intervals. Also, two kinds of data on different vibration frequencies were collected at the same points. Data analysis confirmed that there is a strong reflector about 0.8 to 1 second below the power generation plant. This was considered to reflect the pre-Tertiary system structure, which is attracting much attention as a deep underground geothermal reservoir. A reflexive face that features excellent continuity near 0.4 second is thought to correspond to altered andesite in the Kunimi-Touge Formation. Based on such analytical results, the seismic reflection method using microearthquakes was confirmed to be an effective means of analyzing the geological structure in the geothermal zone, because of its ability to make use of a long offset distance, acquire detailed data and control the frequency of the microearthquakes generated.

(b) VSP

To reveal the geological and fractured structure of the field, in addition to analysis results of the seismic reflection method, VSP using a maximum offset distance of 725 m was implemented, and a deep exploration well located on the seismic reflection method measurement line was made the receiving well; vibrators were used as earthquake sources at six points. The receiving points were located at intervals of 20 m in the 80 to 600 m section, and the total number of microearthquakes was 148. The related analysis showed that the time for the return travel from the downhole and from the reflectors could be compared, so it was possible to compare the reflector face section, obtained with the high-resolution seismic reflection method, and the geological section. It was also learned that there is a strong reflector near the 0.25 second point, which presumably corresponds to the andesite in the ground layer of the Donokami hot spring. S-transmission waves were observed, so the VSP method was found to be an effective means of clarifying geothermal resource reservoirs.

(c) Development of geothermal-use downhole equipment

The improvement and operating tests of geothermal downhole equipment, to be used for VSP and seismic wave tomography, were implemented, and the safety and practicability of the equipment were confirmed through its actual utilization in VSP experiments. Main points of improvement were the development of a heat-proof electromagnetic clutch in a revision of the sensor-unit safety mechanism and a smaller temperature increase in a thermos bottle through reduction of power required in the electronics section.

(d) Revision and measurement of core analysis equipment

Based on the measurement of core samples through a high-temperature, high-pressure seismic wave speed measuring instrument, it was surmised that the reflector of 0.8 to 1 second, measured under the seismic reflection method, constitutes the border between the Kunimi-Touge Formation and the pre-Tertiary system. With regard to residual magnetism measuring instruments, a measurement support program to analyze and record characteristics of each fracture section using visual images, and a program to record the relative movement direction of fractures were developed during the year. In the field of fluid content measurement, a quantitative analysis program based on a Laser Raman spectrum-measuring instrument was developed. Furthermore, the quality-equalizing temperature and ice-melting point of samples from the Kakkonda area were measured.

(e) Overall analysis

The results of tests in the Kakkonda area and existing information, such as geological sectional views, were subjected to a comparative study. As a result, the anticline structure, soil layer borders and intrusive rock shapes corresponding to the foundation rocks (pre-Tertiary system) just below the power generation plant, were estimated based on reflection records. Further, it was confirmed that, in the vicinity of the power generation plant, weak zones of the reflectors are distributed in the shallow subsurface ground, so that the reflection pattern there is different from that in other areas. It was also ascertained that, with VSP, the lost circulation portion in the shallow underground is characterized by reflection events of major amplitude. Thus, VSP was confirmed to be effective in detecting lost circulation spots.

1.3 Future Tasks

In connection with the future development of seismic wave exploration methods to be conducted in fiscal 1995 and thereafter, the geothermal development area in Ogiri, Kagoshima Prefecture, was selected as the exploration field, because it is a representative area where a prominent vertical-type fault forms a geothermal reservoir. Through the application of exploration methods and comparison of its results with existing data, practicability and effectiveness of various exploration methods will be studied in the future.

2. Deep Geothermal Resources Survey

2.1 Objectives and Contents of Survey

(1) Past Development of This Survey

Regarding the promotion of geothermal power generation, the approach considered to be most prompt and effective in Japan is to increase the capacity of geothermal power plants already in operation. From this perspective, investigation is being conducted on the possibility of developing deep geothermal resources that are located below shallower subsurface geothermal reservoirs. Deep geothermal resources (approximately 2,000 m or deeper) are considered promising in terms of resource volume, economy and locational conditions, but as depth increases, exploration difficulties grow phenomenally, and many drilling impediments are expected. The current state of affairs is that, because of the strong possibility of resultant cost increases, deep subsurface development cannot be undertaken in consideration of the risk. In order to promote the development of deep geothermal resources, it is necessary to understand the nature of their existence and at the same time proceed effectively with the research of exploration/drilling technologies, as well as the possibilities for utilizing these resources.

(2) Objectives of the Survey

The objectives of this survey are to investigate (a) the three factors needed for the formation of geothermal resources (i.e., supply of geothermal fluids, a fracture system that forms the reservoir structure and heat supply from a heat source), (b) the condition of deep-seated geothermal resources, (c) the overall environment of geothermal systems, including shallower geothermal resources, and (d) the possibility of utilizing the resources.

Because a fairly high temperature (over 350°C) is anticipated in deep locations, the research on drilling techniques under high temperatures will be carried out concurrently. The final goals are to work out technological guidelines necessary for the exploration and exploitation of deep geothermal resources and to reduce development risks, thereby promoting development of resources in deeper location and increasing geothermal power generation capacity.

(3) Contents of Survey

The Kakkonda area in Iwate Prefecture was chosen as the survey field because sufficient shallow subsurface data on the area was available and several wells deeper than 2,500 m have already been drilled, and also because the existence of a deep geothermal reservoir has been confirmed to a certain extent. Here, a 4,000-m class exploration borehole will be drilled, and a borehole geological survey, borehole logging, and flow tests will be conducted. Contents of the surveys are broadly grouped into the following four categories:

(a) Modeling of a deep geothermal reservoir

Using a deep exploration borehole, various kinds of geological, geochemical and geophysical surveys will be carried out. When a deep geothermal reservoir is reached in the course of drilling the well, discharge tests and temperature/pressure monitoring will be enforced. A reliable deep geothermal model, which can serve the purposes of deep well-drilling projects and deep subsurface geothermal resource surveys, will be formed by summarizing and analyzing these survey and test results.

(b) Development of deep reservoir survey methods

Efforts will be made to enhance the accuracy of survey methods that are effective in deep subsurface exploration. Surveys that use microearthquakes and specific resistivity, as well as borehole temperature logging using synthetic fluid inclusion, will be conducted in order to establish methods for deep well-based surveys.

(c) Systematization of deep drilling

For drilling high-temperature subsurface areas, systematization of safer, surer and economical drilling technologies will be executed. A variety of existing drilling technologies (mud cooling technology, top-drive technology, etc.) will be applied to the drilling of deep exploration boreholes, and the results will be evaluated and systematized as deep drilling technologies, for eventual reduction of drilling risks.

(d) Research on deep-hydrothermal fluid utilization technology

Improved economy of deep geothermal fluid utilization will be sought by conducting casing corrosion/erosion tests during discharge experiments and determining the casing material type suitable for deep geothermal fluids.

2.2 Summary for FY1994

(1) Drilling of a Deep Exploration Borehole

During 1994, work on the 4,000-m class exploration borehole continued, with the 1,505 m to 2,950 m deep section completed. For the preparation of a drilling plan to realize high-temperature, high-pressure deep-area drilling, information was also collected from U.S. drilling developers.

Drilling activity in fiscal 1994 was started on January 13, 1995, using a top drive drilling system. The 9-5/8" casing, originally planned to be set at a depth of 2,950 m was set at a depth of 2,550 m to stop lost circulation after lost-circulation drilling. After cementing, the drilling of the 8-1/2" well was undertaken and, at a depth of 2,600 m, the drilling trajectory was modified. This attempt, changing the drilling direction so as to pass through the allowable range, was successful. To study and evaluate the cooling effect during the top drive use, memory gauge temperature logging was implemented at a depth of 2,687 m. After drilling to a depth of 2,950 m, the work will be continued in fiscal 1995.

(2) Geological Surveys of Wells

Geological surveys of cores and cuttings, involving cores that included five depth-stage cores collected between 1,505 m and 2,950 m subsurface, were conducted. The geology of the well below 1,500 m is composed of the Kunimi-Toge Formation, a layer corresponding to the Obonai Formation, pre-Tertiary Formation and Kakkonda granite (young granite) from top to bottom. Within the three former layers, intrusion of older rocks is observed. On electrical logging of Formation Micro Imager (FMI) charts, many drilling induced fractures were witnessed. Together with natural fractures that exist on cores, etc., these fractures are used for the analysis of local and regional stress fields.

(3) Resistivity-Used Surveys

In fiscal 1994, after the development of tools for Multi-frequency Array Induction Logging (MAIL) and Vertical Electric-Magnetic Profiling (VEMP), on-site measurement within the well (MAIL method) and between the well and the ground surface (VEMP method) was conducted from 0 m to 1,505 m in the exploration borehole. The MAIL tool, the prototype for the current survey, was made to have a maximum thermal resistance of 260°C and to endure a maximum pressure of 240 kgf/cm^2. In the local measurement under the VEMP method using a deep subsurface exploration borehole, sufficiently stable signals were received at an observation point 1,875 m away. Furthermore, surveys under the hybrid MT method (CSAMT method (1-4,096 Hz) + MT method (0.01-125 Hz)) were conducted at 60 measurement points near the deep exploration borehole.

In order to develop the MAIL method analysis software, study of one-dimensional inversion model was carried out. But because of some problems in applying the model to actually measured values, the study will be further continued. Because two-dimensional analysis of the CSAMT method was also carried out, two-dimensional inversion will be implemented hereafter, using CSAMT-method, MAIL-method and well data.

(4) Synthetic Fluid Inclusion Surveys

This survey is designed to measure high temperatures in excess of 350°C, where electronics cannot be used, and to artificially form fluid inclusions in host crystals put into the well for the purpose of directly collecting deep-seated geothermal fluid. During fiscal 1994, preliminary synthetic fluid inclusion tests were carried out at a depth of 1,505 m, in preparation for full-fledged tests at a depth of 3 to 4 km. The host crystals were placed at six different depth levels for 27 days. The homogenization temperature obtained as a result of these tests was almost identical to the outcome of temperature logging. Accordingly, it was verified that this method is effective as a means of high temperature logging.

(5) Microearthquake Activity Survey

As an on-ground survey to elucidate the overall picture of geothermal systems, microearthquakes were continuously observed. In fiscal 1994, a microearthquake observation network was improved, with continuous observation started on November 25, 1994. Two observation points added on the northwest side of the deep well were close to other observation points horizontally. But because their altitudes were different from the other points, the vertical-direction accuracy is expected to improve in the seismic source assessment of microearthquakes. The seismic source distribution, obtained by analyzing three months of data, suggests the existence of a fracture system at a deep subsurface level.

(6) Acoustic Emission (AE) Observation

In this study, ground-base drilling sound is monitored during well-drilling from 1,505 m to 2,950 m in depth; the reflexive face for such sound sources will be analyzed; and AE that accompanies lost circulation will be measured, for the purpose of assessing the distribution of fractures encountered. Thus far, waveform analysis was carried out for AE observed at six depth levels. To further confirm the reflexive face, analysis is planned for deeper sections hereafter.

(7) Gravity Survey

With a view to elucidating the subsurface structure to a depth of about 4 km, a gravity survey was implemented within the area of 17 km from east to west and 16 km from north to south. Lacoste gravimeters were used, at a total of 340 measuring points. CPS measurement was simultaneously carried out at all these points. As a result of compiling existing gravity data with high locational accuracy in addition to the data from this survey, major geographical effects appeared on isogal maps, when the density was set below 2.0 g/cm^3. As such, analysis was executed with the density set at 2.3-2.4 g/cm^3.

(8) Recharge Area Survey

For the objective of using a hydrothermal flow model in the survey area, the chemical composition and properties of river water and spring water were examined. River water was collected at 55 points in five valleys, with four items measured — pH, electric conductivity, δD and $\delta^{18}O$ — in addition to the flow volume of the river. Regarding the cold and hot spring water survey, samples were collected at five locations, and measurement was made on 16 items — SiO_2, Cl, SO_4, Na, K, Ca, Mg, Fe, Al, T-CO_2, H_2O and tritium in addition to four aforementioned items.

(9) Research on Deep Fluid Utilization Technologies

For purposes of solving such problems as erosion and corrosion of materials of the casing and ground facilities and scale deposits on them, programs to conduct erosion and corrosion tests of casing materials and ground facilities were studied. Regarding the former, an erosion-corrosion test-use casing will be established before discharge testing in order to expose it to deep-geothermal fluid, and the state of erosion and corrosion will be studied by recovering tubes from the casing after the conclusion of the test. Also, Ultra Sonic Imager (USI) logging will be conducted to investigate the erosion and corrosion status of the casing within the well.

2.3 Future Tasks

When the deep exploration well reaches a deep geothermal reservoir, discharge tests and temperature/pressure monitoring will be implemented to evaluate the reservoir and to study deep area fluid utilization technology. The drilling of the exploration well will be carried out to the depth of about 4,000 m, while overall analysis will be executed through well geology surveys, etc., and a deep geothermal model will be produced.

II

Development of Technology for Geothermal Power Generation Systems

To efficiently use hot water resources (150-200°C), NEDO is developing technologies for a binary cycle power plant that uses downhole pumps to pump up hot water. To reduce geothermal power generation costs, NEDO is developing drilling and production techniques for deep seated geothermal resources. Furthermore, elemental technology, such as artificial reservoir development techniques, to utilize the geothermal energy of hot dry rock are being developed.

1. Development of Binary Cycle Power Generation Technology

1.1 Development of a 10MW-Class Demonstration Binary Cycle Plant

1.1.1 Development of a 10MW Plant

(1) Objectives and Work Program

A binary cycle power plant will be developed that transfers thermal energy from medium- to high-temperature (150-200°C) hot water to a low boiling temperature medium and uses the medium's steam to rotate a turbine and generate power.

(2) Summary for FY1994

(a) Plant design

Detailed design of geothermal system testing equipment was carried out, and surveys were implemented to examine the interior state of the wells.

(b) Plant construction

For the purpose of plant construction, detailed civil engineering design was carried out, and documents concerning applications for government permission were prepared.

(c) Surveys of effects on the environment

Ground meteorology, river flow quantities and hot springs were monitored. With regard to ground meteorology, wind direction, wind velocity, temperature, humidity, precipitation, duration of sunshine and radiation balance were measured at places selected for test plant construction. Flow volumes were continually measured in four rivers, and river flow conditions were surveyed. The temperature, flow rate and chemical composition of hot spring water yields at four places in the vicinity were also monitored.

(d) Observation of underground water level behavoir

Continual monitoring was executed at four monitoring wells (MW-1, -2, and -4, and BW-3). Due to the effect of seasonal precipitation, water levels reached a peak around July-August and declined thereafter. At the Ushirotani-gawa well (MW-4), distinct cyclical changes in water levels were not observed throughout the year, unlike with other wells, presumably because of its greater depth.

Air pressure and water level were found to be in almost inverse correlation, while water temperature was almost constant in all observation stations throughout the year.

(e) Confirmation of a geothermal water pumping system

With regard to the verification of the geothermal water pumping system, a conformation downhole pump (200 t/h, 380 m under ground level, 400 kW) was improved to enhance its reliability during start-up. Related tests were subsequently completed at its location.

1.2 Studies on Hot Water Production and Reinjection

1.2.1 Development of Technology for Increasing Geothermal Energy Recovery

(1) Objectives and Work Program

The technology for increasing energy recovery creates artificial fractures by injecting pressurized water into poorly producing wells or activates existing fractures, thereby increasing the flow of fluid and reviving and regenerating these wells.

(2) Summary for FY1994

(a) Development of methods for predicting and judging the effects of hydraulic fracturing and development of hydraulic fracturing methods

(i) Development of methods for predicting and judging the effects of hydraulic fracturing

a. Development of a method for permeability evaluation with limited intervals

Packer test results and permeability testing methods, based on PTS logging data in these wells, were evaluated, and their evaluation results were compiled.

b. Development of measurement techniques of fractures using magnetic fluids

Certification tests were implemented for a developed magnetic fluid tracer for geothermal fluid-use, as well as for magnetism measurement systems for BTBR (borehole transmitter/ borehole receiver method), based on a medium/high-temperature-use triaxial magnetometer, and for STBR (surface transmitter/borehole receiver method). Results of these tests were evaluated, and such results were compiled.

c. Development of the method to predict output increase effect

Output increase effect predicting simulation was conducted, using an improved/expanded geothermal reservoir simulator, and its results were studied and evaluated. Prediction methods were then compiled from an overall viewpoint.

(ii) Development of hydraulic technology design/control methods

a. Development of subsurface stress measuring techniques

Evaluations were made using the AE-DR (Acaustic Emission-Deformation

Rate) and DSCA (Differential Strain Couve Analysis) methods. As a result of the development of a stress analysis method using fractures along the borehole axis by BHTV (borehole televiewer) logging data, the excellence of the DSCA method and the method using fractures along the borehole axis was ascertained, based on comparison with actual fracturing tests. Thus, subsurface stress measuring techniques suitable for geothermal wells were compiled.

b. Development of fracturing design and control methods

Through hydraulic fracturing tests, the progress of multi-fractures was confirmed, and the applicability of a multi-fracturing model to hydraulic fracturing design was ascertained. Furthermore, overall application methods, etc., were compiled.

c. Development of hydraulic fracturing methods

Data on fracturing fluids under high temperature were collected through laboratory tests and actual small-scale borehole tests, and such data were subsequently improved. With regard to fracture-holding materials, laboratory test data were added and improved. Furthermore, the monitoring system and materials necessary for hydraulic fracturing were sorted out and compiled.

1.3 Development of MWD (Measurement While Drilling) System for Geothermal Wells

(1) Objectives and Work Program

This project aims to develop a MWD system that can provide real-time acquisition of downhole data during the drilling of geothermal wells and that leads to improvement in well-drilling precision and capability.

The content of the project is divided into two main parts: development of hardware to acquire and measure downhole data, and development of software to analyze the data. The hardware consists of downhole and surface equipment. The downhole equipment consists of a sonde and sensor-sub that will enable it to acquire data in the well on a real-time basis in an environment where temperatures reach 200°C. It transmits data to the surface equipment as pressure wave signals (mud pulse) that are affected by fluctuations from the pressure of drilling mud circulation. The surface equipment receives and displays the acquired data.

The software system enables a computer to perform all analyses of data obtained from the detectors, to monitor well tracing and to evaluate the well.

(2) Summary for FY1994

(a) Development of detection equipment

(i) Bottomhole equipment

a. Mud-pulse generation equipment

The number of mud-pulse generation valves was reduced, drilling mud permeation countermeasures were studied, and the design of the valves was changed so that replacement of their parts would be possible.

A heat-resistant motor, the driving equipment for mud-pulse generation valves, was manufactured. In three driving tests implemented in a thermostatic bath, based on constant torque and voltage, the motor functioned well at a temperature of 200°C.

In connection with the control device of the driving equipment for mud-pulse generation valves, operational tests were implemented in a thermostatic bath. The output voltage of the control device was stabilized at 200°C.

b. Bottomhole signal processing equipment

Heat resistance tests of a single device was carried out at a maximum temperature of 220°C, and its stable operation was ascertained.

c. Mode changeover switch

In high-temperature operating tests, the mode changeover switch moved at 45 rpm at a temperature of 200°C. A circulation switch utilizing fluid vibration was manufactured on a trial basis. Vibrational acceleration that is generated during circulation in a miniloop was measured.

d. Inclination information sensor

A flux gate-type direction sensor was manufactured on a trial basis, and its performance at a high temperature was monitored. Also, shock tests of the sensor unit were carried out.

Concerning the inclination sensor, a unified triaxial type sensor unit and a high-temperature electronic circuit were manufactured. Although the target precision was attained at normal temperatures, output declined in the high-temperature range.

An inner-equipment temperature sensor was also tested.

e. Sonde-integrated vibration-resistant design

Vibration during drilling was monitored, and based on the monitored data the strength during the sonde vibration was evaluated.

f. Equipment attached externally to sonde

A spearpoint was manufactured on a trial basis, and its lifting performance was confirmed. With regard to a centralizer, spring rigidity and attachment position were studied. A landing rod and a mule shoe sleeve were manufactured on a trial basis, and their functions were confirmed.

(ii) Ground facilities

a. Test analysis program

The program was revised from the viewpoints of its composition and physical-volume indication time.

b. Automatic identification program for rectifying a deteriorated S/N ratio

The model was revised based on newly acquired lost circulation data.

c. Calculation for simulation

Pulse-wave transmission characteristics of a high-pressure test loop were calculated.

(b) Development of analytical systems

(i) Trajectory control support system

With regard to trajectory planning/indication systems, the function of showing intersecting point coordinates on a fracture face, etc., was added, and the trial use and revision of the system were carried out.

The functions of judging the resonant conditions during rotary drilling and projecting the trajectory suitable for rotary drilling were added to the trajectory prediction system.

(ii) Well evaluation support system

Effects of temperature data errors on the well evaluation support system, which is a temperature analysis system, were evaluated. For the purpose of improving convergence in the case of error inclusion, a program for the system was revised.

2. Development of Hot Dry Rock Power Generation Technology (Development of Elemental Technology)

(1) Objectives and Work Program

Developing and utilizing geothermal energy in hot dry rock, the undeveloped geothermal resource, requires the construction of an artificial geothermal reservoir in high-temperature rock and the fabrication of a circulation system consisting of an artificial reservoir and injection and production wells.

The development of this technology will focus on high-temperature, low-permeability rock mass in order to develop an artificial reservoir development technique based on the hydraulic fracturing method, a fracture-mapping technique for measuring the extent of an artificial reservoir, well logging and elemental technologies for extracting heat from an artificial circulation system. The feasibility of a system for generating electricity from hot dry rock will then be examined.

The research and development was started as an auxiliary project of the Sunshine Program in fiscal 1985. Various tests have since been conducted at the Hijiori hot dry rock test field with four wells and an artificial reservoir at Okura-mura in Mogami-gun, Yamagata Prefecture.

In fiscal 1991, a long-term (90-day) circulation test was implemented using multiple wells, with the target area limited to the shallow (1,800-m-deep) artificial reservoir. The tests of thermal extraction from this reservoir were successful.

In fiscal 1992, hydraulic fracturing was carried out by pouring water into the HDR-1 well. Accordingly, a deep-seated artificial reservoir was successfully formed at 2,200 m.

During fiscal 1993, the existing HDR-3 well was further deepened, to the depth of about 2,300 m, and the linkage of the well to a deep artificial reservoir was confirmed.

(2) Summary for FY1994

(a) Making artificial hydrothermal systems

(i) Deepening of an existing well (HDR-2 well)

A deeper trajectory for the HDR-2 well was determined with consideration given to the status of deep artificial reservoirs, as well as the inter-well distance. Based on the determined trajectory, the well was reclaimed with cement up to the depth of 1,589 m. With the direction and inclination sufficiently controlled, the well was then deepened to a depth of 2,303 m. Further, at 2,105 to 2,109 m, oriented coring was carried out.

Before this deepening of the HDR-2 well, the shallow plugged-back portion of the HDR-1 well was repaired. In the pressuring test after the curing of cement, pressure resistance of 220 kg/cm^2 was confirmed, and the improved state of cement was ascertained through sonic logging.

(ii) Tests of water injection into deep geothermal reservoirs

After the deepening of the HDR-2 well, water injection tests were carried out to evaluate characteristics of deep reservoirs. Regarding changes in the water level following injection into the HDR-1 well, the HDR-2 well was highly satisfactory. In the case of water injection into the HDR-2 well, most of the injected water flowed out into shallow geothermal reservoirs.

(iii) Geochemical surveys

Water-rock interreaction in hot rock reservoirs was studied through Na-Cl and K-Cl diagrams. When the y intersect was assumed to be the added volume of Na and K due to the interreaction of water and rock, the added volume of both Na and K in the circulation within shallow geothermal reservoirs proved to be the greatest in the case of the produced water at HDR-1. Furthermore, preliminary water-rock interreaction tests were carried out, with rock grain diameter and flow volume changed.

(iv) Geological surveys

In the surveys of cuttings and oriented cores during the deepening of HDR-2, most of them turned out to be granodiorite, with granodiorite porphyry and dolerite dykes observed in some depths. The running inclination of fractures measured through an oriented core (2.8 m) was strongly concentrated at N80°W strike and 70°N dip, so the inclination was analogous to that of the fractures in the oriented core at HDR-3.

(v) Analysis of geothermal reservoirs

The speed acceleration and memory reinforcement of reservoir analysis equipment were implemented, and the two-phase fractured reservoir behavior simulation program was revised. Further, the transmissibility and the coefficient of storage were evaluated, based on water-injection test results at deep reservoirs. Water permeability near the HDR-1 well was lower than the permeability of the whole deep reservoir, so it was surmised that, as the distance from the well increases, the reservoir becomes thicker (the fluid channels expand).

(b) Fracture mapping and well logging techniques

(i) Fracture mapping

Seismic source parameters of some of AE waveforms so far measured through a ground-surface AE observation network were obtained. The seismic moment was 1 - 48 x 10^{14}dyne.cm; the hypocenter radius was 10 to 50 m; stress decline volume was 0.6 - 28 x 10^{2} bar; the discharge wave energy was about 1 - 1,200 x 10^{7} erg; and the average Q value was 244.

(ii) Well logging

The open hole logging (of resistivity, sound waves, caliper) and BHTV surveys of the deepened portion of the HDR-2 well were carried out. Through the fracture analysis of BHTV, it was confirmed that fractures whose E-W strike and N high dip are dominant. Many vertical fractures were observed above 1,700 m and also between 1,999 m and 2,050 m.

During water injection after the deepening of the HDR-2 well, PTS logging was carried out. The injection point of HDR-2 was the same as in the preceding year. The injection points and flow rates of the HDR-2 well were 20% at 2,138 m to 2,142 m, 45% at 2,164 m to 2,167 m, and 35% at 2,185 m to 2,199 m. When water was injected into the HDR-2 well, more than 90% of the injection volume flowed out to the shallow reservoir.

As a measure against noise from the borehole radar, connectors were concentrated in a single spot, with their arrangement changed, while ferrite was laid in the lower part of the antenna can. Subsequently, performance confirmation tests were implemented within a bath, and reflexive waves were confirmed to have been captured during these tests.

(c) Environmental surveys

(i) Microearthquake monitoring

Monitoring of microearthquakes was implemented near the Hijiori area of Yamagata Prefecture. No effects of microearthquakes on the environment, including water injection, were recognized based on results of seismic source analysis.

(ii) Geochemical surveys of river/hot spring water

River and hot spring water were collected in the Hijiori area of Yamagata Prefecture and their chemical composition was analyzed. At a frequency of once a month (twice a month for tests conducted in Hijiori), a total of 15 surveys were carried out. No effects on the environment were found from geochemical analysis results.

3. Development of Drilling and Production Technology for Deep-Seated Geothermal Resources

3.1 Development of Drilling Technology for Deep-Seated Geothermal Resources

(1) Objectives and Work Program

Technologies to drill deep geothermal wells safely and effectively will be developed.

(2) Summary for FY1994

(a) Overall development design

From an overall drilling technology viewpoint, domestic and overseas technological trend surveys were implemented by launching investigations abroad and carrying out technological research in Japan. As a part of the study of, and support for, overall testing methods regarding individual drilling-element technologies, downhole cement sample curing to evaluate the decline of cement strength was carried out using actual goethermal wells.

(b) Development of hard, high-temperature formation drilling element technologies

(i) Development of heat-resistant, durable three-cone bits

Based on design tests and concept design of testing devices for individual element technologies, implemented during fiscal 1993, high-temperature diaphragm testing equipment for the pressure adjustment mechanism was manufactured in fiscal 1994, and various kinds of prototype diaphragms were tested and evaluated using the equipment. An insert wear testing device was also manufactured, and a variety of prototype insert samples were tested and evaluated.

(ii) Development of high-temperature drilling mud system

With results of the study conducted during fiscal 1993 taken into account, performance of mud materials at 300°C was evaluated. Using various mud materials, a drilling mud system stable at 250°C was established. Subsequently, concept design of a drilling mud system stable at 300°C was implemented.

(iii) Development of high-temperature cement slurry

Effects of base cement composition and properties on the specific gravity, contraction strength at 350°C and water permeability were assessed for technological orientation of the development. With regard to dehydrating and adjustment agents, their functions at high temperatures were evaluated.

Further, as part of the study to evaluate heat durability, hanging tests were implemented in a well, and the compression strength of hardened bodies was analyzed.

(c) Development of high-precision, highdirectional drilling technologies

(i) Development of high-temperature downhole motors (DHMs)

A heatproof element testing machine for helicoidal-type DHM stator materials was manufactured, and testing was carried out. Also, a DHM performance simulation program was developed.

3.2 Development of Production Technology for Deep-Seated Geothermal Resources

(1) Objectives and Work Program

Technologies for safe and efficient production of deep-seated geothermal resources will be developed.

(2) Summary for FY1994

(a) PTSD logging technologies

The logging sonde consists of three memory-type probes. Regarding the PT (pressure and temperature sensor) probe, high-temperature, high-pressure sealing tests for the pressure housing and heatshield were implemented, with promising seal materials selected as a result.

As for the S (spinner, or flow meter) probe, materials and sizes of individual structural members to be used were studied, a measurement circuit was manufactured on a trial basis, and performance tests were carried out.

Regarding the D (fluid density sensor) probe, performance tests based on varied line source spacings were conducted, and the design policy was determined based on the results of these tests.

(b) Monitoring technologies

(i) PTC monitoring technology

In connection with PT (pressure and temperature) monitoring, characteristics of high temperature-use optical fiber sensors and linkages of different kinds of optical fiber sensors were studied, and heat resistant tests of metal-coated optical fiber sensors were conducted. Based on the results of these activities, conditions for using optical fiber sensors at high temperatures were compiled.

In the course of C (chemical, or sampler) monitoring, the study of the corrosion resistance of metal materials and evaluation tests of dynamic seals were implemented. Subsequently, study themes were determined from the results of the aforementioned study/tests.

(ii) High-temperature tracer monitoring system

Following basic tests for vapor-dominated geothermal reservoirs with regard to thermal characteristics of alcohols in fiscal 1993, basic testing was conducted with regard to halogens during fiscal 1994.

(iii) Scale monitoring technology

Using the autoclave introduced in fiscal 1994, silica polymerization tests — to observe the pre-scale generation process — were carried out. Through these tests, characteristics of testing equipment were comprehended, and themes related to scale analysis were studied.

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CHAPTER 4

DEVELOPMENT
OF
COAL ENERGY UTILIZATION TECHNOLOGIES

DEVELOPMENT
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COAL ENERGY UTILIZATION TECHNOLOGIES

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I

Development of Coal Liquefaction Technology

With coal liquefaction technology, hydrogen is added to coal that is being subjected to high temperature and pressure. This breaks down the coal's molecular structure and it becomes liquefied, producing a new and clean form of energy.

NEDO has been constructing a 150 t/d pilot plant and carrying out other research to develop bituminous coal liquefaction technologies and, particularly, to obtain the data needed for the operation of the 150 t/d pilot plant.

Furthermore, NEDO has also been developing technologies related to upgrading and utilizing liquefied oil. These efforts are expected to bring coal liquefaction technology up to a fully practical commercial technology level.

1. Development of Bituminous Coal Liquefaction Technology

1.1 Research Using Pilot Plants

(1) Objectives and Work Program

The objective of this study is to demonstrate the performance of the NEDOL process through the design, construction, and operation of a pilot plant, and to establish the requisite operational technology. In addition, the study is intended to collect a wide range of technical data and know-how for use in commercial plants in the future.

(2) Overview of Results Obtained in FY1994

(a) Research plans

(i) Revision of operation plans

Basic operations plans were revised, with these revisions including changes to the number of times facilities were to be operated. Furthermore, in consideration of the fact that Tanito Harumu coal had been selected as the standard coal to be used in operations, the heat balance and other operating parameters of the slurry pre-heating furnace were revised, and it was confirmed that no problems exist in terms of operation using current facilities.

(ii) Compiling the results of basic and supporting research

The results of the PSU operation and other research were compiled for pilot plant operation.

(iii) Detailed operation plans

Data obtained from the operation of equipment, including developed equipment, was collected and organized according to the basic operation plan, and preparations for making a "bituminous coal liquefaction technical package" were conducted.

(iv) Project control system

Annual reports were stored with

other related data on optical disks.

(b) Planning of construction

(i) Construction preparation

Purchasing and installation was completed in fiscal 1995, and the creation of plans and writing of specifications for the purchasing of equipment and materials and related construction work were performed.

(ii) Applications and reports submitted to government agencies and ministries

In accordance with partially revised facility plans, an application was submitted for authorization as required under the High-Pressure Gas Regulatory Law and the Fire Protection Law. In regard to the requirements of the Labor Safety and Welfare Law, inspections were performed for two boilers and for two Class-1 pressurized containers. An application was also submitted for authorization of construction plans as required under the Electric Power Utilities Law.

(c) Construction

(i) Work performed in preparation for procurement and installation

A detailed design was created for an operation data processing system.

(ii) Procurement of equipment and materials

A total of 27 vats and chambers, 2 heat exchangers, 26 rotators, and 9 other pieces of equipment were procured. A portion of the measuring instruments, electric equipment and materials, and piping equipment and materials were also purchased.

(iii) Construction work

Approximately 160 pieces of equipment were installed. The construction work mainly consisted of installing pipes and conduit systems. With the exception of 6 piping and conduit systems, the main installation was completed. Furthermore, a portion of the electrical wiring and instrumentation systems was performed, and painting, insulation, and sealing with fire-resistant materials was also carried out. Pipe racks, catwalks, and other infrastructure were also constructed.

(d) Preparations for operation

(i) Operations personnel

In accordance with the basic operation plan, plans were created for the implementation of operations procedures and for operations personnel, and key operations personnel were hired.

(ii) Training programs

A training plan was made, and an operations training program which included actual hands-on PSU operations was implemented for key operations personnel. Work was also begun on the creation of operation manuals.

(iii) Study of raw materials used in operations

Studies were performed on the amounts and types of raw materials and secondary raw materials (e.g., coal, solvents, COG, catalysts, etc.), solutions, and chemicals to be used in operations, as well as on acquisition plans.

(iv) Contractors

A plan was created for the analysis of operations samples. Studies were also performed regarding maintenance plans and systems for the implementation of these plans. Plans were created for the contracting of work concerning facility maintenance.

(v) The processing of products

Studies were performed on the processing of waste water, liquefied oil, and other materials generated in production, and on the external processing of waste catalysts, waste slurry, waste sediments, waste amino acids, and other waste materials. A detailed study was also performed on the processing of residues in cement plants.

(e) Surveys

(i) Tests and surveys

a. Development of high-performance liquefaction catalysts

In order to establish a natural pyrite crushing system for the pilot plant, continuous natural pyrite crushing tests were performed using dry roller mills, wet bead mills, and wet ball mills. Evaluations were then performed of the processing capacity and stability of each of these three types of crushers and of the liquefaction performance of the pulverized catalysts obtained therefrom. In accordance with the results of these evaluations, it was decided that the crushing system to be adopted for use in the pilot plant should consist of a two-stage system with a wet ball mill and a wet bead mill connected together in series.

b. Establishment of a liquefaction reactor data analysis system

Using the data obtained in the BSU, heat analyses and generated heat analyses and studies were performed on the initial reaction process, the rate of heterogeneous phase reactions, and the flow pattern in the reactors. Analyses and studies were also performed on the heat generated. The results of these analyses were used to improve the simulator. PSU data was also used to verify the result of simulation, and a prototype of a simulation software package was developed for the pilot plant.

(ii) Technical surveys

a. Feasibility study

Two coastal regions were selected as possible sites for the construction of a pilot plant in China, and surveys were then performed in these two regions. The results of these surveys were used to calculate estimated construction costs and overall balances between input and output materials, and the DCF method was then used to calculate estimates of the cost of producing liquefied oil. These results were then used to perform sensitivity analyses and economic analysis of the feasibility of establishing a commercial venture for the liquefaction of coal in China. Technical issues were proposed in order to reduce the costs incurred.

(f) Future tasks

It should be possible to create an environment in which the pilot plant will be able to begin operations smoothly and without difficulties by completing the remaining work. Furthermore, in subsequent test operation, it will be necessary to obtain data and verify the effectiveness of the NEDOL process and to establish a technical package designed for a commercial plant.

1.2 Pilot Plant Support Research

1.2.1 Research Using Experimental Plants

1.2.1.1 Research Using a 1 t/d Process Support Unit (PSU)

(1) Objectives and Work Program

The objectives of the research are to design and construct a 1 t/d PSU plant to confirm the stability and operability of the NEDOL process, and to support the liquefaction research work for the pilot plant through optimization studies of the PSU.

Furthermore, the correlation between the PSU and the pilot plant will be evaluated and the data for scaling up will be obtained through expansion of the range of application of the coal.

(2) Overview of Results Obtained in FY1994

(a) Modification and maintenance

(i) Modification

In order to study flow pattern and reactions within the liquefaction reaction tower, Neutron Attenuation Tracer (NAT) technique, sampling devices, and differential pressure measurement unit were installed.

(ii) Maintenance

a. Inspection of the inside of the vessels and repairs were performed after each operation.

(b) Research planning

(i) Annual and long-term operation plans were produced.

(ii) Operation procedures and standards were made.

(iii) A test program was formulated to gain an understanding of the characteristics of the liquefaction reactor.

(iv) A research program for the support of the pilot plant was completed.

(c) Research work

Using Tanito Harum coal, 50 days of slurry operation were performed for each of Run 0601 and Run 0602, and problems which occurred during these periods of operation were solved.

(i) Study of the liquefaction characteristics of natural pyrite catalysts

Using Tanito Harum coal, product yields were obtained by using natural pyrite (NP) as a liquefaction catalyst and the effects of the catalyst on the operation and product slate were investigated. In order to compare the results with those obtained by using wet method synthetic iron sulfide (W-SIS), the operating conditions consisted of standard operating conditions (i.e., a reaction temperature of 450°C, a reaction pressure of 170 kg/cm^2 G, G/L 700-N liter/kg, and a catalyst of 3wt%), conditions under which the reaction temperature was set at 465°C (i.e., with a reaction temperature of 465°C and with all other conditions being equivalent to standard conditions), and the maximum conditions under which the temperature was set at 465°C (i.e., a reaction temperature of 465°C, a reaction pressure of 190 kg/cm^2 G, G/L 900-N liter/kg, and a catalyst of 4wt%). Table 1 shows the operating conditions used in these test operations, and Figure 1 and Figure 2 show the effect of a natural pyrite catalyst on product yields.

a. Virtually no differences were observed in terms of yields of liquefied oil, gas, water, and residues when using natural pyrite in comparison with the yields obtained using W-SIS. No matter which liquefaction catalyst was used, the liquefied oil yields obtained under the standard condition came to approximately 52wt% (on a daf coal basis), and under the maximum temperature condition of 465°C the yield came to approximately 59wt% (on a daf coal basis), which is equivalent to 4.4 barrels per ton of daf coal.

b. Virtually no significant differences were found between NP and W-SIS in terms of operation and handling characteristics, such as increases in differential pressures in the slurry pre-heater and the solvent hydrogenation heater, removal of deposit in the liquefaction reactor, the softening point of residues, and the discharging of residues.

In this run, a momentary power outage caused blockage of the coils of the BA301 pre-heater installed in the vacuum distillation tower. Studies were performed to determine the cause of this problem and measures were implemented to prevent its reoccurrence.

(ii) Liquefaction characteristics of dry synthetic iron sulfides

Using Tanito Harum coal, a study was performed on the operation and handling characteristics obtained when using dry synthetic iron sulfides (D-SIS) as a catalyst, and the effect of the catalyst on product yields and slates was investigated. In order to compare the results to those obtained when using W-SIS and NP, operations were performed under the standard condition, 465°C condition, and 465°C maximum condition. Table 1 shows the operating conditions used in these tests, and Figures 1 and 2 show the effects of D-SIS as a catalyst have on production yields.

a. The oil yield obtained when using dry D-SIS under the standard condition came to 54.6wt% (daf). While this is somewhat higher than the yields obtained when using W-SIS and NP, the yield of residue and gas were found to be somewhat lower. The same tendencies could be seen to exist under the 465°C condition and the 465°C maximum condition, and the highest oil yield was obtained when using D-SIS under the 465°C maximum condition, which came to a level of 61.8wt% (on a daf coal basis). Converted into standard volume yields, this comes to a total of 4.6 barrels per ton of daf coal.

b. Virtually no differences were found between different liquefaction catalysts in terms of operation and handling characteristics, such as increases in differential pressures in the slurry pre-heater and the solvent hydrogenation pre-heaters, removal of the deposit in the liquefaction reactor, the softening point of residues, and the discharging of residues from the vacuum distillation tower.

(iii) Study of the hydrogenation characteristics of improved hydrogenation catalysts

Table 1 Operating Conditions in FY1994

Operating conditions	Standard conditions	Conditions at 465°C	Conditions at 465°C max.
Coal	Indonesian coal (Tanito Harum coal)		
Liquefaction catalyst	Natural pyrite (Run 0601) Dry-type iron sulfide compound (Run 0602)		
Reaction temperature (°C)	450	465	->
Reaction pressure (kg/cm^2G)	170	->	190
G/L (Nl/kg)	700	->	900
Amount of catalyst addition (wt%)	3	->	4
fa of circulation solvent	0.5	->	->

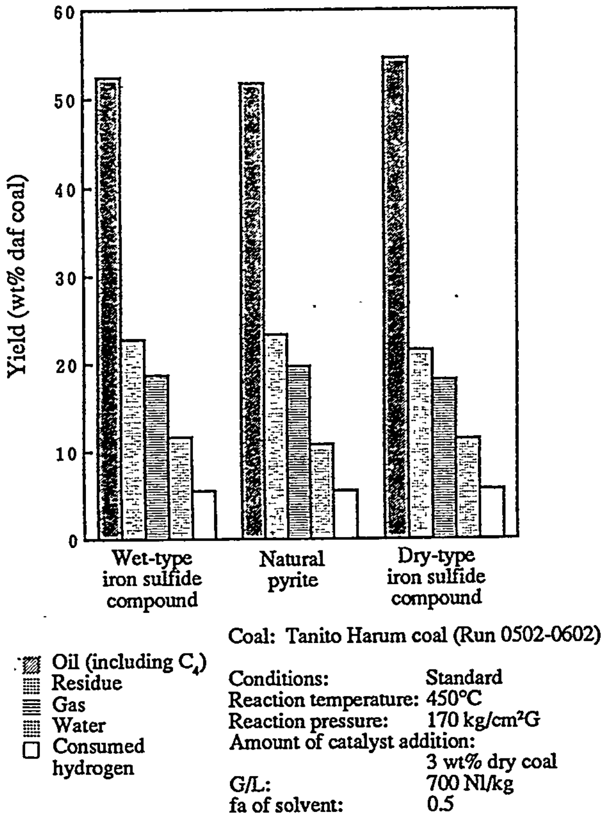

Fig. 1 Effect of Liquefaction Catalyst on Distribution of Product Yield

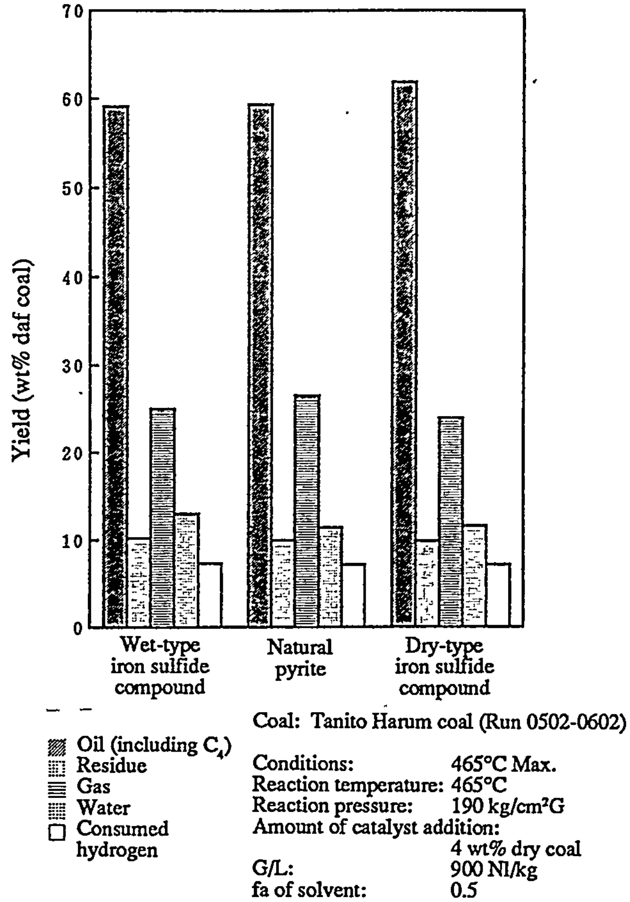

Fig. 2 Effect of Liquefaction Catalyst on Distribution of Product Yield

The effectiveness of the improved CH-401 hydrogenation catalysts was examined and compared with the KF-153S catalyst.

a. During a 50-day period of test operations, CH-401 hydrogenation catalysts used in the solvent hydrogenation process proved that the effective life of the catalyst was longer than of the conventional KF-153S catalyst. It was also confirmed that no problems existed with respect to the use of the catalyst in the pilot plant.

b. No difference was found to exist between CH-401 and KF-153S catalysts in terms of operation and handling or in terms of issues related to operations control such as the temperature of the hydrogenation reactor or the fa of hydrogenated recycle solvent.

(iv) Liquefaction reactor characteristics

A high-temperature and high-pressure sampling unit, a differential pressure measuring unit, and a measurement unit using the Neutron Attenuation Tracer (NAT) technique were used to perform a study of liquefaction reaction characteristics. The results confirmed that it would be possible to apply these methods to the pilot plant.

a. A high-temperature and high-pressure sampling unit was used to perform sampling during coal slurry operation. As shown in Figure 3, it was elucidated that there were differences in the specific gravity of samples collected from different positions of the liquefaction reactor. The results showed that it should be possible to gain an understanding of the reaction conditions in the reactor.

b. A differential pressure measuring unit was used during coal slurry operation. The measurements made it possible to determine the amount of gas retained in the liquefaction reactor. A comparison of the amounts of gas retained under different conditions is shown in Figure 4. It was confirmed that the amount of PSU gas retention was close to that of the EDS.

c. NAT was used to obtain data on the flow pattern related to the average retention time in the liquefaction reactors and during coal slurry operation. Table 2 shows the average liquid phase retention time in the liquefaction reactor when using NAT.

It was also elucidated that the average liquid phase retention time during slurry operation differs in accordance with the reaction conditions and that the average retention time for all three reactors ranged between 92 to 147 minutes.

(d) Environmental surveys

(i) Process waste water survey

A study of the characteristics of liquefaction process waste water and tests to evaluate the toxicity of active sludge produced when using Tanito Harum coal were

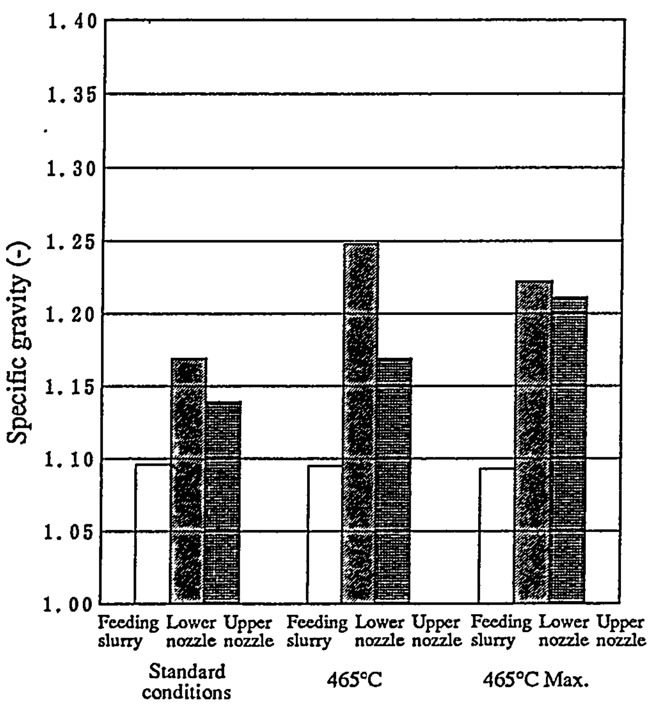

Fig. 3 Specific Gravity of Sample Solids and Liquids in Liquefaction Tower

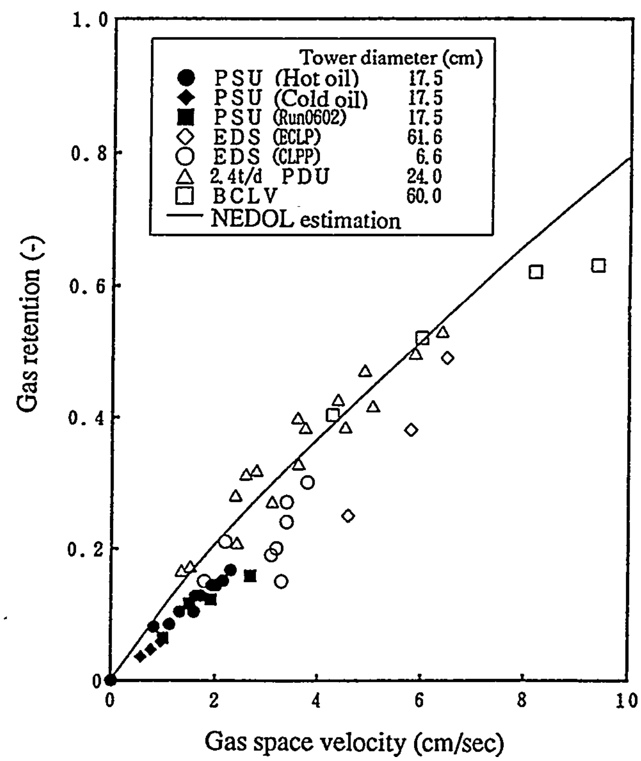

Fig. 4 Comparison of Gas Retention

Table 2 Average Liquid Phase Residence Time in Liquefaction Reactor by NAT Method

Type of operation	Operating conditions					Average residence time (min.)	
	Liquid flow (kg/hr)	Tem-perature (°C)	Pressure (kg/cm^2G)	G/L (Nl/kg)	Catalyst amount (wt/%)	One reactor DC201	Total of three reactors DC201-203
Hot oil	106.0	385	170	700	3.0	26.6	68.3
Slurry operation	108.8	450	170	700	3.0	26.8	91.5
	108.3	465	170	700	3.0	50.7	118.0
	108.5	465	190	900	4.0	50.8	146.7

performed, and proposals concerning methods of processing waste water were studied. As a result, it was confirmed that no problems existed which would prevent the use of the processing methods used previously.

(ii) Environmental monitoring

Samples of atmospheric air were taken and measurements were made of the level of noxious odors and tar mist during operation, and it was found that the levels of all items measured fell far below control limits, thus confirming that no problems exist in terms of operation of the plant or its effect on the environment.

(e) Applications and reports submitted to government agencies and ministries

All applications and reports which had to be submitted to government agencies and ministries in accordance with changes to the facilities and modification of the plant were drawn up and submitted.

(i) Inspection of the performance and safety of Class I containers used to store pressurized gases (Industrial Safety & Health Law)

(ii) Safety inspection of facilities for the production of high-pressure gases (High-Pressure Gas Control Law)

(iii) Application for authorization for the modification and installation of facilities and completion inspection (High-Pressure Gas Control Law, Fire Service Law, Radioactive Contamination Prevention Law)

(f) Technical surveys

The following technical surveys related to the liquefaction of coal were performed in preparation for plant operation.

(i) Technical survey on slurry characteristics

(ii) Technical survey on fluid dynamics

(iii) Technical survey on solid sedimentation in the reactor

(iv) Studies concerning the results of measurements of the distribution of different liquefaction catalyst particle sizes

(v) Tests performed to evaluate the liquefaction performance of D-SIS

(3) Future Tasks

(a) Research to support the effective operation of the pilot plant

Through technical exchanges, programs of technical cooperation, and the exchange of information with pilot plant personnel, work will be performed to obtain an accurate quantitative understanding of both processes and facilities within the pilot plant and problems associated with the creation of operation plans. The results must be reflected in research plans so as to perform supporting research in the most effective manner.

(b) NEDOL processing technology package

Proposals must be drawn up for the tests and survey plans required to create a NEDOL processing technology package which makes sufficient use of PSU functions, and all possible efforts must be made to promote the performance of these tests and the implementation of these plans.

1.2.1.2 Evaluation of Advanced Materials for Coal Liquefaction Plants

(1) Objectives and Work Program

New types of materials were examined to evaluate their applicability to coal liquefaction equipment, which is subject to erosion and corrosion. For materials which showed good results, in-plant tests in the process support unit (PSU) and pilot plant (PP) were performed to confirm their effectiveness, and the reliability and cost reduction efficacy of equipment used in coal liquefaction plants were discussed.

(2) Overview of Results Obtained in FY1994

(a) Preliminary tests

(i) Tests of resistance against friction and corrosion

In order to select and develop materials with excellent resistance and durability against friction for the construction of the proposed coal liquefaction plant, a series of long-term comparative tests designed to determine the anti-erosion properties of various types of surface coatings and other materials were performed as part of an experimental-scale evaluation of the resistance of candidate materials to erosion caused by friction.

Two series of tests of the anti-corrosive properties of these materials were also performed, using test equipment designed to simulate a fluid environment under environmental conditions similar to what the pipes and equipment in the liquefaction reaction facilities would be subjected (i.e., at a temperature of 400°C, a pressure of 200 kg/cm^2 G, a rotation speed of 500 rpm, a testing period of 60 days, and with the fluid being used consisting of liquefied coal oil with a mixture of 10wt% of silicon oxide particles with an average diameter of 100 nanometers). Tests which simultaneously inserted 6 different materials into the test environment were also performed. The test materials used in these tests of durability against friction and corrosion consisted of five types of metals with polished surfaces (i.e., 2.25 Cr-1 Mo, 3 CR-1 Mo, SUS347, SS400 and SUS316 metals used as control materials) together with five types of surface coatings (i.e., stellite 6 B, tungsten carbide (TS-10713), CoNiCrAlY, NiCrAlY, Al_2O_3, all of which contained a base of 2.25 Cr-1 MoFe).

After completion of the testing, an

investigation was made on the external appearance of the test materials in terms of both their appearance to the naked eye and their appearance in photographs taken under an electron microscope, cutaway views of these materials obtained from both photographs taken under an electron microscope and the results of EPMA analyses, and the amount of erosion which had occurred in terms of changes in weight expressed in units of loss of area in millimeters per year. The results of these investigations were then used to evaluate the resistance of these materials to the stresses of friction and corrosion. A description of the principal results obtained from these tests is given in the paragraphs below.

a. Visual inspections of the surface and inspections of photographs of cutaway views taken under an electron microscope showed the metallic luster of the SUS316 and SUS347 materials could still be seen once the grit which had adhered to their surfaces was cleared away. Similar inspections showed that a light degree of corrosion could be observed all along the surfaces of the SS400, 2.25 Cr-1 Mo, and 3 Cr-1 Mo materials, that the Al_2O_3 coating had peeled away from the base material after it had been extracted from the test material after the completion of testing. While all other surface coating materials were covered by materials which had adhered to their surfaces, virtually no corrosion or erosion was observed for any of these materials.

b. The results of cutaway EPMA analyses showed that no effects of corrosion or erosion could be observed for the SUS316 or SUS347 materials, that no effects of erosion could be observed for the stellite 6 B, tungsten carbide (TS-10713), CoNiCrAlY, or CiCrAlY materials, and that these three materials offered sequentially decreasing levels of resistance to sulfur penetration, that sulfuric corrosion could be observed in the SS400 material, and that sulfides and acids could be found in the 2.25 Cr-1 Mo and 3 Cr-1 Mo materials. Al_2O_3 proved to be inferior in terms of resistance to peeling, and sulfide was found on the upper half of the Ni-Cr base layer.

c. Differences in the weight of the test materials before and after the tests showed that the amount of wear resulting from erosion and corrosion came to approximately 0.1–0.3 millimeters per year for the SS400, 2.25 Cr-1 Mo, and 3 Cr-1 Mo materials. For the SUS316, SUS347, stellite 6 B, tungsten carbide (TS-10713), CoNiCrAlY, and NiCrAlY materials, however, it was found that the amount of wear for all of these materials came to less than 0.1 millimeter per year, thus showing that these materials are highly resistant to erosion and corrosion.

(ii) Anti-corrosion application testing

Tests were performed by spraying an Al_2O_3 plasma on the surface of containers and observing their resistance to wear under liquefaction conditions and against continued exposure to a process of heating and cooling. It was also confirmed at this time that non-destructive testing methods could be used to evaluate the ability of the sprayed film against wear.

In applications tests designed to evaluate the ability to withstand corrosion, two autoclave test containers treated with a protective coating were created to the following specifications: diameter of 75 mm, internal capacity of 500 cc, base material consisting of 2.25 Cr-1 Mo, surface coating consisting of a base layer of 50 Ni-50 Cr and an upper coating of Al_2O_3. The test containers were then used to evaluate the resistance of the sprayed coating against corrosion resulting from continued exposure to a process of heating and cooling, and studies were performed on ways of performing non-destructive tests of this spray coating.

To test durability, the material was subjected to the following four-stage process of heating, reaction, cooling, and release: (1) heating at a pace of 5°C per minute; (2) reaction at a temperature of 450°C, a pressure of 170 kg/cm^2 G, a mixing speed of 400 rpm, a reaction time of 60 minutes, a quantity of 24 grams of coal, a quantity of 36 grams of hydrogenated solvent, a quantity of 0.72 grams of catalyst, an initial hydrogen pressure of 75 kg/cm^2 G, and a G/L ratio of 520 NI/kg; (3) a two-hour process of cooling consisting of forced cooling after allowing the material to return to room temperature; and (4) release. Cracks were observed in the first test container soon after the beginning of the test process, and cracks were observed in the second test container near the end of the testing process.

After the coating had been sprayed, it was subjected to non-destructive testing consisting of ultrasonic tests designed to search for cracks in the coating, and after the completion of anti-corrosion application testing, non-destructive ultrasonic tests were performed and inspections were made of the external appearance of the surface of the material as viewed by the naked eye, the surface of the material as viewed under an electron microscope, and an EPMA cutaway view of the material, after which the ability of the spray coating to withstand wear was then evaluated.

A description of the results of these tests is given in the following paragraphs, together with a description of the evaluations obtained therefrom.

a. As a visual inspection of the exterior of the first of the two containers revealed a tortoise-shell-shaped crack in the Al_2O_3 layer of the coating on the lower surface of the container after the 11th repetition of the cycle of heating and cooling, all further testing was suspended at this point. Similarly, peeling along a length of 3 millimeters within the coating on the lower surface of the container could be seen in the second of the two test containers after the 11th repetition of the testing cycle, and this peeling had expanded to cover a third of the total area of the lower surface of the container by the 20th repetition of the testing cycle. Testing was continued, however, until the 36th repetition of the testing cycle.

b. The results of examinations of cutaway views of the test containers showed that the tortoise-shell-shaped cracks and peeling which had been observed on the lower surface of these containers had occurred in the Al_2O_3 layer of the coating and that the base layer of the spray coating had not been damaged. It was also discovered that the thickness of the Al_2O_3 spray coating which remained on the lower surface of these containers was significantly higher than that called for by specifications, and it was found that large differences could be observed in the thickness of the Al_2O_3 spray coating along the lower part of the inner walls of the containers. Note that it is believed that the causes of these differences lie in the fact that the test containers were small in size and the fact that restrictions on the shape of these containers had made it impossible to properly apply the spray coating.

c. While an examination of the above does show that defects were found to exist in the shape and design of the test containers which resulted in cracks and peeling, at the same time it was found that, with respect to the area which had been sprayed with a coating of Al_2O_3, just as was found to be true in the preliminary testing and in-plant testing performed thus far, H_2S penetrates through the sprayed-on Al_2O_3 layer during the initial stages of liquefaction and a portion of this H_2S reaches through to the surface of the base material. As time passes a phenomenon could be seen in which holes in the sprayed coating close, thus providing evidence confirming that an Al_2O_3 coating does indeed serve as a mechanism to prevent unwanted corrosion.

d. A non-destructive ultrasound evaluation of the coating of the containers was performed using ultrasonic waves of a frequency of 10 Hz, and from the height of the echo waves from the lower surface of the containers, it was found that it was possible to evaluate defects in the coating and the scale of large differences in the thickness of sprayed coating before the implementation of corrosion-resistance application testing and after the application of the coating. However, it was also discovered that the water penetration method which had been used as the method for measuring these defects tended to cause the sprayed coating to rust, and for this reason it will be necessary to search for some other method of performing this test.

e. In ultrasonic tests performed after the completion of tests of resistance to corrosion, it was found that the amplitude of echo waves from the lower surface of the container increases by roughly 10 decibels from the amplitudes measured before testing. Note that while the magnitude of the change in the amplitude of these echo waves indicates the need to answer the question of what serves to cause these changes, it was also determined that it was possible to detect significant levels of deterioration in the sprayed coating.

f. In past tests, cylindrically-shaped test materials in which the external perimeter was sprayed with a coating of Al_2O_3 were used, and it was found that the Al_2O_3 coating provided excellent resistance against abrasion and corrosion, and it was expected that similar results would be obtained in the current series of tests. As noted above, the results of corrosion-resistance testing showed instead that the Al_2O_3 provided inferior resistance to corrosion, thus giving evidence confirming that the size and shape of the container being sprayed affects the method used to apply the spray coating and influences the durability of the Al_2O_3 coating.

(c) In-plant testing

(i) Metallic materials

In order to evaluate the ability of materials to withstand hydrogen penetration in actual production environments, fragments of exposed 3 Cr-1 Mo reinforced iron test samples were inserted into the DC-203 PSU liquefaction reactor as a follow-up to similar tests which were performed in fiscal 1993. The total length of time over which these materials were exposed during Run 0601 and Run 0602 in fiscal 1994 came to 100 days, with the environment to which these test samples were exposed consisting of reactions using Tanito Harum coal at reaction temperatures of 450–465°C and at reaction pressures of 170–190 kg/cm^{2}G. The test samples exposed during the current series of tests consisted of the same samples which were exposed for a period of 50 days in Run 0502 during fiscal 1993 (i.e., materials corresponding to those subject to influences of welding heat, exposed to a temperature of 1,200°C for a period of 0.5 hours, after which they were cooled by water over a period of 17 hours to a temperature of 690°C, thus yielding cylindrical test samples with a diameter of 30 millimeters and a length of 60 millimeters with a surface sprayed with a coating of Al_2O_3) which were inserted into SUS316 support rods with their surfaces sprayed with a coating of Al_2O_3, after which they were inserted into the DC-203 liquefaction reactor.

Note that evaluations (i.e., tensile-strength testing and studies of deterioration of materials in Charpy testing) of the test samples which were exposed for a period of 50 days during Run 0502 in fiscal 1993 and the test samples which were exposed for a period of 150 days in Run 0502 through Run 0602 will, in consideration of the PSU operation schedule, be performed together in 1995.

(ii) Surface covering materials

With the objective of comparing the resistance of 6 types of test materials sent from the United States (i.e., 2.25 CR-1 Mo, 3 Cr-1.5 MO, 9 Cr-1 Mo, FAS, FAL, FA180*) to corrosion from exposure to sulfides with that of three similar test materials sent from Japan to the United States (i.e., diffuse aluminum covering material No. 1, diffuse aluminum covering material No. 2, and diffuse chromium covering material), the materials were inserted into the PSU liquefaction reactors (i.e., DC 202 and DC 203) and exposed to actual production conditions during 50 days of operation during Run 0602 for Tanito Harumu coal PSU operation (reaction temperature from 450–465°C and a reaction pressure of 170–190 Kg/Cm^2 G). Note that evaluations (i.e., observation of the external appearance, weight, and changes in dimensions of the material, together with observations of cutaway EPMA and organization observation of model welds of the diffuse covering material) of the exposed materials will, in consideration of the PSU operation schedule, be performed in 1995.

* Note that FAS, FAL, and FA180 all consist of Fe-Al materials.

(3) Future Tasks

All planned preliminary testing has been completed, and in order to now achieve all research objectives, it will be necessary to perform the following studies:

(a) Study of the resistance to hydrogen-induced wear on the part of metallic materials during in-plant tests performed in fiscal 1993 and fiscal 1994 (scheduled to be completed in fiscal 1995)

(b) Perform in-plant tests of the materials sent from the United States. (Evaluations also to be performed in fiscal 1995 of materials exposed to production environment in fiscal 1994. Tests to be performed in fiscal 1995 and thereafter as well, and associated evaluations also to be performed.)

(c) Evaluation of deterioration in materials caused by long-term use of actual production equipment (PSU liquefaction reactor: 3 Cr-1 Mo/SUS347)

1.2.2 Research on Solvent Hydrogenation Catalyst

(1) Objectives and Work Program

The objective of this research is to develop technology for processing recycle solvents for bituminous coal liquefaction (i.e., the NEDOL process).

(a) The development and improvement of hydrogenation catalysts and evaluation of their applicability to mass production.

The development and improvement of hydrogenation catalysts, which are applicable to solvents derived from a wide variety of different types of coal, and evaluation of the applicability of improved catalysts to mass production.

(b) The development and improvement of an n-paraffin catalyst and evaluation of its applicability to mass production

As a countermeasure for cases when n-paraffin accumulates, development of an n-paraffin cracking catalyst and study of the process for using this catalyst are being conducted.

(2) Overview of Results Obtained in FY1994

(a) Evaluation of suitability of hydrogenation catalysts for use in industrial applications

(i) Evaluation of suitability of developed catalysts with respect to Tanito Harum coal recycle solvent

Using the Tanito Harum coal recycle solvent, obtained from 1 t/d PSU operations, as a raw material, long-term continuous hydrogenation process testing was performed on a hydrogenation catalyst which had been developed over a period of 2,400 hours. The hydrogenation processing tests were performed under temperatures of 300–380°C, a pressure of 100 kg/cm^{2}G, LHSV 1 hr^{-1}, and a G/L ratio of 1,000 N 1/1. During the latter half of the testing period, the reaction temperature was varied, and data on the reaction characteristics after the passage of long periods of time were obtained therefrom.

No major decrease in reactivity was observed even after a period of approximately 2,200 hours of oil operation, thus providing evidence of a stable level of catalytic reactivity. In addition, the temperature effects of the aromatic ring hydrogenation reaction obtained during the latter half of continuous long-term testing (i.e., from 2,200–2,400 hours) were virtually identical to that obtained during hours 250–500 of operation during the reactivity tests performed in fiscal 1993.

(ii) Analysis of raw material solvents

To analyze the Tanito Harum coal recycle solvent and the hydrogenation processing oil, GPC, distillation gas chromatograph and GCMS analyses were performed. As a result, it was found that not only was there an increase in the hydrogenation processing temperature, but also that these materials contributed to the hydrogenation of aromatic rings and to a lower level of hydrogenation decomposition.

(b) General evaluation of the newly-developed catalyst

A general evaluation of the results which had been obtained as the result of the newly-developed hydrogenation catalyst and n-paraffin decomposition catalyst was performed from the perspectives of the development of catalysts, the need to evaluate their performance, and their suitability for use in industrial applications.

(3) Future Tasks

While the research described herein is scheduled to be completed in the current year, one point remains as a final task which must be completed in order to ensure the success of support research performed for the 150 tons/day pilot plant: verification tests and operation research for the 1 ton/day PSU using the newly-developed hydrogenation catalysts.

1.2.3 Materials and Design of Equipment for Coal Liquefaction Plant (Letdown Valves, Etc.)

(1) Objectives and Work Program

Under this research program, ceramics, cemented carbides and other new materials including composites were subjected to evaluation and selection as candidates for use in coal liquefaction plant equipment and instrumentation. Prototypes were fabricated with designs suited for the optimum operating conditions of the plant, and verified in the process support unit (PSU) and pilot plant (PP). The development of letdown valves, block valves, and slurry flow meters for use in a large-scale plant, demonstration plant (DP) or commercial plant (CP) after PP verification is the final target.

(2) Overview of Results Obtained in FY1994

(a) The proposal and evaluation of research and testing plans

From the results of all the tests performed up to the preceding year, it was found that when using the let-down valves made of sintered diamond and ultra-fine tungsten carbide particles, the materials which had been determined to be the best for let-down valves, it was possible to achieve a level of approximately 1,000 hours of continuous PSU operation. A plan was therefore proposed for the current year calling for the carrying out of PSU verification tests designed to make it possible to achieve even more stable continuous operation over an even longer period of time. In circulation erosion testing, a test plan was created to establish procedures for use in evaluating the effective life of valves. Studies and evaluations were also performed of non-destructive testing methods for use in testing worn plugs and sheet rings. In terms of slurry flow meters, plans were proposed for pulse testing and for PSU verification testing. A preliminary study was also performed concerning the development of large-scale block valves.

(b) Let-down valve circulation erosion test

In circulation erosion and corrosion testing, a series of basic acceleration tests was performed in order to obtain the data needed to predict the effective life of valves and to determine the optimum flow structure of large-scale let-down valves for use in production plants. In tests performed thus far, studies have been performed on factors such as scale-up factors, pressure levels (i.e., flow speed levels), and the relationship between the hardness of materials and slurry quality (i.e., the effects of the hardness of slurry particles) on the effective life of these valves.

In the current year, in order to study the effects of the temperature and type of slurry liquids, hot oil was used to perform a series of circulation erosion tests. Using a model valve constructed of SDK11 material, in place of the water-aluminum slurry normally used, the slurry used consisted of a slurry of hot oil using natural pyrite or coal liquefaction residues as the solids within the coal liquefaction solvent (slurry concentration 1wt%, 3,501/hour, 3 MPa, 150°C). As a result, it was found that no difference could be seen in decreases in the degree of aperture of valves between coal liquefaction residue (i.e., Tanito Harum coal residue) and natural pyrite. Similarly, no difference could be seen in decreases in the degree of aperture of valves in hot oil operation and normal temperature operation. By organizing and evaluating the basic data and the results obtained thus far concerning liquid quality and erosion, it was possible to learn something about the erosion which exists when using water-aluminum slurry and hot oil slurry, and since it therefore becomes possible to compare the data between the two, it became an easy task to reflect the data obtained thus far on water-aluminum slurry on hot oil slurry. Note that plans also exist to reflect this data in methods for the prediction of the effective life of valves in the future.

(c) Fluid pulsation test of slurry flow meter

In order to study the ability of Venturi slurry flow meters to follow differences in speed and volume of fluid, a series of liquid pulsation tests was performed. Under conditions with a liquid flow of 150 liters per hour and a pressure of 2.5 MPa, a pulsation was created in which the frequency of the pulsation was equivalent to 1 Hz and the pressure amplitude was equivalent to 1.5 MPa so that the effects of the pulsation could be observed. The Venturi waveforms thus obtained are shown in Figure 1 together with waveforms as measured using electromechanical flow meters which have been included for comparison. Since this provides an illustration of the relationship between flow and pressure differentials according to the fluctuation of pressure, it was recognized that Venturi slurry flow meters can perform highly accurate pulsation tracking. While a similar series of tests was performed using an orifice flow meter in order to provide a basis for comparison, it was found that the cutaway area of the output flow varies when using an orifice flow meter, and that it is therefore impossible to track variations in the volume and speed of flow.

(d) Verification testing

(i) Let-down valves

Following up on similar work performed during the previous year and based on the results of high-speed spraying tests and circulation erosion tests, PSU let-down valves (1 ton/day) were fabricated and verification tests were performed. The materials used consisted of ultra-fine tungsten carbide particles coated with a TiCN coating (i.e., the same materials as those used in fiscal 1993), and sintered diamond was used as the sheet-ring material. In addition, in order to prevent erosion along the lower part of the sheet-rings, the inner walls of the lower part were reinforced with tungsten carbide, thus improving the durability of the material and its ability to resist wear and tear. The results of PSU verification tests are shown in Figure 2. The results of these tests showed that, in contrast to the tests

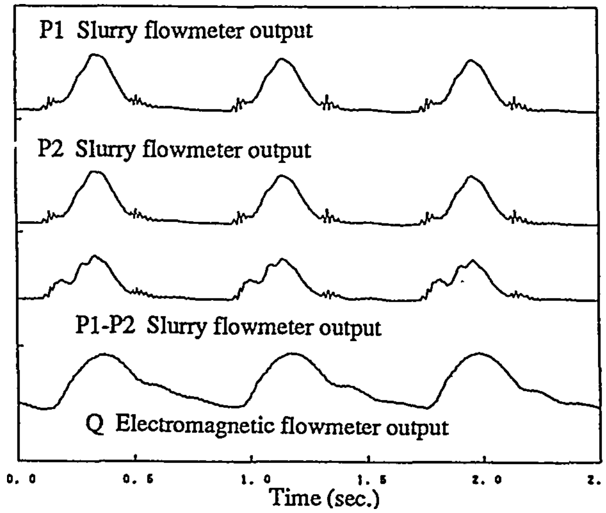

Fig. 1 Samples of Pulsation Flow Pressure and Flow Waveforms (Slurry flowmeter)

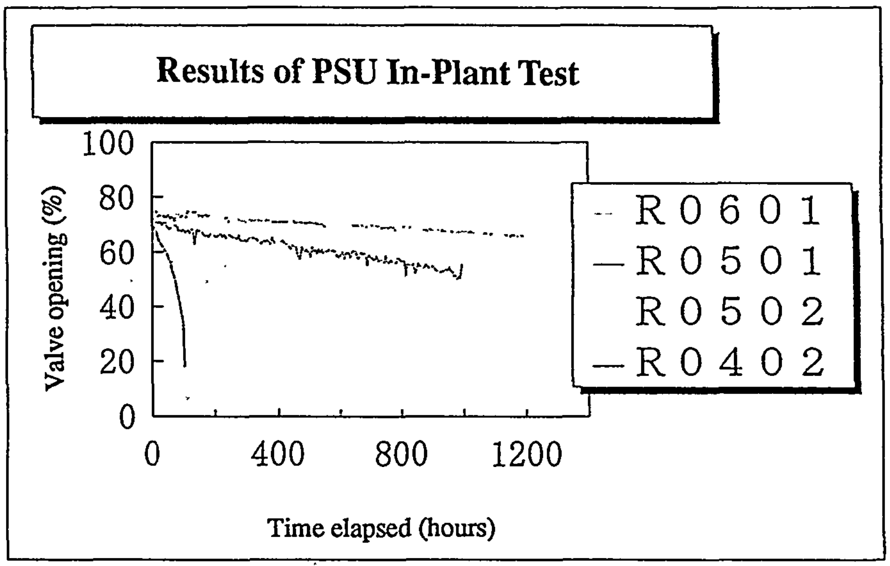

Fig. 2 Results of PSU In-Plant Test

performed in fiscal 1992 in which ultra-fine particles of tungsten carbide were used on plugs and sheet-rings to bring the effective life of valves to a length of roughly 100 hours, in fiscal 1993, when diamond was used on the sheet-rings, it was possible to reach a level of approximately 1,000 hours of continuous operation. These tests further showed that in the current year when the inner walls of the lower part of the sheet rings were further reinforced with tungsten carbide, it was possible to reach a level of approximately 1,200 hours of continuous, uninterrupted operation. In addition, when the sheet rings and the lateral surface of the sheet rings were cut open and inspection after the completion of operations, it was found that virtually no erosion could be seen even after as much as 1,200 hours of operation. From facts such as these, it was confirmed that, as a combination of critical valve materials, the best combination would be one of ultra-fine tungsten carbide particle plugs and orifices together with sheet rings made of sintered diamonds, and that it would be possible to produce let-down valves with a longer effective life with such a combination of materials. Furthermore, it was also confirmed that it would be possible to further improve durability by reinforcing the inner wall of the lower part of the sheet rings. Note that plans exist to conduct even longer periods of continuous operation in the future.

(ii) Slurry flow meters

Venturi slurry flow meters, with high thermal and slurry erosion resistance, were installed at the intake of the slurry heater in the PSU vacuum distillation tower, and the performance of this setup was evaluated in the same manner as it was last year. In addition, a slurry flow meter for a slurry of a high 40wt% concentration was installed in the slurry circulation line, and evaluated last year. The results of these tests showed that, just as last year, the slurry flow meter designed for high temperatures indicated no observable deterioration in the precision of measurement even after approximately 100 days (or 300 days in total) of operation. The flow meter for high-concentration slurry showed no indication of the influence of erosion. This shows that Venturi slurry flow meters should be applicable for the measurement of coal liquid slurry.

(3) Future Tasks

All data collected thus far must be brought together to create a set of guidelines for designing the equipment which will be used in a commercial plant.

1.2.4 Research Using Small-Scale Devices (Research on Iron Sulfide Catalyst Compounds)

(1) Objectives and Work Program

The objective of this program was to manufacture and perform research concerning the iron sulfide catalyst compound used as the liquefaction catalyst in the NEDOL coal liquefaction process. Dry-type production technology data on the iron sulfide catalyst, which is the standard catalyst used in bituminous coal liquefaction process, was obtained. A pilot plant was operated in order to provide iron sulfide catalyst compounds for the Process Support Unit (PSU) and other support research. Operating data on the liquefaction of coal using iron sulfide catalyst was obtained using the dry-type method.

(2) Overview of Results Obtained in FY1994

(a) Catalyst provision operation

After implementing improvements to the facilities in accordance with the results of test operation and research performed in fiscal 1993, in order to study improvements to be made to the facilities and other processes, the ability of equipment to withstand the stresses of continuous operation, and the provision of catalyst and increases in production volumes to PSU Run 0602, the feeding of raw material was begun on October 27, 1994, and operations were performed until the scheduled halting of operations on the following November 6th (Run 9401).

In order to obtain FeS_2 catalyst of a purity of over 90wt%, operating conditions were set so that, in accordance with the results of operations and research performed in fiscal 1993, iron sulfate A was used as the iron sulfate raw material, the reaction temperature was set to a range of 480°C to 490°C, the molecular ratio of sulfur to iron used in the reaction set to 3.1, and the speed of the lower air tower of the fluid fluidizing bed reactor set to 0.20–0.22 meters per second.

In order to produce the catalysts to be provided for use in PSU Run 0602, eight days of operation were performed under conditions of a production rate of 11 kilograms of catalyst being produced per hour, thus resulting in a total production of some 2,030 kilograms of catalyst. Of this total amount, the iron sulfide weighted average purity of the catalyst to be provided in Run 0602 (overflow product and cyclone product for a total of 1.986 kilograms) was above the target value of 92wt%. The particle size of the overflow product and the cyclone product came to 124–164 μm and 40–71 μm, respectively. Note that these measured particle sizes varied at the sub-micron level when they were subjected to a five-minute period of ultrasound treatment before measurement. In contrast to this, however, the distribution of particle sizes obtained for products of the electric dust collector did not vary at the sub-micron level even after the performance of the same operation.

The operating times recorded during this period came to a total of 184 hours and 34 minutes of actual operation time used for the feeding of raw material and 7 hours and 46 minutes of stoppage within a total of 192 hours and 20 minutes of operating time, thus resulting in a run factor of 96%. This is significantly higher than the run factor of 44% recorded during the previous run (i.e., Run 9303), thus providing evidence of greatly improved operation. Note that the stoppages were caused by blockages in the raw material feeding mechanism and corrosion found in the exhaust gas cooling system.

During the final two days of operations, in order to study the conditions required for increasing the volume of production, the plant was operated under conditions calling for production volumes of 12 kg/hour and 13 kg/hour of production, and it was found that the raw material feeding mechanism proved unstable under both sets of conditions. The average iron sulfide purity of the obtained material (i.e., the weighted average of overflow product and cyclone product) came to 90wt% when operating at a capacity of 12 kg/hour and to 91wt% when operating at a capacity of 13 kg/hour. No difference was found in terms of particle-size distributions.

In order to prevent the settling of material and ensure that particles remain of an even size within design specifications during PSU supply, mixing and crushing processing was performed. Note that the target particle size of crushed particles was set at an average of under 2–5 mm and a maximum of 40 mm of wet compound iron sulfide catalysts which have proved effective in actual use. A number of different methods were studied, and a wet mixing batch-type mill was used to mix and crush the material. As a result, a value of $D_{50} = 1.0\ \mu m$ was obtained as the particle size of catalyst to be provided for use in the process.

(b) Maintenance and upgrading of facilities

In order to prevent the closure of the gas cooling unit as a result of the deposition of sulfur residues from exhaust gas, a sulfur residue combustion removal unit was installed upstream of the exhaust gas cooling unit. In addition, as a means of maintaining the insulation performance of the electric dust collection unit, the insulation was strengthened by covering the hanging electrode rods with quartz tubing.

As a result of catalyst production operations, the burning of sulfur raised the temperature of exhaust gas from 535°C to 700°C, and no deposits of sulfur could be seen on the exhaust gas cooling unit. The effectiveness of the sulfur residue combustion removal unit made it possible to achieve a high operation run factor. As for the electric dust collector, the concentration of output vent dust reached a level of 1.5 grams/Nm^3, thus providing evidence of significant improvement.

After the completion of catalyst production operations, improvements were made to upgrade the mist separator of the exhaust gas processing mechanism.

(c) Basic evaluation of catalyst liquefaction performance

Before Run 0602 of the PSU, autoclave tests of the liquefaction reactivity of the materials obtained in catalyst production operation Run 9401 were performed.

The catalyst obtained in Run 9401 had a oil yield of 68.3wt%, and it was confirmed that this catalyst possessed a liquefaction performance roughly equivalent to the oil yield of 67.5wt% obtained for the catalyst in Run 9303. In addition, in comparison with the oil yield of 68.3wt% obtained in the case where oil ultrasonic dispersion of catalyst was performed before autoclave reaction, the oil yield in the case where this was not performed came to 67.3wt%, thus showing that there is little difference between the two. As for the effects of the amount of catalyst added, when the amount added comes to 2wt% of the amount of coal used, the oil yield is 67.0wt%, and when the amount of catalyst added is lowered to 1wt%, the oil yield falls to a level of 60.8wt%.

(d) Technical evaluation of the dry production method

Based on operations and research performed in fiscal 1993 and fiscal 1994, studies were performed on the operability of small-scale devices. Note that at the present time testing is still in an intermediate stage, and that in the future these tests must be completed so that they may be used in performing technical evaluations of the effectiveness of dry synthetic iron sulfide as a liquefaction catalyst. These studies will include studies of problems related to the development of dry production methods.

(e) Creation of research plans

A detailed research plan was created for fiscal 1994 together with a research plan for the upgrading, maintenance, and test operations of facilities, as well as for the basic evaluation of catalyst liquefaction performance and evaluation of dry production method technologies.

(f) Applications and reports submitted to government agencies and ministries

The applications and reports which had to be submitted to government agencies and ministries in order to upgrade small-scale devices for use in the production of synthetic iron sulfides were created and submitted, and authorization was obtained for the implementation of the planned improvements.

• Application for authorization to modify facilities for the production of hazardous materials (application submitted on September 30, 1995 and authorization received the following week, on October 5)

• Completion inspection of plants for the production of hazardous materials (receipt of certificate attesting that completion inspection had been performed on October 19, 1994)

(3) Future Tasks

Based on the record of operation of small-scale devices up until fiscal 1994, and with the aim of achieving operation of even greater levels of stability, facilities improvements must be studied and implemented, and the effectiveness of these improvements must be confirmed at some time in or beyond fiscal 1995, at the time of dry synthetic iron sulfide catalyst production operation to be supplied to PSU and other support research. In addition, based on engineering data obtained during operation and research, technical evaluations must be performed concerning the following items:

• Studies of the operability of small-scale devices

• Evaluation of dry synthetic iron sulfides as liquefaction catalysts

1.2.5 Survey for the Selection of Coal Types (Test of Performance of Chinese Coal in Liquefaction)

(1) Objectives and Work Program

The goals of Japan-China joint research are to clarify the performance and liquefaction characteristics of Chinese coal and to prepare basic data for the selection of coal and the development of technology.

(2) Overview of Results Obtained in FY1994

A small-scale continuous bench-scale unit was used to perform once-through, solvent recycling, and NEDOL mode operations with Heilungchiang coal, Shantung coal, Liaoning-Fushun coal, Liaoning-Chinyo coal, and Liaoning-Fushin coal.

NEDOL mode operations were performed using three sets of once-through conditions for Heilungchiang coal, one set of conditions for solvent recycling, four sets of conditions for NEDOL mode, and a total of eight sets of conditions for other types of coal. The solvents used consisted of DOA or hydrogenated solvents, and the catalysts used consisted of sulfur with Fe_2O_3 added as an auxiliary catalyst and FeS_2, and these solvents and catalysts were used to perform liquefaction tests.

As a result of liquefied oil analyses, it was discovered that the characteristics of Heilungchiang coal were equivalent to or better than the characteristics of Fushuku coal, the coal that had displayed the best characteristics in the past. In addition, as a result of NEDOL mode operations, it was found that, just as it was found last year, there was a tendency for the amount of hydrogen consumed to be lowest and for oil yields to improve at times when hydrogenated solvents were used as solvents.

(3) Future Tasks

Liquefaction performance tests must be

performed for Chinese coal using small-scale continuous bench-scale unit so as to accumulate a sufficient body of data. NEDOL mode operations with Chinese coal using hydrogenated solvents as solvents must be performed so as to study the possibility of using this coal in a bituminous coal liquefaction pilot plant with a capacity of 150 tons per day.

2. Development of Basic Liquefaction Technologies

2.1 Uses of Coal Liquefaction Products and Refining Technologies

2.1.1 Research Using Test Plants

(1) Objectives of and Description of Development

With the objective of smoothly introducing liquefied coal oil into the currently existing petroleum product distribution system, the optimum processes related to the hydrotreatment, cracking, and reforming of liquefied coal oil will be designed, a process development unit will be used to obtain engineering data, and engine tests will be conducted in order to evaluate actual performance.

(2) Overview of Results Obtained in FY1994

(a) Review of PDU preliminary design

The capacity of the PDU was set at 40 bbl/day, and the preliminary design was reviewed using a distillation unit, the No. 1 hydrotreating unit, the No. 2 hydrotreating unit, a catalytic reforming unit, off-site facilities, and common facilities as the basic structure.

(b) Detailed design

Based on the plan created in accordance with the basic design, detailed designs of individual devices were created. The main design items consist of items such as the basic flow, basic equipment specifications, pipe system, construction, and electric measuring instrument facilities.

(c) Storage and control of liquefied coal oil

Continued test analyses were performed on stored liquefied coal oil as controlled in the past.

Test samples:

Yalung liquefied coal oil (brown coal pilot plant) and Wandoan coal liquefied coal oil (PDU)

Frequency of analyses:

Two times per year

Analysis items:

Bromine value, viscosity, total acid value, SS, sludge volume

With respect to the total acid value, a tendency could be observed of a slight decrease in value, and it is judged that this is due to the fact that gradual reduction takes place under exposure to a nitrogen atmosphere.

(3) Future Tasks

The PDU for which construction is scheduled for fiscal 1995 will be used to verify the liquefied oil upgrading process. In addition to obtaining engineering data in operations and research, test samples collected in the PDU will be used to perform engineering tests and studies which will in turn be used to verify the practicality of the liquefied coal product.

2.1.2 Laboratory-Scale Unit Research

2.1.2.1 Upgrading of Liquefied Coal

(1) Objectives and Work Program

The goals are to develop a suitable refining process and application technologies for coal-derived oil.

(2) Overview of Results Obtained in FY1994

(a) Upgrading of naphtha and kerosene and light oil components

(i) Hydrotreatment of naphtha components of Indonesian liquefied coal oil

With respect to Indonesian Tanito Harum liquefied coal oil, the nitrogen concentration present is higher than that found in the types of liquefied coal oil tested thus far. In order to satisfy the reformer requirement calling for a nitrogen concentration of 1 ppm, it proved to be necessary to process the coal under the following severe conditions: a temperature of 320°C, a pressure of 80 kg/cm^2, and an LHSV of 0.5 hr^{-1}.

(ii) Hydrotreatment of Indonesian liquefied coal oil kerosene and light oil components

Just as was found to be the case with naphtha, it was found that the nitrogen concentrations found in kerosene and light oil components of liquefied coal oil were also high, and the results of gas chromatography tests show that in the nitrogen-removal reaction of kerosene components, nitrogen compounds undergo aromatic ring hydrogenation, and it is believed that nitrogen is removed after going through a stage of conversion into anilines. Additionally, when the pressure at which hydrogenation is performed was raised, the hydrogenation of aromatic compounds proceeded as expected, but no progress was made in the cracking of paraffin or naphthalene rings. In view of this fact, it has been concluded that it would be difficult to raise the cetane index using ordinary nitrogen-removal catalysts even if the reaction pressure were to be increased, and that it will be necessary to perform the hydrogenation process in two separate stages.

(b) Research into kerosene and light-oil hydrotreating technologies

(i) Research into upgrading technologies

With respect to Tanito Harum liquefied coal oil kerosene, light oil, and kerosene/light oil components, hydrotreating experiments using commercially available catalysts were performed, and a study was performed on hydrotreating reaction conditions of the first-stage, which affect the removal of heterogeneous elements (i.e., nitrogen and oxygen).

When hydrotreating was performed under mild conditions, the nitrogen removal ratio ranged from 50% to 73%, and the oxygen removal ratio ranged from 75% to 93%, thus indicating that the removal was not sufficient. When hydrotreating was performed under severe reaction conditions, while the nitrogen removal ratio came to 99.9%, the oxygen removal ratio was limited to somewhere in the range of 80% to 99%, thus indicating that oxygen removal was somewhat more difficult.

In addition, hydrotreating experiments were also performed using kerosene and light oil components of Tanito Harum coal, and a comparison was performed of the catalytic performance of one type of Ni-W catalyst (i.e., UGC-424, a catalyst developed by NEDO) and two types of Ni-Mo catalysts (i.e., H01 and H02, two commercially available catalysts), and as a result it was found that Ni-W catalysts displayed the highest levels of reactivity.

When the second stage of hydrotreating tests was performed in which petroleum was mixed together with a hydrogenated oil created using the Ni-W catalyst under conditions satisfying the light-oil No. 2 JIS cetane index of 45, it was determined that it was possible to mix liquefied oil with petroleum to a degree of 30%.

(ii) Development of applied technologies

In order to gain an understanding of the relationship between the depth of hydrotreating and sludge refinement, kerosene and light oil components of Tanito Harum liquefied coal oil were combined with raw material oil and eight types of refined oil with different depths of hydrotreating, ASTM acceleration/storage stability tests were performed, and the amount of sludge produced during the thirteenth week was measured. As a result, it was found that the amount of sludge produced rose as the depth of hydrotreating increased, and that the refined oil nitrogen and oxygen content decreased as the sludge production increased. Even in mild hydrogenation processing with a nitrogen removal ratio of approximately 40%, sludge production was markedly limited.

(3) Future Tasks

(a) Creation of a two-stage processing system for kerosene and light oil

(b) Gaining an improved understanding of the catalysts used in the second stage of processing

2.1.2.2 Development of New Catalysts for Upgrading Liquefied Coal

(1) Objectives and Work Program

To develop hydrogenation and hydrocracking catalysts suited for use in refining liquefied oil.

(2) Overview of Results Obtained in FY1994

(a) First stage: hydrogenation/removal of N,O compounds

It was discovered that Ni-W/Al_2O_3 catalysts with additional nickel displayed a high level of reactivity and possessed a long effective life. A catalyst prepared for use in long-life testing was supplied for hydrotreating tests carried out by the Research Association for Petroleum Alternatives Development.

Studies were performed on the relationship between compound acid carriers, sulfurization, and catalyst life, and the effects of the characteristics of surface zirconia, aluminum zirconia supports and the effectiveness of sulfurization at high temperatures of 400°C and above were observed.

(b) Second stage: hydrocracking

A variety of Na-Y zeolites were prepared as improved forms of support-component zeolites for use in performing selective reactions of open naphthalene rings.

(c) Related catalyst increase adjustment tests

In order to establish a method for the mass production of the first-stage hydrogenation catalyst, volume production tests were performed for newly developed catalysts which had displayed higher degrees of reactivity and longer effective lives than commercially available catalysts.

(3) Future Tasks

(a) Study concerning the stability of surface metals

(b) Study concerning US-Y zeolite preparation

2.1.2.3 Separation of Heteroatomic Compounds from Coal-Derived Oil

(1) Objectives and Work Program

The objectives of this development program are to reduce the cost of upgrading coal-derived oil and to improve the economic viability of the liquefaction process by increasing the production of value-added end products. These objectives will be pursued by developing an effective set of techniques for the separation of heteroatomic compounds from coal-derived oil and by finding ways to make effective use of the products.

(2) Overview of Results Obtained in FY1994

(a) Study of alkali and acid extraction methods

While a number of different alkali and acid extraction methods have been selected from among a range of different processes using naphtha and kerosene and light oil components in past research, in consideration of the need for economic viability it was decided to study the processing method summary components of liquefied oil (i.e., concentrated phenols). As a result of distillation tests and compositional analyses of liquefied oil, it was discovered that components at temperatures ranging from 150°C to 250°C were suitable for summary components, and in experiments designed to extract these components it was possible to achieve extraction rates of 94%.

(b) Explaining the association state of heteroatomic compounds

With respect to phenol extract using Wyoming coal liquefied naphtha as raw material, in order to learn about the influence of layer separation related to solvent extraction and separation performed using water and methanol solvents, when a comparison was performed between the conventional method whereby water is added and separated after the addition and separation of methanol and a new method whereby water is added and separated all together before separating methanol, no great difference was seen in the extraction ratio, and it was judged that the latter method was in practical terms the better one.

(c) The establishment of alkali and acid extraction techniques

With the objective of simplifying processing, when xylene was added to the oil layer during the phenolate decomposition process, it was discovered that it is possible to slow the dissolution of phenolates in the oil layer.

(d) In addition to this, basic tests and studies were performed concerning the hydrogenation reaction characteristics of roughly separated heterogeneous oil and the environmental suitability of these oils at the time of the combustion removal of heterogeneous oils.

(3) Future Tasks

(a) Research to improve component technologies such as phenolate dissociation and alkali recovery

(b) Study on coal liquids obtained from various types of coal and evaluation of the merits of heteroatom removal

2.1.3 Environmental Safety Evaluation Tests

(1) Objectives and Work Program

The objective is to secure the health of workers at coal liquefaction plants, create a socially acceptable environment, and ensure safety at the time of using coal liquid oils. This will be done by conducting animal tests with the respective coal liquid oils under development and obtaining basic data. Test items will be selected from among those in the Industrial Safety and Hygiene Law, the Law Concerning the Examination and Regulation of Manufacture, etc. of Chemical Substances, and the MPD items of the OECD. As a supportive effort, an analytical study and the investigation of overseas literature will be conducted as well.

(2) Overview of Results Obtained in FY1994

In the current year, tests were performed mainly on bituminous coal rough oil naphtha components derived from operations in the PSU.

(a) Physical and chemical properties:
Physical and chemical properties were measured in accordance with applicable guidelines given in the OECD/MPD document titled Tests of Physical-Chemical Properties.

(b) Acute oral toxicity:
Levels of oral toxicity were measured using Crj:CD(SD) male and female rats in accordance with applicable guidelines given the OECD/MPD document titled Acute Oral Toxicity Tests.

(c) Repeated oral doses:
Tests described in the section of the Chemical Substances Review Law titled, "Repeated Dose Toxicity Tests in Mammalian Species" were performed following the applicable guidelines using Crj:CD(SD) male and female rats (SPF).

(d) Mutagenicity testing:
Tests described in the sections of the Chemical Substances Control Law and the Industrial Safety and Hygiene Law titled "Chromosomal Aberration Tests in Cultured Mammalian Cells" were performed following the applicable guidelines using CHL/IU cells, with these tests taking into consideration cases assuming both the presence and the absence of metabolic activation.

(e) Bioaccumulation:

Tests described in the section of the Chemical Substances Control Law titled "Bioaccumulation" were performed in accordance with applicable guidelines using carp.

(3) Future Tasks

From this year, tests related to the evaluation of the environmental safety of oil derived from bituminous coal will be performed, data will be selected from among the appropriate MPD items of the Chemical Substances Control Law, the Industrial Safety and Hygiene Law, and the OECD, and this data will be evaluated from a general perspective.

2.2 Developing Environmentally-Friendly Coal Liquefaction Technologies

2.2.1 Research Designed to Improve and Rationalize Liquefaction Processes

(1) Objectives and Description of Development

With the objective of significantly improving the reliability, economic feasibility, and environmental friendliness of the coal liquefaction process, small-scale continuous-operation liquefaction devices and other equipment will be used to solve technical problems, improve the general level of coal liquefaction technologies, and develop a better technology package for the year 2000. In order to achieve these objectives, the following research and development projects will be pursued:

(a) Improvement of coal properties

By pre-processing coal in a liquefaction solvent before submitting it to a liquefaction reaction, efforts will be made not only to limit the scalarization of metallic compounds and improve process reliability, but also to develop improved coal characteristics and increase energy efficiency by increasing slurry concentrations. In addition, the carbonated gas produced from this process will be concentrated and made easier to remove, and this will in turn make it possible to improve overall environmental friendliness.

(b) Optimization of liquefaction reaction conditions

In addition to the development of improved catalysts and solvents and the optimization of the conditions under which they are used, CLB and gas recycling routes, recycling locations, and recycling volumes will be optimized to produce high-grade liquefied oil, obtain high liquefaction yields, and improve the economic viability of the process as a whole.

(2) Overview of Results Obtained in FY1994

(a) Improvement of coal properties

(i) It was discovered that the decomposition of carboxyl group found within the coal being processed becomes highly noticeable at a level of somewhere around 250°C, and that at temperatures of 400°C approximately 90% of these carboxyls become decomposed and generate carbonated gas.

(ii) The metallic carboxylate found within the coal and believed to be a scale precursor was decomposed by processing it in oil, and it was confirmed that it was converted into a carbonate. It was further determined that a temperature of over 400°C would be necessary to decompose over 50% of the carboxylate.

(iii) It was determined that it was possible to restrain the degradation of coal even at temperatures of over 400°C by processing the coal in oil in the presence of hydrogen-donor solvents, and it was similarly determined that it was possible to reduce decreases in the reactivity of the liquefaction process.

(iv) It was discovered that it is also possible to obtain effects similar to those obtained by performing processing in the presence of hydrogen-donor solvents by adding catalysts and hydrogen and processing in oil.

(v) The results of FT-IR and XRD analyses showed that calcium contained within the coal existed in the form of carboxylates, and that calcium carbonates were produced at temperatures over 400°C. It was also discovered that the production of calcium carbonate could be further stimulated by the use of pyrite catalysts.

(vi) A test piece was attached to the mixing shaft of the autoclave, and scale adherence behavior was investigated. As a result of XRD, SEM-EDX, and Auger spectral analyses, it was found that the materials which could be detected as having adhered to the test piece consisted of $Fe_{1-2}S$, $CaMg(CO_3)_2$ (i.e., dolomite), and sodium. When the amount of calcium, magnesium, and sodium which had adhered to the test piece was analyzed using the ICP method, it was found that the amount of material which adheres is small when pyrite catalysts or coal processed in oil are used, thus indicating that a tendency exists for the behavior to match that of scale generation in reaction units in BSU operation.

It was concluded that this method would be useful as a simple method of evaluating carbonate scales using autoclaves.

(b) Optimization of liquefaction reaction conditions

(i) In order to lighten the composition of the product, tests were performed using heavy solvents that have the boiling point range between 350°C and 420°C. As a result, it was found that under conditions in which gas is circulated using a BSU continuous reaction device (i.e., GF volume 3.8 Nm^3/kg-mafc), the yield of liquefied oil rose in proportion with increases in the CLB recycling volume, and the solvent component balance was also improved. The solvent balance becomes positive when the CLB recycling volume reaches a level of 53% mafc, and the liquefied oil yield obtained at this time reached a level of 60% mafc. Moreover, virtually all of the oil obtained consisted of C_5-300°C, lower boiling point fractions.

In view of these results, it was concluded that it would be possible to achieve high oil liquefaction yields of over 60wt% mafc and create a process capable of producing light product oil (of which the major portion would be C_5-300°C) by using heavy solvents with boiling points in a range from 300°C to 420°C.

(ii) From autoclave tests using gamma iron hydroxide catalysts crushed in oil, it was discovered that it was possible to reduce the amount of catalyst used by one-third from the amount required by the conventional method using dry crushed pyrite (2 mm) catalyst and by two-thirds from the amount required by methods using pyrite catalysts crushed in oil.

(iii) It became clear that gamma iron hydroxide could be easily sulphurated and converted to pyrrhotite at the relatively low temperature of 200°C over a period of 10 minutes, and that the liquefaction reactivity increased as the crystalline size of pyrrhotite decreased.

(iv) As a result of investigations into the effects of adding molybdenum, tungsten, cobalt, and nickel to gamma iron hydroxide, it was discovered that reactivity could be improved through the addition of molybdenum.

(v) When an evaluation of the performance of gamma iron hydroxide as a catalyst was performed using a BSU continuous reaction device, it was confirmed that it showed higher reactivity than that of pyrite catalysts. Under gas and bottom recycling conditions (G/R = 9 Nm^3/hour, B/R = 53wt%), and with the amount of catalyst as iron at 3wt%, a liquefaction oil yield of 61.0wt% mafc was obtained. In addition, while a large amount of sediment could be found within the primary reactor, the total volume of sediments within the reactors was found to be roughly the same as that produced when using pyrite catalysts.

(vi) Tests were performed to investigate the effects of the particle diameter of raw brown coal on liquefaction reactivity, and as a result it was found with particle diameters below 75 mm and with particle diameters in ranges of 75–500 mm, 0.5–1.0 mm, and 1.0–3.0 mm, no great difference could be seen in liquefaction reactivity.

(vii) In order to learn about the mechanism of the effects of gas flow volume, studies were performed using 5L flow-type AC to find the BTM/catalyst concentration in the liquid phase and factors influence things such as reaction time. As a result, it was found that with respect to increases in liquefaction oil yields, large contributions were being made mainly by liquid-phase BTM concentration and reaction time increases. On the other hand, with respect to CLB lightening (i.e., increases in HS concentration) which forms a feature of the effects of gas flow volume, it was discovered that increases in reaction time proved to be effective.

(viii) As a result of studies into the effects of CLB recycling volume on the raw material processing section, a liquefied gas yield of 54% mafc was obtained under conditions of a gas flow volume of 3.8 Nm^3/kg·mafc and a CLB recycling ratio of 90% mafc. The contribution of CLB recycling with respect to increases in liquefied oil yield proved to be less than in experiments in which gas flow volumes were small.

(ix) The increases in liquefied oil yields obtained when CLB was recycled to the reaction unit directly was smaller than when CLB was recycled to the raw materials processing section. It is believed that the primary reason for this lies in the fact that the S/C ratio increased when the CLB was recycled to the reaction unit, and it was concluded that it would be necessary to perform experiments using the same S/C ratio in order to determine the precise nature and extent of the influence of CLB recycling routes on liquefaction reactions.

(x) When gas recycling was performed, the amount of hydrocarbon gas produced decreased, and it was confirmed that the liquefied oil yield increased, that the H/C ratio of the generated CLB was higher, and that it was possible to obtain lighter CLB.

(3) Future Tasks

(a) Improvement of coal properties

(i) While it was proved that decreases in reactivity during oil processing were reduced significantly by improving both the processing conditions and the solvents used in processing, studies will be performed concerning the effects of the characteristics and composition of the solvents and the effects of the catalysts used.

(ii) With respect to simplified evaluation methods for evaluating the amount of carbonate scales using autoclaves, the correspondence to scaling behavior in BSU will be investigated to confirm the utility of this method.

(b) Optimization of liquefaction reaction conditions

(i) While it was confirmed that it was possible to obtain high oil yields of mostly light oil by using solvents with high boiling points to optimize reaction conditions, further studies must be performed to investigate the effects of using solvents with even higher boiling points, the effects of using mixtures of solvents with high and low boiling points, and the effects of adding hydrogenation solvents. The objective is to find the optimal nature and composition of the solvents which ought to be used.

(ii) It was confirmed that the reactivity of synthetic gamma iron hydroxide catalysts was higher than that of the pyrite catalysts now being used, and in view of this fact studies must be performed to determine the minimum amount which may be used and to learn about the effective life and scaling of such catalysts over long periods of operation.

(iii) While CLB and gas recycling was performed mainly for the primary reaction unit, studies should be performed to learn about the features and effects obtained when recycling to the secondary reaction unit.

2.2.2 Research Designed for the Development of More Advanced Basic Coal Liquefaction Technologies

2.2.2.1 Research Designed for the Development of Revolutionary New Coal Liquefaction Technologies

(1) Objectives and Description of Development

In order to develop revolutionary new technologies, including advanced environmentally-friendly technologies for the liquefaction of coal, studies concerning the development of component technologies needed to increase the efficiency of liquefaction reactions and to create new process concepts will be performed, and efforts will be made to improve the overall level of coal liquefaction technology and develop advanced technological packages by the year 2000.

(a) Searching for highly reactive, high-dispersion catalysts

In order to investigate the possibilities for developing high-performance catalysts, studies will be performed on methods of processing ultra-fine particles and using emulsions to create high-dispersion methods. In addition to evaluating the catalyst characteristics, liquefaction reaction activity, and nature and composition of the produced materials, evaluations will also be performed on non-iron catalysts.

(b) Study of the feasibility of the complete coal liquefaction process

With the objective of minimizing the costs incurred in coal liquefaction, a study will be performed on the initial conditions of liquefaction reactions, and efforts will be made to improve yields of liquefied oil and gas and learn about the feasibility of a complete coal liquefaction process. A particular effort will be made to investigate ways of optimizing liquefied oil and gas yield ratios from the point of view of reducing the costs involved in the production of hydrogen.

(2) Overview of Results Obtained in FY1994

(a) The processing of iron-loaded coal

(i) While it was believed that in the ion-exchange iron content method virtually all of the calcium, magnesium, and sodium found in coal could be removed and that this method was an effective one, it was discovered that the liquefaction reactivity was lower than that of gamma iron hydroxide catalysts. It was concluded that the cause of this lay in the fact that the decomposition of iron carboxylates takes place at a slower rate, and in the fact that the vulcanization and conversion to pyrotite (a type of active agent) is slow.

(ii) In the iron hydroxide impregnated method, the calcium and magnesium found in coal forms hard-to-dissolve hydroxides, and while it was found that it is difficult to remove these materials, it was also found that the liquefaction reactivity is higher than that of the ion exchange method. In addition, in the metal impregnated followed by alkaline treatment method, it was found that while the reactivity grew higher in proportion to increases in pH value, the reactivity in either case is lower than that obtained when using gamma iron hydroxide catalysts, and it is believed that further improvements are required.

(iii) A non-ionic active surface agent (i.e., polyoxyethylene-nonylphenyl ether) was added to cyclo-hexane to create an emulsion of ferric ammonium sulfate solution and ammonia solution. The particle diameter of the micelles generated were in the range of several tens of nanometers, and an inspection of high-resolution TEM photographs showed that they possessed a structure close to an amorphous structure. This emulsion liquid was then used to add iron to brown coal and investigate its liquefaction reactivity, and it was found that this improved the THFI conversion ratio and the HS yield ratio.

(b) Study of the feasibility of a complete coal liquefaction process

(i) As a result of investigations of the product yields and nature and composition of product during the process of increasing the temperature up to the point at which liquefaction reactions take place, it was found that improvements could be obtained in THFI conversion ratios and the HS yield ratios at temperatures over 400°C (i.e., at temperatures at which heat decomposition becomes highly active) by adding tetralin, a hydrogen-donor solvent. In addition, from changes in the H/C (i.e., atomic ratio) of the product, it was surmised that the hydrogen transfer was being produced by the solvent at relatively low temperatures in a range of somewhere around 300°C.

(ii) It was found that in a liquefaction reaction performed at a temperature of 450°C it is possible to improve THFI conversion and HS yields and reduce gas yields by performing pre-heating processing for a period of 30 minutes at intermediate temperatures during heating. It was also discovered that processing at a temperature of 350°C was more effective than processing at a temperature of 300°C. The H/C of THFI at this time was relatively high after the liquefaction reaction, and it is believed that the supply of hydrogen to the coal took place effectively during the stage of pre-heating processing. In addition, in view of the fact that this effect was not observed when under nitrogen atmosphere conditions, in which no catalysts or hydrogen exist, it was concluded that the contribution of activated hydrogen atoms in catalysis was great.

(iii) The proportions of tetralin and 1-MN in the solvent were changed to learn about the effects of the volume of catalysts and transferable hydrogen, and it was discovered that CLB yields declined and liquefied oil yields increased in the presence of transferable hydrogen or catalysts. The addition of catalysts in the presence of solvent components or transferable hydrogen was particularly effective in increasing naphtha content. In the presence of both catalysts and transferable hydrogen, the generation of hydrocarbon gas was restrained, and it was also discovered that liquefied oil yields increased.

(iv) From the results of structural analyses of the produced CLB, it was discovered that when the amount of transferable hydrogen increases, the hydrogenation of aromatic rings and other compounds is stimulated and the fa becomes smaller. It was also discovered that while the average molecular weight shows virtually no change, in the presence of a catalyst not only is the hydrogenation of aromatic rings stimulated, the average number of rings within a unit structure decreases. It was also found that the average molecular weight decreases. In addition, in the presence of transferable hydrogen or catalysts, a tendency was observed for the length of side chains to increase and large numbers of substitutes to be created. This indicates that it is possible to restrict the generation of hydrocarbon gas by having hydrogen transfer take place via solvents or catalysts.

(v) It was found that the physical structure of coal changes greatly by processing it in oil at a relatively low temperature range from 150°C to 350°C, and it is believed that the relative surface area increases dramatically when tetralin is added as a result of increases in the number of micro-level pores.

(vi) It was discovered that when tetralin is added, the heat of adsorption of t-butyl-pyridine per unit of surface area on the surface of coal decreases steadily together with oil processing temperature, and it was concluded that this was due to a decrease in the number of functional groups containing oxygen at the point of adsorption. However, when 1-MN was used as the only solvent, it was found that a local maximum occurred at 300°C, and it was found that differences exist in the surface structure of coal caused by heat decomposition in cases where there is no hydrogen transfer from the solvent.

(vii) From the results of TG-MS analyses, it was discovered that when using brown coal carbon dioxide, water vapor, carbon monoxide, and other gases containing oxygen began to be generated somewhere around a temperature of 200°C, and it was discovered that the generation of hydrocarbon gases increased sharply at temperatures in the neighborhood of 400°C.

(viii) The radical concentration in coal, as measured using ESR measurements, was found to increase sharply in the neighborhood of 350°C when in 1-MN, but in DHA (a hydrogen-transferable solvent) it was found that spectrums increased in range and that radical densities decreased over a temperature range from 200°C to 350°C in which heat decomposition becomes active, and it is believed that this is due to the transfer of hydrogen from solvents to coal radicals.

(c) Test surveys performed on a contract basis

With the objective of developing more advanced basic liquefaction technologies, surveys of technological trends in next-generation coal liquefaction catalysts, molecular chemical technologies for complete liquefaction process, and coal energy conversion technologies were contracted out to the Japan Energy Academic Association, Ltd.

(i) Next-generation coal liquefaction catalysts

Catalytic activity of various types of oil-soluble chemical compounds in coal liquefaction processes; the use and liquefaction characteristics of functional groups in coal surfaces; improving the accessibility of catalysts and coal; catalytic activity and characterization of oil-soluble iron catalysts; coal activation processing and learning about the mechanisms underlying catalytic reactions; the design of multi-purpose catalysts and the use of such catalysts in liquefaction processes

(ii) Molecular chemical technologies for a complete liquefaction process

Studies on five areas designed to gain an understanding of the reactivity of coal: evaluation of reactivity at low temperatures, the pre-processing of coal in order to improve reactivity, the drying of coal and the occurrence of concomitant structural changes, types of ores and new separation methods, and the structure and reactivity of coal.

Studies on four areas related to coal liquefaction processes: the initial heating process, schemes for complete liquefaction, the chemical structure of solvents and reactivity in the hydrogen transfer process, and conversion reactions of coal and hydrogen-supplying resources.

Studies on the three areas related to refinement and processing of liquefaction products: the structure of liquid residues and hydrogenation refinement, the thermal decomposition of liquid residues, the gasification of liquid residues, and the disposal of ash.

(iii) Survey of trends in coal energy conversion technologies

With respect to environmentally-friendly synthetic energy technologies, the future of coal use, the current status of clean coal technology, coal energy resources, and the development of coal conversion technologies, current awareness and problems were identified and summaries created concerning future prospects and related issues.

(3) Future Tasks

(a) Searching for highly reactive, highly dispersed catalysts

With the objective of affixing and dispersing active metals on the surface of coal, further studies must be performed concerning the ion exchange method, the iron hydroxide impregnated method, and impregnation followed by alkaline treatment method. Also, with the objective of developing highly dispersed ultra-fine-particle catalysts, further studies must be performed concerning emulsion methods using active surface agents.

(b) Study of the feasibility of a complete liquefaction process

With the objective of improving the initial reaction conditions of liquefaction, studies must be performed concerning the influence of the speed at which temperatures are raised during the initial stage of reaction, the effects of the amount of hydrogen content in solvents subject to possible transfer, and the effects of catalysts. Further studies must also be performed concerning changes in the structure of coal during oil processing.

2.2.2.2 Research into the Conditions Required for Coal Liquefaction

(1) Objectives and Description of Development

As part of a study of the feasibility of reducing the amount of catalysts needed in the coal liquefaction process, attention was focused on highly-dispersed iron catalysts and research was performed on methods for the preparation and liquefaction of the coal adhesive catalysts which form one of these catalysts, as well as on the liquefaction reactivity of these catalysts. In the current year, studies were performed on a system in which an actual liquefaction plant was applied.

(2) Overview of Results Obtained in FY1994

(a) Selection of catalyst preparation methods

(i) While colloidal iron sulfide adherence catalysts (CIS method), iron hydroxide adherence catalysts (AIP method and AWIP method), and other coal adherence-type catalysts all possess similar liquefaction performance when used in amounts from one-fourth to one-fifth of those of standard catalysts, in terms of both cost and performance, AWIP, which uses coal liquefaction process waste water as one of the preparation raw materials, is the method which offers the highest potential for realization (see Table 1).

(ii) The AWIP method may be applied for use with a wide variety of different types of coal, including Wandoan coal, Black Thunder coal, and Tanito Harum coal.

Table 1 Highly-Dispersed Iron Catalysts

1. Colloidal iron sulfide catalysts (CIS) $FeSO_4 + Na_2S \rightarrow FeS + Na_2SO_4$ $Coal^* + FeS \rightarrow$ FeS on coal * Pretreated by a surface-active agent.
2. Fe / catalysts using ammonia (AIP: Adding S during reaction) $FeSO_4$ + Coal + Ammonia -> Iron hydroxide on coal
3. Fe / catalysts using process waste water (AWIP: Adding S during reaction) $FeSO_4$ + Coal + Process waste water -> Iron hydroxide on coal

(iii) It was confirmed that under the AWIP preparation method it would be possible to use PSU process waste water similar to that which would be produced at an actual plant.

(b) Processing conditions and liquefaction characteristics in the AWIP method

(i) With respect to raw materials which constitute the main components of catalysts, in terms of both its ease of handling and the obtained catalyst performance, iron (II) sulfate is superior to iron (III) sulfate.

(ii) The proportions with which catalysts and raw materials should be mixed and other preparation conditions were identified and the relationship to catalyst component adherence was made clear.

(iii) The amount of water content remaining after dewatering increases as the amount of catalyst component adherence increases. In addition, while the water content ratio decreases in accordance with an increase in coal particle diameters, it was found that the effectiveness is poor when the amount of iron adherence is somewhere around 5wt% (see Fig. 1).

(iv) In the mixing liquefaction method, in which a portion of the coal to be supplied for liquefaction is treated by adhering catalytic components to the coal and in which the liquefaction reaction is performed after mixing this treated coal with the remainder of the raw coal, it was confirmed that it is possible to reduce the mixing ratio of AWIP catalyst adherence coal to a level of 5–10wt%.

(v) In cases where the average catalyst amount was set at a fixed level of 0.6wt% in mixing liquefaction tests using undried AWIP coal and dried AWIP coal, while it was found that there was a tendency for oil yields to decrease slightly when mixed in low proportions using undried AWIP coal in batch liquefaction tests, the results of continuous liquefaction tests showed that even when compared to the results of using standard catalysts (3.0wt%), the same oil

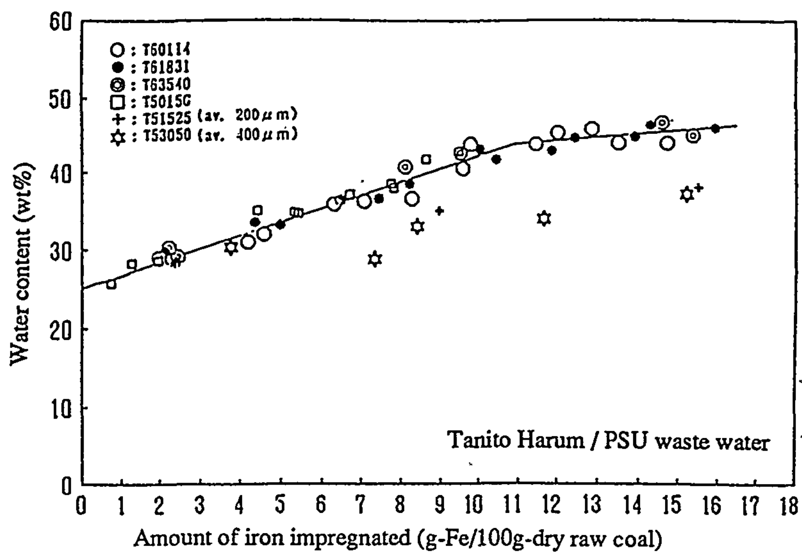

Fig. 1 Relationship between the Amount of Iron Impregnated and Water Content

yield and characteristics were obtained. This is an issue which requires further study in the future.

(vi) Oil yields were highest for Wandoan coal, Tanito Harum coal, and Black Thunder coal, in that order (see Fig. 2).

(vii) It was found that it is possible to obtain good oil yields using the AWIP method, even when performing liquefaction of high-concentration coal slurry, just as was found to be the case with the AIP method (see Fig. 3).

(c) Studies concerning the reactivity of AWIP

(i) In view of the fact that oil yields decrease when liquefaction is performed without adhering catalyst components to

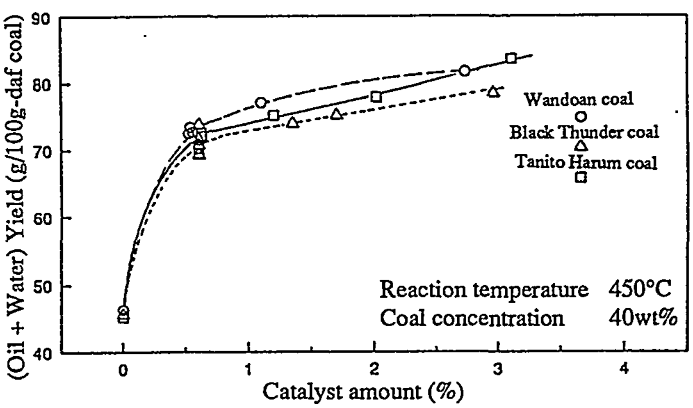

Fig. 2 Relationship between Catalyst Amount and (Oil + Water)Yield (AWIP, comparison of coal types, batch-type liquefaction tests)

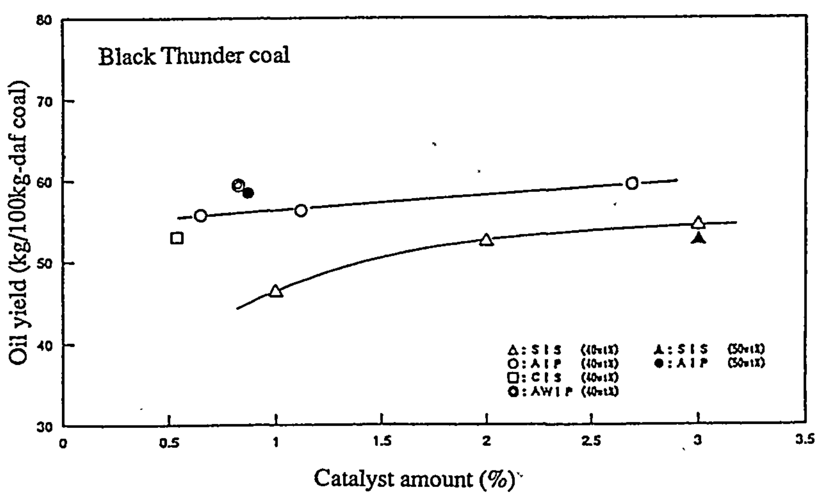

Fig. 3 Relationship between Catalyst Amount and Oil (HS) Yield (Comparison of catalyst types, flow-type liquefaction tests)

coal (i.e., AWIP isolation catalysts), it was concluded that the adhering of catalysts is effective.

(ii) It was confirmed that catalysts were transformed to pyrrhotite after presulfiding reactions.

(iii) From X-ray analyses of AWIP isolated catalysts presulfided at temperatures from 280°C to 320°C and of carbon black carrier AWIP, it was found that catalyst activity was high in cases when the presulfiding temperature was low.

In addition, when a continuous liquefaction device equipped with a presulfiding reaction unit was used to perform mixing and liquefaction tests of dried and undried AWIP coal at presulfiding temperatures of 280°C and 320°C, in both cases the oil yield was highest at 280°C.

(iv) From differences in reduction temperatures in the TPR-S method of AWIP isolated catalysts and standard catalysts, it was found that AWIP catalysts had a high hydrogenation reactivity.

(d) AWIP preparation/mixing liquefaction methods

(i) A catalyst adhesion coal preparation, mixing, and liquefaction system was assembled to perform liquefaction reactions after using iron sulfate and coal liquefaction process waste water and taking the catalyst components generated and adhering them to a portion of the coal supplied to the liquefaction process, removing the water from this coal in a vacuum filter, mixing it with the remainder of the untreated coal, and adding sulfur.

(ii) Estimates were calculated of the cost of preparing catalysts, and since it was found that the cost of raw materials, especially the cost of iron sulfide, represented an inordinately large percentage of total costs, it was determined that a need exists to perform further studies of dewatering methods and other issues which must be addressed in order to further improve the efficiency of iron adhesion.

(3) Future Tasks

In fiscal 1995, studies will be performed concerning the AWIP method, with these studies to include consideration of sulfiding and catalytic activity, and particularly the effects of water content. In addition, plans also exist to begin studies on preparation conditions of AWIP coal in continuous system.

2.2.2.3 Surveys and Research Concerning Advanced Coal Liquefaction Technologies

(1) Objectives and Description of Development

Ojectives of development:

In addition to studying the applicability of liquefaction reactions of ultra-fine coal particles and mild conversion technologies together with the restriction of carbonization reactions, studies are also to be performed concerning the development of more environmentally-friendly technologies through the use of microorganisms to process sulfur compounds contained in fossil fuels and the liquefaction of low-coal-content brown coal. The objective of these studies is to build a foundation upon which more advanced coal liquefaction technologies may be developed in the future.

Description of development:

(a) Liquefaction reaction of ultra-fine coal particles:

An attempt will be made to develop high-efficiency liquefaction technologies, including those technologies needed to crush coal and catalysts into ultra-fine particles of a size of approximately 10^{-4} millimeters to increase the effective surface area of both coal and catalysts and improve liquefied oil yields, reduce the amount of catalyst which must be used in liquefaction, and otherwise improve the liquefaction process.

(b) Basic research on mild coal conversion technologies:

In addition to performing studies designed to learn about how the use of plasma heating to remove coal water content and how the use of oxygen-removal processing effect the chemical structure of coal, studies will be performed on the use of hydrogen plasma to subject multi-ring aromatic compounds to hydrogenation and cleavage, with the objective developing a method of hydrogenation which may be performed under mild reaction conditions.

(c) Basic research on the chemical structure and liquefaction reaction characteristics of low-quality coal:

The mechanism whereby root plants are transformed into coal is to be investigated in terms of the chemical reactions involved, and the basic research required to identify the chemical structure of low-quality coal, to identify the conditions required to liquefy low-quality coal, and to identify the associated problems will be performed.

(d) The use of microorganisms for the processing of sulfur compounds contained in fossil fuels:

In order to reduce the levels of environmental pollution created as a result of sulfur compounds contained within coal and other types of fossil fuels, studies will be performed on desulfurization technologies using microorganisms to process such fuels.

(e) Research on liquefaction residues:

In addition to clarifying the mechanism by which unreacted coal found within liquefaction residues and carbonization compounds are generated, studies will be performed concerning methods of preventing carbonization reactions during the liquefaction process.

(2) Overview of Results Obtained in FY1994

(a) Liquefaction reaction of ultra-fine coal particles

Experiments were performed in order to study the effects of iron oxide concentrations and the addition of diffuse solutions on reactions for the liquefaction of ultra-fine pulverized coal and 100-mesh coal. In both cases, the light oil (HS) yield was 4–6 wt% higher for ultra-fine pulverized coal, and the TS and THFS component H/C atomic ratio was also higher. In view of the fact that there was no great difference seen in the amount of hydrogen consumed, it is believed that these results were obtained as a result of increases in the effective area of exposure between catalysts, solvents, and gaseous-phase hydrogen. Upon adding a COM dispersing agent to the reaction system, it was found that when nonionic and cationic dispersing agents were mixed together in a 1:1 ratio, with both ultra-fine pulverized coal and 100-mesh coal showing improved HS yields. In addition, since the composition and characteristics of coal change significantly as a result of oxidization, the features of gas generated as a result of heat decomposition during the heating process were studied. As a result, it was found that for both raw 100-mesh coal and ultra-fine pulverized coal particles with a diameter of approximately 4 mm, no changes could be seen in the main generated gas features in a non-reactive environment. In contrast to this, however, when heat decomposition was performed in a hydrogen atmosphere, the volume of hydrogen sulfide generated when using ultra-fine pulverized coal decreased and the range of temperatures at which hydrogen sulfide was generated was higher on the whole. It is believed that this change in the behavior exhibited in terms of the generation of hydrogen sulfides indicates that some slight degree of oxidization of the coal had taken place.

(b) Basic research on mild coal conversion technologies

Under conditions involving exposure to a nonequilibrium plasma of hydrogen and helium gas, Indonesian Tanito Harum coal, a type of coal used in the NEDOL method, was processed together with Yalung coal, a type of coal which was chosen as a control sample, and after measuring relaxation time, methanol adhesion heat, and FTIR, changes in the physical and chemical structure of the coal were analyzed, and a correspondence was created between these results and the results of autoclave liquefaction reactions in an effort to study how to obtain the basic materials required in order to develop mild coal conversion technologies. At this time it was found that the deoxidization of oxygen groups contained within the coal exerted a heavy influence on the liquefaction reaction.

(c) Basic research on the chemical structure and liquefaction reaction characteristics of low-quality coal

In order to learn about the chemical structure and liquefaction reaction characteristics of low-quality coal, underwater heating processing of cellulose and Japanese red pine was performed, and the solid material obtained from this process (i.e., artificial coal) was then studied and compared against natural Morewell brown coal and Morewell charcoal to learn about its chemical structure and the characteristics of its hydrogenation products.

In cellulose hydrogenation, the main materials produced consisted of hexane, methyl-cyclopentane, and hydrogen carbides with a value of C5 or below, and there was very little in the way of medium- or heavy-weight components. In contrast to this, however, in cellulose heat processing reactions, cyclohexanes, condensed multi-ring compounds, heavyweight components, and other materials which were generated only in infinitesimal quantities when using cellulose were produced, and the amount of such materials was similar to those obtained when using Morewell brown coal. In view of these results, it was surmised that underwater heat processing at a temperature of 200°C causes cellulose structures to be transformed into excited molecular substances possessing a structure similar to that of Morewell brown coal.

(d) The use of microorganisms for the processing of sulfur compounds contained in fossil fuels

Dibenzo-thiophene (DBT) and DBT derivatives were selected for use as model compounds of those solution-resistant organic sulfur compounds found in coal and in dried coal component materials, and studies were performed concerning the use of microorganisms to decompose these compounds under mild atmospheric conditions. In fiscal 1994, of those microorganisms which were found to possess a high ability to decompose DBT and 4- and 6-diobenzo-thiophene, studies were performed on the bacteriological characteristics of six strains of gram anionic bacteria, and the bacteria were then identified.

Organic sulfides found within fossil fuels may be classified roughly into three types: thiophenes, sulfides, and thiols. It has recently been discovered that methyl-mercaptan (MM) extracted and refined from thio-bachirusuthioparusu sulfur oxide bacteria possesses the ability to decompose thiols (mercaptans) with complex structures, and it is believed that methyl-mercaptan bacteria may prove to be highly effective as a means of using microorganisms to remove sulfur content from fossil fuels. It is for this reason that the characteristics of this oxygen were studied. As a result of studies designed to determine the effect pH has on this oxygen, it was found that the levels of reactivity obtained when pH ranges from a value of 6.5 to 9.0 are more than sufficient. In order to study the effects of blocking agents on this oxygen, sulfur ions, metal ions (i.e., copper, zinc, nickel, and cadmium ions), and a metal chelate solution (EDTA) were added during the liquefaction reaction, and it was discovered that while copper ions serve to block oxygen, none of the other materials added did. Since it is known that this oxygen decomposes not only in the presence of methyl-mercaptan but in the presence of other mercaptan compounds as well, more detailed studies were also performed to learn about variations in the speed of decomposition. While it was found that ethyl-mercaptan decomposed at the same speed as methyl-mercaptan, the speed of decomposition fell to about half of this speed when using n-propyl-mercaptan and n-butyl-mercaptan and the speed fell even further to one-tenth of its original level when using benzyl-mercaptan. As a result of further studies performed concerning n-propyl-mercaptan and n-butyl-mercaptan, it was found that as decomposition progressed, the speed at which it progressed slowed further and further until virtually no decomposition was taking place at all. While it was originally believed that the cause of this lay in the property of aldehyde to block such decomposition, later experiments showed that aldehyde does not act to block methyl-mercaptan carbon monoxide.

(e) Research on liquefaction residues

The hydrogenation of partially oxidized or partially carbonized coal is an important factor in blocked materials in continuous coal hydrogenation reaction units. There are times when coal particles with extremely high reflectivity rates are generated within the carboniferous sediments found within bench-steel continuous reaction units. It is believed that these particles come from partially oxidized or partially carbonized coal. If liquid materials produced from the partial oxidization of coal form the basis of coke, then it is possible that of all of the intermediate substances generated in the production process of coke, it is materials such as these which act as binders and result in the production of solid residues. These materials probably speed up the closure of the reaction tube. In order to study the possibilities of such phenomena actually occurring, a series of batch autoclave tests were performed and the residues obtained from reactions were then examined under an electron microscope. In contrast to the evenness with which carbonization takes place, oxidization results in the creation of a new uneven material. This is the oxidization of the periphery and the center of vitrinite particles. This provides evidence that the oxidization of vitrinite particles exerts a more complex set of influences on continued hydrogenation reactions than carbonization. It would appear that partially oxidized or partially carbonized vitrinite is transformed into vitroplast and that at the same time vitrinite particles are transformed into massive anisotropic particles without passing through a liquid phase. If particles such as these accumulate within a reaction chamber, and if that reaction chamber is made of plastic, it is possible that the chamber and the particles merge together. In a small-diameter reaction chamber this would stimulate occlusion, and in a large-diameter reaction chamber this would increase the formation of solid sediments.

(3) Future Tasks

(a) Liquefaction reactions of ultra-fine pulverized coal particles

In consideration of the influence which particle size distributions have on liquefaction reaction rates and the heat reaction characteristics of ultra-fine pulverized coal particles, a series of liquefaction experiments must be performed under a variety of different reaction conditions and catalyst concentrations. At the same time, a study must be performed concerning the yields of liquid materials in hydro-pyrolysis reactions.

(b) Basic research on mild coal conversion technologies

In order to investigate the relationship between structural changes and reactivity of plasma-treated coal, measurements must be made of the distribution of ESR radicals in treated coal and of relaxation phenomena. In addition, measurements must be taken of the degree of swelling and heat-induced changes in the adhesion and release of various types of solvents with respect to coal so as to analyze structural changes occurring in this coal. In addition, actual liquefaction reactions must be performed so as to learn about the nature of the mutual relationship between structural changes and reactivity, and basic research directed at the development of mild coal conversion technologies must be performed. Studies must also be performed of the effects of hydrogen plasma absorption in the presence of a variety of different catalysts with respect to various types of multi-ring aromatic compounds and heterogeneous compounds. At the same time, the results obtained from these studies must be compared to the results obtained from catalytic reactions performed thus far, and basic research must be performed to learn about the reaction characteristics of hydrogen plasma with respect to these types of compounds.

(c) Basic research on the chemical structure and liquefaction reaction characteristics of low-quality coal

Low-quality coal must be decomposed using contact hydrogenation decomposition at mild temperatures and a variety of other decomposition methods and the characteristics of the materials produced analyzed in detail in order to learn about the chemical structure of these compounds. Model compounds designed to offer the same reactivity as that of the various types of chemical structures thus discovered must then be used to perform studies in which the mechanism whereby root plants are transformed into coal is reproduced in terms of its chemical reactivity and to thereby study ways of developing technologies for the liquefaction of low-quality coal.

(d) The use of microorganisms for the processing of sulfur compounds contained in fossil fuels

In addition to determining the raw decomposition path of hard-to-remove organic sulfur compounds, work must begin on obtaining and learning about oxygen compounds which act as catalysts to decomposition reactions. Furthermore, in addition to determining the basic nature of compounds from which sulfur oxides have been removed, work must begin on studies of optimal desulfurization conditions.

(e) Research on liquefaction residues

Autoclave tests must be performed in order to learn about the process whereby liquefied products are converted into mesophase compounds. Studies must also be performed on the feasibility of rehydrogenating carbonized residues obtained from continuous devices. Surveys must also be performed on advanced coal liquefaction technologies in countries throughout the world.

2.2.3 Project for the Internationalization of Coal Liquefaction Technology

2.2.3.1 Survey of the Siting Possibilities of Coal Liquefaction Plants

(1) Objectives and Description of Development

Through programs of international cooperation directed towards the development of coal liquefaction technologies, surveys are to be performed to investigate the siting possibilities of coal liquefaction plants overseas, to create training programs for foreign technical personnel, and to promote the growth and development of these personnel. Information exchange programs will also be conducted with other countries promoting the development of coal liquefaction technologies in an effort to improve the level of such technologies both in Japan and abroad.

(a) Survey of the siting possibilities of coal liquefaction plants

On-site surveys will be performed concerning those types of foreign coal resources viewed as promising coal resources (i.e., Indonesian and Russian coal), samples will be collected, and these samples will be analyzed and their liquefaction characteristics evaluated.

(b) International technical exchange and technical surveys

Surveys will be conducted on the technological trends in countries overseas. In addition, conferences to be attended by experts in coal technologies will be held jointly with Indonesia, local technical personnel will be invited to the meetings, and local surveys will be performed.

(2) Overview of Results Obtained in FY1994

(a) Survey of the siting possibilities of coal liquefaction plants

(i) Collection of foreign coal samples and performance of local surveys

Collection of samples and surveys of coal fields in southern Sumatra, Indonesia

Approximately one ton of South Banko coal was collected for use as a raw material in evaluating operability using BSU continuous reaction units, and small quantities of samples of coal were also collected from surrounding areas. It should be noted that the Indonesian government extended its fullest cooperation in all aspects related to the collection and shipment of these coal samples.

In order to study the liquefaction characteristics of Russian Kansk-Achinsk coal, three samples of coal were obtained from the Natural Organic Chemistry Research Institute of the Siberia Bureau of the Russian Academy of Sciences.

(ii) Analysis of the form and composition of foreign coal

It was discovered that South Banko coal, Central Banko coal, and Banjarsali coal possess low ash contents ranging from 1.4% to 2.1%, that these three types of coal possess extremely low inherent moisture contents ranging from just 15% to 20%, and that their H/C value is high and their oxygen content low. With respect to Indonesian coal, it was also discovered that the amount of silicon and aluminum contained in the ash content is high, that the relative content of sodium and magnesium is low, and that it possesses virtually no chlorine content.

As for Kansk-Achinsk coal, while the inherent moisture content was found to be a low 16% to 18%, it was found that this coal is characterized by a very high ash content ranging from 5% to 10%. It was also discovered that large quantities of iron, silicon, and calcium existed in the ash, that the sodium content was low, and that there was virtually no chlorine content.

(iii) Slurry viscosity and materials characteristics of coal

In terms of the relative surface area as measured using the nitrogen-absorption BET method, no great difference could be seen between Australian Yallourn coal, Indonesian coal, and Russian coal. It was also discovered that the porous area of Indonesian coal as measured using the mercury penetration method was a quite low 0.15–0.18 cc/g.

Upon measuring the slurry viscosity at a temperature of 50°C after changing the solvent-to-coal ratio, it was found that the slurry viscosity of both Indonesian and Russian coal was lower than that of Yallourn coal, thus providing evidence that it ought to be possible to reduce the solvent-to-coal (S/C) ratio used in the liquefaction process.

(iv) Thermal decomposition behavior

The behavior observed in terms of changes in weight occurring as a result of the heating of coal were the same for both South Banko and Beryozov coal; gas was seen to be generated once the coal had reached a temperature of somewhere around 300°C, and the amount of gas generated reached its maximum when the temperature reached a range of between 400°C and 450°C. It was also discovered that no great difference could be observed in terms of the generation of carbon oxide gas, water, or carbon monoxide.

A high-temperature ESR measuring unit was used to measure radical densities when the temperature of coal in a nitrogen atmosphere was raised from room temperature to 450°C, with measurements being taken both during the heating process and at a time in which the temperature of the coal was maintained at a temperature of 450°C. It was discovered that while the radical density was high at room temperature for South Banko coal, the relative change during the heating process was small. In addition, the rapid rise in the radical density which occurred in the neighborhood of 400°C matched the behavior of TG-MS thermal decomposition.

(v) Liquefaction reaction characteristics

Four types of Indonesian coal and three types of Russian coal were selected, and using 1-MN as a solvent and gamma iron hydroxide as a catalyst, the autoclave liquefaction reaction characteristics were evaluated.

Among the Russian coal samples, both Borodino coal and Beryozov coal showed good liquefaction performance, but Beryozov coal displayed the best reaction performance.

When using Indonesian coal it was found that the yield of water, carbon monoxide, carbon dioxide, and other oxygen compounds produced was small, thus indicating that it would be possible to obtain high liquefaction oil yields using this coal. In addition, from the total yield of the liquefied oil and CLB produced, it was estimated that the maximum liquefaction oil yield which might be obtained from this coal would be somewhere around 70–75wt% mafc.

South Banko coal and recycled creosote oil solvent were used in a BSU continuous reaction device, and when operations using pyrite catalysts (2.0 mm) were performed under conditions in which the solvent-to-coal (S/C) ratio was set to 2.0, the temperature to a level of 450°C, 14.7 MPa, and no gas or bottom recycling, the same liquefaction characteristics were observed as those obtained using the autoclave. In addition, from the state of operation and from the results of observations after the operation, it was found that no major problems exist with respect to operations.

It was discovered that the viscosity of South Banko coal slurry decreased in proportion with decreases in temperature, and measurements taken using a high-temperature high-pressure viscosity meter confirmed that no rapid increases in viscosity occur during the pre-heating process

(b) International technological exchange and technological survey

In accordance with the terms of an agreement formed between NEDO and the Indonesian Agency for the Assessment and Application of Technology (BPPT), a program of technological exchange was started, a joint local survey conducted, coal samples collected, an operability evaluation using BSU continuous reaction devices performed, training programs conducted for Indonesian technical personnel in coal liquefaction technologies, and support was provided for the installation of autoclaves.

(3) Future Tasks

To follow up on initial evaluation tests of the liquefaction characteristics of Indonesian South Banko coal, tests must be performed on recycled systems under high liquefied oil yield conditions.

With the objective of fostering the development and growth of foreign technical personnel, technical training will be provided and programs of international technological exchange and technological surveys will be continued.

2.2.3.2 Preliminary Survey of Mongolian Coal Resources

(1) Objectives and Description of Development

While Mongolia formerly imported oil and petroleum products from the Soviet Union, the breakup of the Soviet Union has led to a situation in which the demand for oil and other forms of energy far outstrips the supply. Although abundant reserves of coal exist within Mongolia, the increasing age and growing obsolescence of equipment and facilities, as well as shortages of necessary parts, have led to decreases in production. In order to ensure stable supplies of energy, a Mongolian gasoline project for the production of liquid fuels from coal has been created, and plans call for this project to get under way sometime in the first few years of the 21st century. In consideration of the fact that the general level of scientific and technological sophistication in Mongolia is low, as well as the fact that there also exists a lack of sufficient investment capital, Mongolia has made requests to Japan to provide cooperation in the development of related technologies.

The objectives of the current survey include, but are not limited to, the study of Mongolia's resource and energy conditions, infrastructure, and research and development policies, and the selection of the optimal coal conversion process. A study of issues such as the need for research guidance to be provided to technical professionals in order to improve and spread Mongolian coal utilization technologies will also be undertaken.

(2) Overview of Results Obtained in FY1994

(a) Mongolia

(i) Social and economic conditions

Democratic and economic reforms are both proceeding at a rapid pace. Mongolia is currently in the midst of the transition from a planned economy and communist rule to a market economy and democratic freedom, and this transition has brought with it a great deal of economic confusion. As of 1992, while fully 25% of the total population is concentrated in the capital of Ulan Bator, as much as 36% of the population remained employed in the agricultural and livestock sector. Education in Mongolia is widely available; the country boasts a literacy rate of 97%, and there exist a total of 28 universities throughout the nation.

(ii) Energy

Mongolia produces none of its own petroleum, and instead relies on Russia as the sole source for all of the 600,000 to 700,000 tons of oil it imports each year. Some sources estimate that Mongolia possesses a total of 100 billion tons of coal reserves. This would make Mongolia one of the top 10 nations in the world in terms of coal reserves, and indeed coal accounts for fully 80% of all energy consumed in Mongolia. Central energy systems have been built in and around Ulan Bator and in other major cities, and these systems are used to provide energy in the form of electricity, steam, and hot water. Villagers and semi-nomadic rancher-farmers rely on diesel electric power generators and on coal, manure, and other forms of low-quality fuel.

(b) National development plans

Mongolia has abandoned use of the long-term 5-year plans which were prevalent in the communist era and is now in the process of implementing a 3-year plan which went into effect in 1993. Studies are now under way to come up with a long-term development plan, and plans call for studies to be performed of a long-term plan for the use of coal in 1995.

In order to address the fear created by relying solely on Russia for all oil imports, and with the objective of strengthening the country's economic infrastructure, Mongolia is currently proceeding with the implementation of the following energy policies in cooperation with a number of industrially-developed nations:

- Survey and development of domestic petroleum resources (Mongolia Petroleum Project)
- Development of technologies for the production of fuel oils from coal (Mongolia Gasoline Project)
- General Coal Use Plan

(c) Research and development infrastructure

(i) Energy research facilities and their respective fields of research

National Research Center of Chemistry and Technology of Coal (NRCCATC):

Coal gasification, liquefaction, production of smoke-free fuel

Institute of Energy:

Electric power, steam, and hot water supply plans; plans for upgrading electric power plants

Mining Institute:

Coal mining technologies, briquette production, analysis of varieties of coal used to fuel electric power plants

Institute of Chemistry:

Coal chemistry

Institute of Natural Energy:

Solar energy, wind power, hydroelectric energy, thermal energy

Note that the research facilities of the Coal Chemical Technology Research Institute are capable of being used for little more than performing element composition analyses and industrial application analyses of coal, that it has virtually nothing in the way of equipment, and that it is intended to function as a body working toward the development of coal use technologies.

(ii) Researchers and research programs

All of the research institutions noted above are currently operated under the auspices of the Mongolian Academy of the Sciences or under a particular government ministry or ministries holding jurisdiction over their operation. A total of nearly 1,800 scientists now work at these institutions. Of the 34 researchers currently working at the Coal Chemical Technology Research Institute under the director, several are graduates of former Soviet engineering universities.

As part of a program designed to provide training for Mongolian technical personnel, two researchers were invited to Japan to view Japanese research facilities, collect technical information, and undergo training in the use of evaluation and testing methods, and it is believed that this training has proven to be valuable.

In a survey performed in Japan of literature available on coal research, it was found that a total of 24 journals existed, but the majority of these consisted of reports of joint research projects conducted with the Soviet Union.

(d) Coal evaluation and testing

(i) Coal composition

Industrial analyses, element analyses, and structural analyses were performed for the following three types of coal selected by the Mongolian government as candidates for development: Uvudughudag coal, Shivee-Ovoo coal, and Hootiin-Honhor coal. All three proved to have low carbon contents in the range of 60% to 66%, and they were accordingly classified as low-grade brown coal.

(ii) Liquefaction test

The results of autoclave liquefaction tests showed that the liquid yields which may be obtained from Uvudughudag coal and Hootiin-Honhor coal (no-water, no-ash standard) are in excess of 55%, a level on a par with that obtained when testing Wyoming coal using the NEDOL method. Hootiin-Honhor coal, however, possesses a high ash content, and it is believed that it would require pre-processing in order to enable it to be used for liquefaction. Shivee-Ovoo coal was found to possess a high content of inert materials, and the liquefaction yield obtained from this coal was a low 42%.

(iii) Carbonization test

In low-temperature carbonization tests using Shivee-Ovoo coal, which had been selected as a low-pollutant fuel for use in the production of coal oil, it proved impossible to obtain the desired results, and further studies must be performed in the future.

(3) Future Tasks

From the results of the surveys that have been performed thus far in response to requests for cooperation in the development of energy resources from the Mongolian government, the following items have been identified as issues which must be addressed in the future:

(a) In view of Mongolia's abundance of coal resources and untapped labor reserves, the prospects for the development of Mongolian energy resources are good. However, at the present time it is difficult for the Mongolian government to promote the development of these resources entirely on its own, and cooperation from abroad is required.

(b) Equipment and facilities are required in order to perform research and development, and it is absolutely essential that Mongolia receive foreign aid in this regard.

(c) It is necessary that something be done to increase the general level of technical training and sophistication of Mongolian researchers and technical personnel in order to promote the development of coal use technologies in Mongolia.

(i) In order to improve the skills of technical personnel and spread the use and knowledge of coal-related technologies, these personnel must be provided with information on coal use technologies, Japanese technical personnel must be dispatched to Mongolia, and Mongolian personnel must be invited to Japan to receive training in research techniques and methods used in evaluating research results.

(ii) In terms of providing support for the development of coal technologies, support must be provided for the creation of development plans and for the upgrading and expansion of development facilities.

(d) More tests and evaluations of other types of coal must be performed in order to evaluate the suitability of Mongolian coal for use in planned applications.

II

Development of Coal Gasification Technology

Following up on earlier work along the same lines, test operation of a pilot plant with a capacity of 200 tons per day is being conducted as part of an effort to develop an entrained flow coal gasification power generation plant. In addition, disassembling research utilizing a pilot plant with a capacity of 20 tons per day was completed as part of an effort to develop technologies for the production of hydrogen from coal, and the results of this research were summarized. Finally, an assessment of coal hydrogasification technologies was also conducted.

1. Development of an Entrained Flow Coal Gasification Power Generation Plant

1.1 Development of an Entrained Flow Coal Gasification Power Generation Pilot Plant

(1) Objectives and Work Program

To increase the use of coal in power generation, NEDO has developed integrated coal gasification combined cycle power generation technology because of its higher thermal efficiency and environmental acceptability. This technology is superior in terms of operational capability, flexibility for various types of coals and ease of increasing the capacity. An elemental study and operating study of the pilot plant have been conducted.

(2) Overview of Results Obtained in FY1994

(a) Elemental study

(i) Research for the development of full pressure and full-scale combustor

With the objective of developing large-scale gas turbines for use in entrained flow coal gasification demonstration plants, the results of combustion tests performed up until the previous year were used to perform studies of testing conditions.

(ii) Research involving simulations of an entrained flow coal gasification power generation system

With the objective of developing a total control system capable of controlling all aspects of the operation of a pilot plant with a capacity of 200 tons per day, operations and testing data obtained from the operation of a pilot plant using design coal were used to make improvements to a simulation model which had already been made, and studies were performed to gain a better understanding of the operating characteristics of the plant and to examine the effectiveness of the control system.

(b) Operation tests of the pilot plant

Problems occurred in the gasifier of the pilot plant due to slagging, and for this reason work was performed on improving the gasifier from July to November. After this work had been completed, tests were performed from November 1994 to February 1995 to verify the effectiveness of the improvements which had been made, and high-load test operations were performed. Finally, beginning March 3, 1995, long-term continuous operation for evaluating the reliability of the plant was performed.

Accumulated time for operations performed up until April 5, 1995 are as follows:

- Gasifier

  Total operating time: 2,913 hours, 19 minutes

  Maximum time of continuous operation: 789 hours, 0 minutes

- Gas clean-up facility

  Total operating time: 1,764 hours, 41 minutes

- Gas turbines

  Gas turbine generation time: 766 hours, 37 minutes

(c) Demonstration plant survey

Following up on work performed in the previous year, design studies were performed on integrated coal gasification combined cycle power generation on a demonstration plant scale.

1.2 Surveys and Research on Coal Processing Technologies for Use in Coal Gasification

1.2.1 Survey on the Selection of Coal Types

(1) Objectives and Work Program

[Objectives]

The goal of the research was to study the major types of coal from both domestic and overseas coal fields to learn about resource and production situations, the management of stored samples, and the basic and reaction characteristics of coal in processes such as gasification. In addition, data on stored samples, resources and production situations, and basic and testing characteristics of coal were to be collected in a matrix and analyzed for the preparation of basic data to be used for evaluation of coal types.

[Work Program]

(a) Sampling survey

For the major types of coal from both domestic and overseas coal fields, resource and production situations were surveyed and samples to be stored were collected.

(b) Characteristics test

(i) Basic characteristics

The basic characteristics of the stored samples were analyzed and data werer collected.

(ii) Test characteristics:

Evaluation and testing of the characteristics of the gasification process, evaluation and testing of the characteristics of the hydrogenation reaction, and evaluation and testing of the characteristics of partial combustion was performed, and test data were collected.

(c) Coal-type matrix evaluation

From the perspectives of technology for

the use of coal, methods for matrix analysis and evaluation were developed for resource and production data and basic and testing characteristics data.

(d) Preparation of data files

Coal-type data files consisting of resource and production data and basic and testing data were prepared.

(2) Summary for FY1994

(a) Sampling surveys

A survey of the literature on the nature, extent, and production of major coal mines and resources in Mongolia's main coal fields were performed, and samples for storage were obtained. In addition, a survey of the literature on the nature, extent, and production of major coal mines in Thailand was performed.

(b) Testing of characteristics

(i) Basic characteristics:

Basic analysis and testing of the characteristics of Mongolian and Chinese coal were performed for a variety of types of Indonesian coal.

(ii) Test characteristics:

a. A gasification characteristics test device was used to perform gasification tests for 27 types of Indonesian coal, and an understanding was gained of the gasification characteristics of this coal.

b. A hydrogenation reaction characteristics test device was used to perform hydrogenation reaction characteristics tests for 14 types of Chinese coal, and an understanding was gained of the hydrogenation reaction characteristics of this coal.

c. A partial combustion characteristics test device was used to perform partial combustion characteristics tests for three types of Australian coal, and an understanding was gained of the partial combustion characteristics of this coal.

(c) Coal-type matrix evaluation

The CMRCdb coal-type matrix analysis method was used to perform statistical numerical analyses of basic test data, and the results of these analyses were used to gain an understanding of the characteristics of different types of coal and the relationship of such characteristics to hydrogenation reactivity. Data were also created on mine information, shipping, and other subjects.

(d) Creation of data files

Data files were created for the storage of basic data, test data, and data on the nature, extent, and production of coal mines and the primary coal fields and resources of 239 samples in the Pacific Rim region.

(3) Future Tasks

(a) Using the basic data on the characteristics of different types of coal, evaluation and testing data on the characteristics of this coal in gasification, and evaluation and testing data on the performance of hydrogenation reactions, a matrix for use in establishing a coal type matrix evaluation procedure will be constructed.

(b) For sub-bituminous coal, a type of coal viewed as offering excellent prospects for use as a raw material in coal gasification in the main coal-producing nations of the Pacific Rim region, materials on the nature and extent of resources, scales of production, the nature of individual types of coal, and other similar factors will be collected and evaluated with an eye to their use in the possible creation of a commercial gasification facility.

(c) The above will be summarized on an across-the-board basis, and coal type matrix evaluation procedures will be used to create and verify the precision of an effective model for the evaluation of different types of coal.

1.2.2 Development of a Coal Conversion Technology Information System

(1) Objectives and Work Program

In addition to developing an information management system for the management of information on coal conversion technologies (i.e., gasification and liquefaction technologies), a system for the collection and processing of reports on the results of support research and the operation of pilot plants and a conceptual design for a commercial plant will be developed.

(2) Overview of Results Obtained in FY1994

(a) Development of a general technical information database

(i) Design of an input system

The processes involved in data creation and data entry were integrated and an input system was created whereby those responsible for the creation of data could input data directly into the system. This system was then given the name of CADIS, i.e., Computer-Aided Data Input System.

The effect of the introduction of the CADIS system was to reduce the amount of time required for the creation of data, to eliminate errors, and to provide support for persons creating data.

(ii) Design of a control and operating system

In consideration of the nature of this database as one in which the data which may be accessed differs from user to user, a database control system was created to allow user registration, tracking of usage, and billing.

In addition, studies were performed on methods of operating this database so as to allow for monthly updates and backups of data and daily system startup and shutdown.

(iii) Entry of test data for system evaluation

The CADIS system was used to actually enter test data, and it was confirmed that the system performed according to specifications.

(b) Preliminary coal data bank survey

(i) Survey of European coal databases

In accordance with plans to create a coal data bank, a preliminary survey was performed. Since there are few databases which have been developed in Japan containing data on different varieties of coal, a survey was performed of European research institutions.

2. Development of Technology for the Production of Hydrogen from Coal

2.1 Research Using Pilot Plant

2.1.1 Design and Construction of and Operational and Dismantling Research on a Pilot Plant

(1) Objectives and Work Program

The objective is to develop a process for mass producing hydrogen, a clean energy resource whose demand is expected to increase, inexpensively from coal. This process is applicable to fuel, coal liquefaction, oil refining and so on. The research and development of high-temperature gasification by the entrained bed, which is the core technology for coal gasification, is a step toward the goal. In an effort to pursue this research and development, a pilot plant has been constructed and operated to obtain technical data and know-how.

(2) Overview of Results Obtained in fiscal 1994

(a) Research on the dismantling of the pilot plant

After the completion of the research phase of the operation of the pilot plant, in order to determine the degree to which the materials contained in the major parts of the gasification furnace had worn down and deteriorated under use, and to obtain data which might be used in estimating effective plant life and selecting candidate materials, the plant was dismantled and associated studies performed.

(i) On-site inspections and collection of samples

Visual inspections were made of all parts of the main equipment and decisions were made on the locations from which samples were to be collected.

The thickness of the gasifier pressure vessel, the main body of the heat recovery boiler, the main bodies of the cyclone and hoppers, and other pressure-resistant parts and equipment from which samples were not to be collected were measured, and by comparing the results of these measurements against those obtained from the regular inspections which had been performed up to date, it was confirmed that all of these pressure-resistant parts and equipment had withstood the stress of operation without undergoing any significant damage. The attachment joints of the tube plates belonging to the heat exchange unit and other equipment were removed and inspected using liquid penetration tests, and it was confirmed that none of the welded joints or parent materials had undergone any significant damage.

In addition, with respect to char recovery hoppers subjected to continued exposure to heat from high-temperature char, samples were collected of the corrosion which had accumulated on the inner surface of the hoppers and replicas were used to examine the degree of corrosion which had taken place.

After the completion of on-site inspections, samples were cut out of the gasifier and other equipment.

(ii) Analysis and testing of samples

The exterior surfaces of the samples collected were subjected to visual inspections in which they were viewed in an untreated state, and necessary scales were then removed and the thickness of the samples was measured together with their general dimensions; the microscopic and macroscopic structure of the samples were inspected, and they were subjected to tensile strength and EPMA tests. The results of analyses and tests performed for main systems and equipment are described below.

a. Main body of the gasifier

The refractory material on the inner walls of the gasifier had been repaired only in a few places during the whole time of plant operation, and it was found that the thickness of the refractory material on the lower part of the lower burner, which had been subjected to severe heat loads, was thinner than that of the upper part of the burner. However, no peeling was found on the walls of the water cooler, and it was verified that it possessed a high degree of reliability, including in terms of its method of use.

Examinations were then performed on the refractory material near the bottom of the gasifier, the part of the gasifier that is subjected to the largest stress through contact with slag, with these examinations being performed for the shielding which had an iridium covering over the tap and which was used from Run 8-1 to Run 9-2 (i.e., over an operating time of 1,468 hours) and the shielding which had no iridium covering over the tap and which was used during Run 9-3 (i.e., over an operating time of 109 hours). With respect to the former, visual inspections performed after the 1,149 hours of continuous operation during Run 8 showed that, with the exception of a portion of loss through melting on the tap, everything else was in good condition. After Run 9-2, however, it was found that the tap had melted completely away, and it was judged that it must have been subjected to extremely high temperatures. With respect to the latter, however, while the tap was observed to have melted away to some extent, the bottom of the gasifier as a whole was in good condition.

Finally, scales from oxidization and sulpherization were seen to have been generated on the water-cooled tubes on the walls of the valves of the heat recovery unit, and the thickness of these tubes was reduced.

b. Waste heat boiler

Heat conduits were found to have undergone corrosion and disintegration caused by sulphurization and oxidization. It was also discovered that the corrosion that takes place while plants are not in operation cannot be ignored.

c. Cyclone

Corrosion believed to be the result of exposure to high-temperature gases and abrasion believed to be the result of impacts with char and other solid particulate matter were observed on the inside of the cyclone, and it is believed that these two factors together contributed to the disintegration observed here.

d. Water washing section

Cracks in the form of pinholes caused by stress and corrosion were seen in the Venturi scrubber and parts of the other equipment in the water washing section.

e. Piping

Abrasion and other damage was seen in the joints of the coal burner input pipes.

f. In-plant test pieces

The results of observations and comparisons of test pieces removed at regular intervals from the heat recovery boiler and other equipment showed that the corrosion which may be seen in such pieces may be classified roughly into that caused by exposure to high-temperature gases and that caused by corrosion taking place when the plant is not in operation. It was discovered that the degree of corrosion which actually takes place is closely linked to the amount of chrome contained within the material in question, and it is believed that this knowledge will prove to be valuable when selecting materials to be used in the future.

(b) Summary of results

All of the results obtained over the nine years involved in the design of the pilot plant, its construction, operations research, dismantling research, and support research were summarized and a special effort was made to analyze the pilot plant operations data obtained from each run of the plant to determine to what degree each of the original development objectives had been achieved.

In addition, account was taken of the results of conceptual designs of the verification plant, studies of its economic feasibility and ability to fit in with social and environmental needs, and the results of dismantling research. Studies were also performed towards the creation of a commercial plant. The main findings obtained therefrom are described below.

(i) Not only were the basic concepts involved in the design of one-chamber two-stage rotating flow entrained bed gasification furnaces (one of the features of HYCOL gasification furnaces) verified, but the feasibility of state-of-the-art gasification constituent technologies was also confirmed, including technologies for the coal dry feed system, the direct recycling of hot char, the slag self-coating of water cooled tube walls, and self-heating slag taps.

(ii) When development targets are compared to levels of actual performance, it may be seen that not only did it prove possible to achieve carbon conversion rates of 99% against a target rate of 98%, cooled gas efficiencies of 79% against target efficiencies of 78%, continuous operation of 1,149 hours against a target continuous operating time of 1,000 hours, and performance which exceeded development goals in all respects, but the use of four different types of coal to perform stable gasification tests also made it possible to succeed in increasing the number of varieties of coal which may be used. This provides proof of the superiority of the process being studied herein, and it also represents a major step forward towards the development of a commercial process.

(iii) HYCOL gasifiers can be used not only to produce hydrogen for use in creating chemical compounds, refining oil, liquefying coal, and hydrogenating and gasifying coal, but also for use in power generation systems using combined cycle power generation and fuel cell systems and in a wide variety of other applications.

(c) Addressing local concerns and submitting necessary applications and reports to government agencies and ministries

Reports and applications for the authorization required to halt operation of and dismantle the plant in conjunction with the completion of operations research were made, and these reports and applications were submitted to the government agencies and ministries holding jurisdiction over the overseeing and enforcement of the following laws and regulations.

(i) Atmospheric Pollution Prevention Laws
(ii) Water Pollution Prevention Laws
(iii) Law of Waste Treatment
(iv) Anti-Noise Law
(v) Labor Safety and Health Law
(vi) Municipal Fire Prevention Regulations
(vii) Electricity Enterprises Law
(viii) High-Pressurized Gas Treatment Regulations
(ix) Oil Combinate Disaster Prevention Law

In addition, in conjunction with the completion of operations research at the pilot plant, NEDO withdrew from the Nakasode Joint Disaster Prevention Organization on June 30, 1994.

3. Assessment of Coal Hydrogasification

(1) Objectives and Work Program

Coal is widely distributed throughout the world and is the most viable oil-alternative energy source in view of its large reserves. Substitute natural gas (SNG) produced from coal will eventually be used in place of liquefied natural gas (LNG), the demand for which is steadily rising. It is therefore necessary to develop a high-efficiency process for producing SNG from coal which is both economical and environmentally friendly. To this end, the objective is to conduct research on coal gasification processes, focusing on coal hydrogasification technology for the methane, as well as to make technical and economic evaluations of the processes. Other objectives are to propose a new coal hydrogasification process (ARCH process), to study and assess gasifier and other elemental technologies, and to define development issues. Based on the results of these efforts, basic plans for pilot plant development will be studied, along with a schedule for the practical use of such plants.

(2) Overview of Results Obtained in FY1994

(a) The importance of developing coal hydrogenation and gasification technologies

Since the current year is the last in which surveys are to be performed, the results of surveys performed over the past four years were used as a basis from which recent changes in energy conditions and the development of new technologies could be taken into consideration in creating the following summary outlining the importance of developing coal hydrogenation and gasification technologies.

Spurred by the demand for liquefied natural gas on the part of electric power utilities and gas companies, the demand for LNG is rising, and when viewed on an international scale, factors such as the appearance of South Korea and Taiwan as new LNG importing nations and the rising interest in LNG as an environmentally-friendly fuel imply that demand may be expected to grow even further. At the same time, however, when consideration is given to the fact that supplies of LNG are likely to be limited because of the fact that the future development of new gas fields must take place in locations which do not need new infrastructure or which are not subject to severe climactic and geographical conditions, it is expected that LNG supplies will contain larger percentages of carbon dioxide and otherwise will be lower in quality. Furthermore, larger amounts of time and capital will be required to develop these resources, and it is feared that this may lead to increases in price or the inability to ensure stable supplies. In Japan, where LNG accounts for 73.6% of all fuels used in making commercial gas, there is a need to prepare for future shortages by expanding the range of fuels used in the production of commercial gas, to develop greater leverage in price negotiations with gas-producing nations, and to ensure continued national energy security. While studies were also conducted of the potential of coal-bed methane, methane hydrates, and other forms of fuels capable of serving as natural gas resources, the technical issues involved in the use of such fuels are complex, and it is believed that it would take quite some time before such resources could be fully developed. It is for these reasons that it is necessary to develop technologies for the production of SNG from coal at the earliest stage possible.

With respect to the siting of coal SNG production plants, in addition to identifying the main conditions which must be satisfied for the siting of a single dedicated plant, joint studies were also performed in conjunction with steel companies and electric power utilities possessing coal-related facilities to study the feasibility of joint projects for creating conglomerates to produce electric power, SNG, and chemical products. If ties are formed with organizations overseeing the construction and operation of natural gas pipelines in Japan and overseas, then it would become possible to transport coal in a clean and efficient manner, and this would prove to be extremely meaningful in terms of relaxing tensions due to energy and environmental problems between Japan and neighboring countries.

An examination of the economic feasibility of the ARCH process showed that while the degree of economic feasibility is heavily influenced by the price and volume of BTX produced at plants using this process, it is probable that gas produced using this process would be able to compete with LNG sometime around the year 2010 if the trends of coal and natural gas prices continue at current levels.

As for environmental suitability, it would be possible to remove sulfur content, nitrogen content, ash content, and other toxic substances from coal during production using present technologies to produce clean SNG. Since it would be possible to concentrate roughly half of all the energy contained within the raw coal into methane at high efficiencies of 80%, this would also be an excellent way to reduce carbon dioxide emissions.

(b) ARCH process development plan

As the conclusion of five years of surveys, studies were performed on the basic concepts underlying the ARCH process, the general development plan, and plans for the development of injectors and hydrogen and oxygen burners, and the results were then summarized together into a form which would allow them to be easily used in future constituent research.

The basic concept underlying the ARCH process calls for coal to be decomposed at high temperatures in the first stage of processing and made to react with hydrogen by subjecting it to selected temperatures over a given period of time during the second stage of processing so as to control the BTX yield. The most significant advantage offered by the ARCH process is the ability to select from three operation modes to maximize SNG yields, heat efficiency, and BTX yields.

Under the general development plan, after four years of research on constituent technologies, a pilot plant with a capacity of 50 tons per day was operated over a period of eight years to perform the research needed in order to develop a gasifier and associated peripheral equipment. This will be followed by the use of a demonstration plant with a capacity of 500 tons per day designed to make it possible to verify the feasibility of the system as a whole when it is combined with a hydrogen production process, thus preparing for the development of commercial plants and technologies.

The main constituent technologies which had to be developed were those for the development of hydrogen and oxygen burners used to provide supplies of high-temperature hydrogen, and after studying questions such as the design of these burners, the methods to be used for lighting them, and the methods to be used in monitoring their operation, a proposal was submitted for a new burner design.

It was also necessary to develop an injector capable of rapidly injecting and mixing hydrogen and coal heated to high temperatures, and tests were performed using cold and hot models to determine the performance of prototypes using the hydrogen and oxygen burners noted above, and a proposal for improvements to be made was also created.

In terms of basic research and studies to be performed before the development of constituent technologies, the following work was performed: (1) using a simulation model to predict the performance of the gasifier and to find the conditions required in order to increase liquid oil yields, (2) using the laser sheet method to create a visual representation of the flow of gases and solids within the gasifier and to analyze the results, and (3) identifying the heat conducting characteristics of the fluidized cooling facility which treats hot char removed from the coal hydrogasifier.

(c) Trends in the development of coal gasification technologies and views of prospects for the future development of such technologies

In order to promote further development of the ARCH process, broad-based studies were performed to learn about general trends in the development of coal gasification technologies and the development of the ARCH process and its relevance to international relations. The single most significant trend which may be seen in the development of gas-related technologies throughout the world is one towards the development of highly efficient coal gasification combined-cycle power generation systems designed to lower the cost of generating electricity and reduce environmental pollution. Most coal gasifiers in these plants have an entrained-bed design and consist of partial combustion gasification furnaces using pressurized dry-coal supply systems. These gasifiers (e.g., HYCOL gasifier) are suited for the production of hydrogen through the partial combustion of unreacted char coming from the coal hydrogasifier, and improving the performance of these gasifiers would make it possible to improve the efficiency of the ARCH process as a whole.

The need for coal hydrogenation and gasification technology differs from country to country. For example, in China, industry and government leaders would like to see coal converted to SNG and used as commercial gas so as to reduce the amount of acid rain created by the burning of coal in the private sector. For this reason, work should be done to study the possibilities for programs of international cooperation and assistance and to make the ARCH process commercially viable at the earliest stage possible.

(3) Future Tasks

In fiscal 1995, related research will be performed to complement and improve efforts directed towards the development of coal-use and hydrogen production technologies, and work will be performed to make it possible to begin research into constituent technologies in fiscal 1996.

III

Organization for The Promotion of Coal Utilization Technology

Coal is an important form of energy which accounts for roughly one-third of worldwide primary energy consumption, and it offers advantages such as abundant reserves and cost efficiency. It is predicted that the demand for coal will grow, and this demand will chiefly come from developing nations. In order to smooth the path to the increased use of coal, it is essential that efforts be made to respond to problems such as acid rain and global warming. It is for this reason that we are performing research and studies on next-generation clean coal technologies in order to lessen the burden placed upon the environment. We are also performing surveys of trends in the development of clean coal technologies around the world, promoting the exchange of both technical information and personnel between the industrially developed nations, and working to build a foundation from which we can promote the development of clean coal technologies.

1. Surveys for the Development of Next-Generation Technology for Coal Utilization

While the worldwide demand for electricity is expected to continue to increase, global environmental problems are becoming an important international issue. As a response to this, the development of revolutionary clean coal technologies is being pursued by carrying out research surveys, with objectives including the reduction of the environmental load of CO_2 and other emissions by the beginning of the 21st century.

These research surveys began in 1992 with the objective of studying coal combustion, multifunctional pyrolysis, and coal cleaning. Interim evaluations were performed last year. Technological themes deemed necessary by the interim evaluations will move ahead to the next stage of technology development.

1.1 Environmentally-Friendly Coal Combustion Technologies

1.1.1 Topping Cycles

(1) Objectives of Survey

Improving efficiency is a realistic countermeasure for reducing CO_2 gas emission from coal boilers. For this reason, research surveys of topping cycle technologies are being conducted with the objective of dramatically increasing system efficiency by raising the gas temperature for pressurized fluidized bed combustion technology, which currently has one of the highest efficiencies.

(2) Summary for FY1994

(a) Design of topping cycle

Some topping cycles were designed assuming a power generation plant with a capacity of 300,000 kilowatts, with four types of topping cycles being selected according to the structure of the system, the type of gasification furnace used, and other relevant factors. The following is a summary of the results of this study.

(i) The primary conditions for the design were set as follows.

• Values for environmental regulations (SOx, NOx, dust):

50 ppm, 45 ppm, and under 10mg/m^{3}N, respectively

• Design coal:

Datong coal (Note: the following must be studied and taken into consideration in setting the maximum value.)

Sulfur content, nitrogen content, ash content and fuel ratio:

1.2%, 2.0%, 20%, and 2.2 respectively

• Turbine inlet gas temperature:

Around 1,300°C

• Steam conditions:

246kg/cm$_2$ and 593°C/593°C as maximum values

(ii) The following four system designs were selected.

• Air-blown gasifier:

Gasifier/Oxidizer:

Air-blown pressurized fluidized bed gasifier and pressurized circulatory fluid-bed combustors (serial type)

• Oxygen-blown gasifier:

Gasifier/Oxidizer:

Oxygen-blown pressurized entrained flow gasifier and pressurized fluid-bed combustor (parallel type)

• PCPC gasifier:

Gasifier/Oxidizer:

Air-blown pressurized coal partial combustor (entrained-flow) and pressurized coal dust combustor (parallel type)

• PFBC:

Gasifier/Oxidizer:

Air-blown pressurized fluidized bed gasifiers and pressurized fluidized bed combustor (parallel design)

(iii) The following shows the performance estimated for the four systems noted above.

• Power generation (gross): 294–425 megawatts

• Ratio of the power generation gas turbine against steam: 49/51–60/40%

• Efficiency (gross/net;hhv): 46–51%/42–47% (7–12%)

• Gasifier pressure/temperature/coal conversion ratio: 20–28 ata / 950°C–1,600°C / 63–85%

• Oxidizer pressure/temperature: 14–28 ata / 850°C–870°C (PFBC)

• Primary steam and reheating temperatures/pressure:

538°C/538°C–593°C/593°C/170/21–170/37 ata

(b) Overview of evaluation

An evaluation of the potential for the application of each of four prototype-design systems was performed in order to determine which would be the optimal system.

As a result of this evaluation, it was determined that, for the following reasons, the air-blown gasification system constituted the best choice for proceeding with the next stage of research.

• This system offers the highest degree of proven technology. (Recommended on the basis of results of actual design, verification testing, and small-scale testing.)

• The system is both original and simple in design. (The system may be used together with conventional gas turbine combustors; the use of a single high-temperature gas system makes for a simple design; and the use of an independent dry desulfurizer makes for simpler operation.)

• The difficulties of developing the system are relatively few when viewed in the light of the high efficiency which would result. (It is possible to expect a net efficiency of 45–46%.)

(3) Future Tasks

The desulfurization and oxidization reaction characteristics of this system are closely linked to factors such as the performance, design, and operating conditions of the system, and it is therefore important to gain a full understanding of these characteristics.

Basic testing using small-scale equipment should thus be performed to learn about the following characteristics and to confirm that they meet design specifications.

• Desulfurizer; desulfurization reaction characteristics (vary temperature, steam concentration, particle size, and other conditions to learn about these characteristics).

• Oxidization furnace; CaS oxidization conditions (vary temperature, gas flow speed, CaS particle diameter, and other conditions to learn about oxidization status).

• Understanding of oxidization furnace char combustion characteristics (verify that no agglomeration exists and that combustion of char is stable).

• Understanding of long-term behavior of oxidization furnace waste ash (observe any change of the waste ash composition while exposing to air and water).

1.1.2 O_2/CO_2 Combustion Technology

(1) Objectives

To recover CO_2 from coal combustion boiler flue gas without using the separation process for CO_2, advanced combustion technology which replaces air with O_2 was surveyed.

(2) Overview of Results Obtained in FY1994

The following basic research was performed on carbon dioxide reclamation processes using oxygen combustion: (1) dynamic simulations of low-purity oxygen production devices, (2) study of the time required to start low-purity oxygen production devices, (3) oxygen combustion tests, and (4) combustion tests under microgravity conditions. As a result of this research, the following findings were obtained:

(a) Dynamic simulations of low-purity oxygen production devices

Studies were performed concerning the following four types of processes.

Process 1:

Process producing oxygen of nearly the same high purity as that produced when using conventional processes.

Process 2:

Process in which the operating pressure is increased so as to make the process more compact.

Process 3:

Process in which an auxiliary condenser is used in addition to the condenser/reboiler used in conventional processes and in which the operating pressure is lowered.

Process 4:

Process in which a portion of the input air is fed into a low-pressure tower and in which the power consumption of the air compressor is reduced.

As a result of the simulations, it was found that while Process 3 was not suited for use where there are rapid load fluctuations, all other processes displayed excellent load tracking characteristics. The degree of fluctuation in the purity of the oxygen produced was no higher than $\pm 0.7\%$.

(b) Study of the time required to start low-purity oxygen production devices

The times required to start up a low-purity oxygen production unit and a conventional high-purity oxygen production unit which performs argon collection are shown in the table below.

	Hot start	Cold start
High-purity oxygen generator	Approx. 24 hours	Approx. 4-6 hours
Low-purity oxygen generator	Approx. 17 hours	Approx. 2-3 hours

(c) Oxygen combustion tests

Oxygen combustion tests showed that when the secondary gas oxygen concentration was 30%, the heat absorption was equal to that of air combustion. A higher fuel ratio coal tended to increase heat absorption under certain oxygen concentrations.

(d) Combustion tests under microgravity conditions

In order to make it possible to improve pulverized coal suspension devices and observe the background of the combustion zone, during the current year improvements were made to combustion units, and combustion tests under microgravity conditions were performed. Particles and gas from the place of combustion were collected and work was performed to make it possible to measure the temperature of burning particles. As a result, in the oxygen/carbon dioxide atmosphere flame propagation ratio and the particle temperature were much lower than in O_2/N_2 and O_2/Ar.

(3) Future Tasks

Technical issues to be addressed are will be identified when the conceptual design of a power generation plant using oxygen combustion technology is created. In addition, in order to learn about the basic characteristics of pulverized coal combustion in an oxygen and carbon dioxide atmosphere, further combustion tests need to be conducted under microgravity conditions.

1.2 Coal Pyrolysis Technology

(1) Objectives

A research survey focused on the multifunctional pyrolysis processes that thermally decompose coal at moderate temperatures and pressure to produce gas, tar and char for some energy sources was conducted. Co-produced materials, which can be used as chemical feedstocks, were also researched.

(2) Overview of Results Obtained in FY1994

(a) Acquisition of basic data

A pressurized thermal decomposition simulator with a design capacity of 7 tons per day was used to perform a total of 10 thermal decomposition tests in which the type of coal and temperature at which thermal decomposition was performed were varied, and the results of these tests were used as data on product yields. As a representative example of the results obtained, the yields obtained from a single ton of Kalim-Prima coal consisted of 25 kilograms of slag, 72 kilograms of tar, 35 kilograms of kerosene, 255 kilograms of char, and 977 Nm^3 of gas. Data on cooling gas efficiencies in the char gasifier and the carbon gasification ratio were influenced by the feed coal.

(b) Char gasification tests

The evaluation results of the simulation tests were used to update the design of the medium-scale char gasification test unit, and this unit was then created and used in testing. Targets were set for the char/oxygen burner, stable slag discharge, and the materials to be used in the protective tube of the gas thermometer. Data (i.e., carbon gasification ratio, cooling gas efficiency) was obtained on gasification performance, and the results showed that it ought to be possible to reach target levels of gasification performance.

(c) Acquisition of other basic data

With the objective of increasing gas and tar yields, an experimental study was performed on using a solvent to pre-treat coal and increase its swelling. Also, with the objective of reducing the molecular weight of tar, a study was performed on the effects of secondary tar decomposition. As a result, the effectiveness of phenol and cresol in increasing swelling (i.e., in increasing tar yield) was determined and the differences in terms of composition and yield resulting from the secondary decomposition temperature were identified.

(d) Preliminary feasibility study performed to identify issues to be addressed

Using the data obtained from the thermal decomposition simulator tests, a study of the potential of the current process for use in commercial applications was performed, with the basic assumption being made that the amount of coal which could be processed using thermal decomposition would come to 1,000 tons per day. As a result, it was found that it would be possible to keep both plant and equipment costs down and to obtain a return on initial investment in just a few years if the process were designed to make use of existing infrastructure in a steel plant.

(3) Future Tasks

The major issues which remain to be addressed in the future consist of the development of methods for thermally decomposing sub-bituminous coal, determining minimum tar conditions, improving the precision of medium-scale char gasification test data, and using cold models to gain a better understanding of the behavior of particles within furnaces.

1.3 Advanced Coal Cleaning Technology

(1) Objectives

High-performance coal cleaning technologies, through an advanced process of deashing and desulfurization in the coal production and distribution stage, must contribute to the increase of combustion efficiency and reduction of ash disposal and flue gas desulfurization.

(2) Summary for FY1994

(a) Features of individual coal cleaning technologies

In order to produce cleaner coal, five technologies for desulfurization and ash removal were evaluated through laboratory experiments: fine particle dense-medium cyclone, column flotation, improved oil agglomeration, magnetic separation, and a microbial treatment to improve the performance of flotation.

Two technologies for high intensity coal cleaning were also evaluated: UV irradiation decomposition with alkali leaching, and maceral separation using selective flocculation. The characteristics of these cleaning technologies are shown in the table below.

(b) Evaluation of sulfur-removal and ash-removal characteristics

The data on the washability of coal required to design coal cleaning processes and to predict the form and composition of clean coal was obtained, and evaluations were performed of the sulfur-removal and ash-removal characteristics of a number of different types of coal. As a result it was found that when processing coal lacking even relative densities and which cannot be converted into low-ash-content coal by conventional coal cleaning technologies, processes making use of advanced coal cleaning technologies proved to be most effective.

(3) Future Developments

In order to develop more efficient processes for the production of clean coal and to develop ways of using these processes in commercial applications, it will be necessary to improve the ability of advanced coal cleaning technology to remove ash and sulfur content from coal. In order to achieve this objective, the knowledge and data gained thus far will be used to optimize column flotation, pulverized-coal dense medium cyclone, and electromagnetic separation technologies.

2. Clean Coal Technology Promotion Project

2.1 Research and Development Promotion Survey

(1) Objectives and Work Program

As a response to global environmental problems and other issues, it is critical that the development and commercialization of clean coal technology (CCT) be carried out so that the load of CO_2 and other harmful gases on the global environment will be decreased by the early part of the 21st century. In order to establish a foundation to promote clean coal technology, information will be exchanged with coal-related organizations worldwide, surveys of trends in clean coal technologies will be performed, and other related work will be conducted.

(2) Summary for FY1994

In addition to surveys being performed on trends in the development of CCT in

Performance Comparison and Characterization of Various Coal Cleaning Technologies

Technology	Screening principle	Deashing rate	Desulfurization rate	Combustible content recovery rate	Characteristics	Technological development potential
Microparticle dense medium cyclone	Specific gravity	57-84%	13-74%	71-94%	- High deashing rate - Desulfurization and deashing performance controlled by specific gravity setting - A rise in ash melting point achieved	- Large development factors in dense medium recovery methods
Column flotation	Surface characteristics	30-56%	6-48%	81-97%	- Relatively high desulfurization and deashing rates - Performance controlled by the amount of floating agent	- Performance to be improved by the control of floating agent amount and the flow of CO_2 - Combination with microbe, photo-oxidation and other methods possible
Improved oil agglomeration	Surface characteristics	37-56%	1-38%	93-98%	- High combustible content recovery rate - Poor desulfurizing performance	
Magnetic separation	Magnetism	12-58%	5-57%	90-98%	- High iron pyrite removal rate - Desulfurization and deashing performance controlled by magnetic field intensity - A rise in ash melting point achieved	- Dry-type superconducting magnetic separator (magnetic field intensity 4T) undeveloped
Microbial treatment	Microbe absorption	25-32%	30-34%	86-98%	- High iron pyrite removal rate	- Combination with column flotation - Problem of liberation of iron pyrite from coal to be solved
Alkali leaching	Chemical reaction	85-97%	16-82%	85-98%	- High separation efficiency - Production of clean coal with ash content of less than 1% possible	
Selective flocculation	Surface characteristics	20-95%	14-96%	5-96%	- Problem of coal flocculation to be solved	

Note: Desulfurization and deashing rates of microbial treatment represent test results of two coal types, while figures for other technologies cover eight coal types.

advanced nations and of the introduction of these technologies in the developing nations of the world, technical documents were also issued and collected and international seminars were held on CCT.

(3) Future Tasks

In addition to surveying trends in the development of CCT at home and abroad, performing work such as searching for new development themes, and conducting evaluating surveys of joint research with other advanced nations, the exchange of technical information and technical personnel will continue to be promoted.

2.2 Local Model Survey

(1) Objectives and Work Program

With the objective of working towards the establishment of a new environmentally-friendly coal utilization system, local model plans for using CCT in Japan will be surveyed, and new fields of coal utilization technology will be studied.

(2) Overview of Results Obtained in FY1994

As model domestic projects, a feasibility study and a survey of actual conditions were performed on the possibilities for using coal in new applications, and as a means of reducing the load placed upon the environment by the use of coal, a feasibility survey was performed on a general system for the effective use of coal.

(3) Future Tasks

In order to reduce the load placed on the environment by the use of coal, feasibility surveys must continue to be performed on the potential of systems designed to meet local needs in all stages of the coal energy process from production to use, with these systems to be based on the use of coal and all other available forms of energy.

IV

International Coal Utilization Project

As a major substitute for oil, it is expected that the coal will see increasing demand in the future. However, the emission of harmful substances such as sulfur oxides, nitrogen oxides, and coal ash acts as a factor preventing the spread of coal as a source of energy.

In order to contribute to the stabilization of the supply of energy for Japan by decreasing the load on the environment and promoting high-efficiency coal utilization, the International Coal Utilization Project is being conducted together with organizations in Asian and Pacific countries to demonstrate the effectiveness of clean coal technology (CCT), to disseminate the technology, and to create a master plan covering all aspects of coal utilization.

1. Research Program for Environmentally-Friendly Coal Utilization System

(1) Objectives and Work Program

In developing countries in the Asia-Pacific region, coal is often consumed without the implementation of the countermeasures required to ensure the safety and preservation of the environment, and evidence of this fact is clearly seen in the form of problems such as soot, dust, and acid rain. And what is more, unless coal is used efficiently, there may be insufficient supplies of coal to meet future energy demand.

It is for these reasons that, in order to take action against global environmental problems and to stabilize the coal supply and demand situation, NEDO has taken into consideration the present levels of coal utilization technology and the economic status of developing countries and has conducted investigations on coal utilization systems designed to incorporate the technologies needed to protect the environment and improve the efficiency of coal utilization. This is why NEDO is working to create a master plan of research programs for introducing the environmentally-friendly coal utilization systems best suited to the needs of the developing countries.

(2) Overview of Results Obtained in FY1994

(a) Chinese surveys

(i) Using the results of surveys performed in 1992 and 1993, a feasibility survey was conducted on environmentally-friendly coal utilization systems in the Coal Industrial Office, which serves as the counterpart to the Coal Industry Ministry. Studies were also performed on the potential of environmentally-friendly coal utilization systems intended for introduction to the Zaozhuang Mining Bureau in Shandong Province, which had been selected as the Chinese coal industry representative and model mining bureau, and work was performed on the creation of a master plan.

This master plan was designed with particular attention given to the need to implement environmental measures designed in accordance with current conditions in China, the need to increase efficiency, and the need to introduce environmentally-friendly coal utilization systems. The targets of this plan include coal washing plants operated by the Coal Industrial Office and model mining office, CWM production plants, and coal combustion boilers.

(ii) Feasibility studies of environmentally-friendly coal utilization systems to be used by offices other than the Coal Industry Office which serves as the counterpart to the State Planning Commission were performed, with the major part of these surveys consisting of studies of economic and energy problems in the coal consumption sector in the model city (Liaoning Province, Shenyang City), coal utilization system, coal distribution status, and environmental status. In addition, in order to gain an understanding of the state of atmospheric pollution in the model city, atmospheric simulations were performed and necessary data were obtained.

Specifically, surveys were performed on conditions in the model city (Liaoning Province, Shenyang City) in terms of economic and energy problems in the coal consumption sector, coal utilization, coal distribution, environment, etc., and through further local surveys on electric power generation, coke plants, gasification plants, briquette plants, etc., an understanding was gained of the current state of coal utilization and the environment in the model city. Case studies were carried out based on the results of these surveys, beginning with environmental countermeasures and efficiency improvements concerning the use of coal in the model city, with respect to the introduction of environmentally-friendly coal utilization systems.

As for long-term dispatching of experts, experts in desulfurization technologies and CWM (production and combustion) technologies were dispatched to each area of China, and with respect to local coal utilization technologies, environmental countermeasures, etc., in addition to implementing technical advice, seminars concerning Japanese coal utilization technology were held.

The current status of Japanese coal utilization was introduced to the Chinese Urban Planning Committee, the Environmental Protection Bureau, and managers of coal utilization facilities. In addition to providing technical advice, by introducing Japanese coal utilization technology, with respect to environmentally-friendly coal utilization technologies, the understanding of Chinese counterparts parties deepened.

(b) Indonesian survey

Working together with the Indonesian Mining and Energy Ministry, a detailed survey was carried out on the use of coal in the private sector and in the electric power and coal mining industries, and studies were also made of environmentally-friendly coal utilization systems designed to meet local needs. In addition, studies were made of the current state of use and future trends and issues in the general industry sector for which it is expected that the demand for coal will grow in the future.

More specifically, up-to-date data was obtained on the spread of the use of coal briquettes in the private sector, the data thus obtained was then subjected to analysis, a study was performed of briquette production and use systems designed to meet Indonesian needs, and then a number of candidate systems were proposed.

With respect to the electric power industry, up-to-date data was obtained on plans for the construction of new and upgrading of existing coal thermal power plants. After evaluating the possible impact of these plans on the environment, comparisons were made of a number of power generation technologies and power usage systems which would be capable of reducing environmental pollution, and proposals were made concerning a number of candidate systems.

In consideration of the fact that it is feared that the coal used in the future may have higher sulfur contents and otherwise be of poorer quality than that used at present, comparative studies were performed of a number of different pre-processing technologies for the removal of sulfur through the cleaning of coal.

(c) Philippine survey

A detailed survey was performed to learn about economic and energy conditions, coal supply and demand levels, coal utilization technologies, and environmental problems in the Republic of the Philippines.

Regarding local surveys, meetings were held with local Philippine government and industry officials to study local conditions in regard to coal-driven thermal power plants, the cement industries, and other industries using coal, with the content of this survey consisting of studies of the operation of plants, the use of coal, and environmental conditions.

Meetings were held with people from governmental organizations and local surveys were made to learn about economic and energy conditions, coal supply and demand, coal utilization technologies, and environmental problems in the Republic of the Philippines. This made it possible to gain an understanding of the current state of the environment and the coal industry in the Philippines, and studies were then initiated on the possible introduction of the use of more efficient environmentally-friendly coal utilization systems.

(3) Future Tasks

In surveys covering industrial sectors other than the coal industry in China and in surveys on Indonesia, surveys and studies must be conducted on those environmentally-friendly coal utilization systems judged to be usable in those countries, and a master plan must be created together with a plan for the creation of environmentally-friendly coal utilization systems.

In surveys covering the Philippines, detailed surveys must be conducted on coal utilization technologies in individual industries, and surveys and studies must be conducted of those environmentally-friendly coal utilization systems judged to be possible to use in the Philippines.

In addition, with respect to new partner countries, surveys and studies must be conducted on coal utilization in the country or countries in question.

2. Demonstration Projects of Environmentally-Friendly Coal Utilization Systems

(1) Objectives and Description of Project

In order to build an infrastructure in the nations of the Asia-Pacific region and to spread the use of more environmentally-friendly coal utilization technologies throughout the region, projects are to be conducted in cooperation with China, Indonesia, and other Asia-Pacific nations to provide support for the introduction of simplified flue gas desulfurization systems, fluidized bed boilers, and coal briquette manufacturing systems, and joint work is also to be performed to verify the feasibility of water-saving coal preparation systems designed with both local and Japanese technology.

(2) Overview of Results Obtained in FY1994

(a) Demonstration project

In accordance with the basic agreement formed in fiscal 1993, the following items were performed in fiscal 1994:

(i) In accordance with the basic plan and basic design created in fiscal 1993, a detailed design was created.

(ii) After negotiations with partner countries concerning design and specifications, final decisions were made on these documents, and all necessary basic design diagrams and documentation were created.

(iii) Equipment and pipes were manufactured, equipment was purchased, and then it was all sent to the partner countries.

(iv) Supervisors were dispatched to oversee local construction work to be performed by the partner countries, and guidance was begun on construction work.

(v) Related parties from partner countries were invited to Japan, and in addition to surveying and inspecting related equipment, they participated in facility inspections.

(b) Cooperative demonstration projects

The following items were performed in FY1994.

(i) In proceeding with the project, partner country counterparts were identified, and discussions were held on the selection of the sites in which projects were to be implemented, the division of work responsibilities, and other related issues.

(ii) Basic agreements required for the implementation of projects were formed.

(iii) Surveys required for the design and production of equipment and facilities were performed, and after discussions with personnel at the sites where projects were to be implemented, a portion of the work on the design and production of equipment and facilities was performed.

(3) Future Developments

(a) Demonstration project

After machinery and equipment has been installed by working in conjunction with partner country counterparts, test operations and performance testing will be performed and then followed in turn by verification operation. In addition to confirming that this machinery and equipment fulfills required functions, technical instruction and other training required to promote the spread of these technologies in the partner country will be performed.

(b) Cooperative demonstration projects

Working in conjunction with partner country counterparts, equipment and a portion of necessary facilities are to be manufactured and/or purchased, equipment is to be inspected and shipped by sea, a portion of local construction work is to be performed, and training is to be provided for operations personnel.

3. Promotion Program for International Cooperation

(1) Objectives and Work Program

In order to ensure stable supplies of coal while still being able to respond to the expected increases in the demand for coal which have been forecast for the future in Asia, NEDO will support clean coal technology (CCT) projects being conducted under the auspices of the APEC and other organizations so as to contribute to the dissemination of CCT overseas.

(2) Summary for FY1994

In addition to helping organize an annual CCT seminar and CCT training courses held by the APEC Energy Working Group on CCT, NEDO participated in international multilateral cooperative programs directed towards the dissemination of CCT.

(3) Future Tasks

As APEC is a forum for international multilateral cooperation, NEDO will participate in conducting surveys and other work required for the holding of seminars, training programs, and future activities.

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CHAPTER 5

DEVELOPMENT OF COAL RESOURCES

Development of Coal Resources

Contents

Development of Coal Resources

Over the middle and long terms, it is expected that there will be an increase in the worldwide demand for energy, and it is expected that there will be a particularly large increase in the demand for coal to be used in the generation of electrical power. A wide variety of different projects are being implemented covering everything from surveys to development, with the objective of ensuring stable supplies of foreign coal.

In order to entice private corporations to develop coal resources in areas in which it is difficult for them to establish bases and begin operations, up-front surveys of foreign geographical areas are being performed. In addition, basic coal resource development surveys are being conducted in order to develop and learn about high-precision coal resource surveying technologies in Japan and abroad.

In areas in which legal systems and other elements of the infrastructure are required to enable private corporations to participate in coal resource development, the following measures are being implemented to provide support to private corporations searching for and developing foreign coal reserves: (1) the provision of subsidies to offset the cost of performing coal development feasibility studies overseas, (2) loans to provide the capital needed to perform geological surveys, and (3) loan guarantees against capital outlays required for development.

1. Overseas Geological Surveys

(1) Description of Project

With the objective of taking the initiative to expand the range of sources of stable supplies of coal and in view of the fact that the acquisition of a stable source of foreign coal is of the utmost importance in assuring a stable supply of energy in Japan, the current project has been created to perform geological surveys and basic feasibility studies in developing countries and other countries which, although they are expected to contribute to providing a stable supply of a broad range of sources of energy to Japan, remain countries where it is difficult for private companies to conduct business and where the risks of doing so are high.

(2) Summary for FY1994

Geological surveys were conducted in China, Indonesia, and Malaysia, and basic feasibility studies were conducted in Indonesia. An outline of these surveys is given below.

Basic surveys	->	Exploration (Coal reserves surveys) (Coal field evaluation)	->	Feasibility studies	->	Development	->	Production

Development Steps of Overseas Coal

(a) Geological surveys

(i) Liangbaosi Joint Japanese-Chinese Coal Exploration Project

In accordance with an agreement formed in conjunction with the China Coal Field Geological Bureau on May 29 1991, coal exploration is being conducted through joint Japanese-Chinese efforts in the Juye coal fields in the Liangbaosi district of Shandong Province.

The exploration is scheduled to be conducted over the five years from 1991to 1996, with Japanese teams to be responsible for performing geophysical exploration and Chinese teams to be responsible for performing drilling, and with Chinese and Japanese personnel working together to carry out data analyses and write geological reports.

In fiscal 1994, the seismic reflection method was used to conduct geophysical exploration and data analysis work.

(ii) Ombilin Joint Japanese-Indonesian Coal Exploration Project

In accordance with an agreement formed in conjunction with the Indonesian Ministry of Mines and Energy on July 16, 1991, coal exploration is being conducted through joint Japanese-Indonesian efforts in the Ombilin district of West Sumatra Province.

The exploration is scheduled to be conducted over the five years from 1991to 1996, with Japanese teams to be responsible for providing drilling equipment and Indonesian teams to be responsible for performing the drilling and analyzing the samples thus obtained, and with Indonesian and Japanese personnel working together to create geological maps, perform geophysical exploration, evaluate the results of these surveys, and write reports on their findings.

In fiscal 1994, geophysical exploration, drilling, geophysical logging, and data analyses on coal reserves were conducted.

(iii) Central Sarawak Joint Japanese-Malaysian Coal Exploration Project

In accordance with an agreement made in conjunction with the Geological Survey Office of the Primary Industry Ministry of Malaysia on July 20 1994, coal exploration is being carried out through joint Japanese-Malaysian efforts in the central Sarawak district of the state of Sarawak in Malaysia.

The exploration is scheduled to be conducted over the five years from 1994 to 1999, with Japanese teams to be responsible for providing drilling equipment and Malaysian teams to be responsible for drilling, measurement and analyzing the samples, and with Malaysian and Japanese personnel working together to create geological maps, perform geophysical exploration, evaluate the results of these surveys, and write reports.

(b) Basic feasibility studies

In fiscal 1994, geological surveys, sediment surveys, and other surveys were performed in the Muara Lawa North area of East Kalimantan Province and the Air Pilubang area of Benkuuru Province in Indonesia.

(3) Future Developments

(a) Geological surveys

(i) Joint Japanese-Chinese geological survey: the Lianbaosi project

In view of the fact that fiscal 1995 is the last year planned for carrying out surveys, the work performed in this year will consist of physical surveys, sediment surveys, data analyses, and the preparation of final reports.

(ii) Joint Japanese-Indonesian geological survey: the Ombilin project

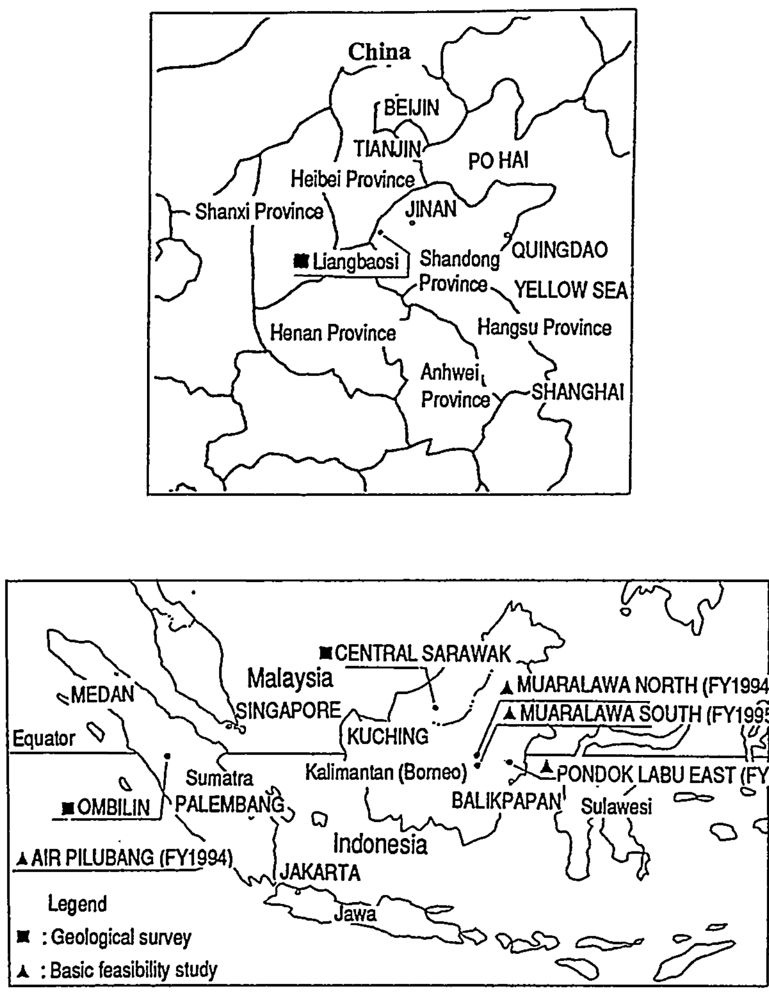
Because fiscal 1995 is the last year planned for carrying out surveys, the work performed in this year will consist of geophysical surveys, coal analyses, and the preparation of final reports.

(iii) Joint Japanese-Malaysian geological survey: the Central Sarawak project

As a follow-up to work which was also done in fiscal 1994, in fiscal 1995 work will be performed on geological surveys, sediment surveys, geophysical logging, and coal analyses.

(b) Basic feasibilty studies

In fiscal 1995, studies will be conducted in the Pondok Labu East area and the Muara Lawa South area of East Kalimantan Province.

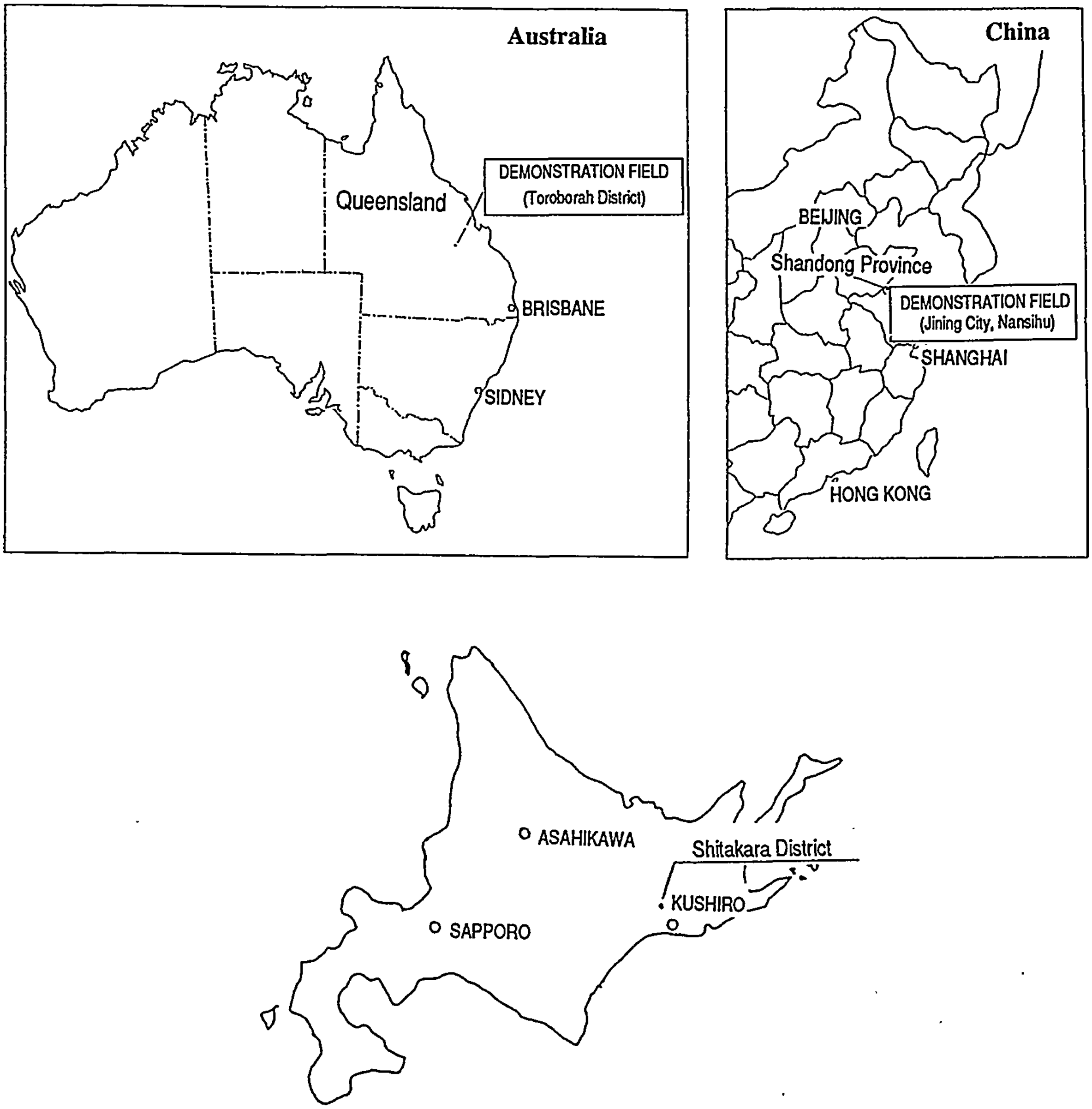


Locations of Overseas Geological Surveys

2. Basic Coal Resource Development Surveys

(1) Objectives and Work Program

In order to foster and develop practical prospecting techniques for coal resources, with reference to the results of physical prospecting and drilling surveys previously conducted by the project and to coal resource development overseas and trends in prospecting techniques, this project is aimed at carrying out surveys, development, etc. for advanced exploration techniques in Japan and abroad.



Locations of Demonstration Fields for Study and Development of New Prospecting Technologies

(2) Summary for FY1994

(a) Study and development of new surveying technologies

(i) In a demonstration field in the Taroborah district of the state of Queensland in Australia, a survey was conducted in order to develop shallow depth exploration technologies. In the Shitakara district of Kushiro in Hokkaido performance tests were conducted for equipment which had been developed and improved in Japan.

(ii) In a demonstration field in the Nansihu area near the city of Jining in Shandong Province, China, a basic survey and performance tests were conducted for the development of underwater mid-depth surveying technologies.

(b) Project for the collection of information

A project for the collection of information on the development of coal resources and on trends in the development of surveying technologies both in Japan and abroad has been implemented, and basic surveys have been performed on coal-seam gas and other resources.

(3) Future Tasks

(a) Study and development of new surveying technologies

(i) In the demonstration field in Australia, concentrated work will be performed on verification tests of shallow depth survey technologies.

(ii) In the demonstration field in China, a basic study and demonstration tests will be carried out in order to aid in the conducting of a general evaluation of underwater mid-depth surveying technologies.

(b) Project for the collection of information

Work is to be carried out on the collection of information on general evaluations and surveys of resources related to coal-seam gas.

3. Feasibility Studies of Overseas Coal Resources Exploration

(1) Outline of Scheme

With a view to promoting the development and importation of overseas coal, subsidies for overseas travel, technical consulting surface surveys, physical exploration, drilling work, and study-related activities are being granted to Japanese corporations and others engaged in such activities as part of the fund for overseas coal resource development-related studies and surveys (including project-finding studies and geological surveys).

(2) Subsidy Rates

Project finding studies	Up to half of the expenditures
Geological surveys (drilling work)	Up to two-thirds of the expenditures

(3) Subsidies Granted in FY1994

Subsidies were granted for two project-finding studies: one in Indonesia and one in the United States.

(4) Subsidies Granted (1977–1994)

Survey	Number of subsidiary projects	Subsidies granted
Project finding studies	51	¥129 million
Geological surveys	30	¥876 million

4. Loans for Overseas Coal Exploration

(1) Outline of Scheme

In order to stimulate the development and importation of overseas coal resources, Japanese corporations and others will be provided with funds necessary for surveys associated with coal prospecting overseas, including boring, pit excavation, infrastructure surveys and environmental surveys.

Effective from fiscal 1992, the lending scheme has been expanded so that at times such as when prospecting organizations that have been funded with loans cannot reach commercial levels of production, consideration will be given to the financial condition, fund position, and other project factors of the borrower. Thus, a "success payment system" has been installed wherein the money loaned may be reduced and/or exempted.

(2) Terms and Conditions of Loans

Repayment period	Up to 18 years.
Repayment method	Repayment in equal semiannual installments
Grace period	The period from the time when the prospecting operation financed by a loan is launched to the time when it starts commercial production may be considered the grace period. The period shall not exceed 8 years.
Interest on loans	3.25% per annum (as of August 1, 1995)
Loan amount	Up to 70% of the required funds
Surety	As a rule, a surety is to be established. The surety shall be an entity or individual who has a close relationship with the borrower.
Collateral	As a rule, collateral is levied. However, if levying collateral is considered difficult or inappropriate, collateral, either in part or in its entirety, may not be levied.

(3) Loans Extended (1977–1994)

Number of projects	Number of loans	Loan total
26	82	¥9,934 million

5. Liability Guarantee for Overseas Coal Development Funding

(1) Outline of Scheme

With a view to promoting the development and importation of overseas coal, the liability for bank loans for coal resource development activities concerning overseas coal exploration is guaranteed for Japanese corporations or others engaged in such activities.

(2) Terms and Conditions of Guarantees

Counterparty to guarantee agreement	Banks, etc.
Guarantee-related debtor	Japanese corporation or individual
Funds covered by guarantee	1. Funds required to acquire overseas coal development rights 2. Funds required to acquire coal-mining, transporting and cleaning equipment, electrical equipment and other equipment needed for coal production 3. Funds required for pit excavation 4. Funds other than those mentioned under 1 to 3 above that are required for overseas coal development 5. Funds required to supply funds mentioned under 1 to 4
Guarantee limit	Up to 50% of the funds in the case of the Export -Import Bank of Japan and up to 100% for commercial banks
Guarantee fee rate	0.4% per annum
Guarantee period	As a rule, the same as banks' lending periods
Surety	As a rule, a joint surety is to be established. The surety is to be one who has a close relationship with the principal debtor. If necessary, a third person who has a close relationship with the principal debtor is to be added.

(3) Guarantees Provided (FY1977–1994)

Number of projects	Number of guarantees	Amount covered by debt guarantee agreement
3	8	¥24,617 million

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CHAPTER 6

DEVELOPMENT OF FUEL AND ENERGY STORAGE TECHNOLOGIES

DEVELOPMENT
OF
FUEL AND ENERGY STORAGE TECHNOLOGIES

Contents

I

Development of Fuel Cell Power Generation Technology

Research in this area is in progress with the purpose of establishing fuel cell power generation systems using fuels such as natural gas, methanol, coal gas, etc., which are characterized by low emission of atmospheric pollutants, as well as the development of a wide variety of high-efficiency fuel cell power generation systems including those employing various fuel cells. These range from phosphoric acid fuel cells, which are closest to the stage of commercialization, and molten carbonate fuel cells, which possess high power generating efficiency and permit the use of a wide variety of fuels, to solid oxide fuel cells and polymer electrolyte fuel cells.

Regarding phosphoric acid fuel cells, research and development has been in progress since fiscal 1981 as a part of the Moonlight Program sponsored by the Agency of Industrial Science and Technology of Japan's Ministry of International Trade and Industry. Pursuant to the development of a 1-MW phosphoric acid fuel cell pilot plant for use in the electric power industry, a 200 kW system for on-site use was designed, constructed, subjected to operational studies, and completed in fiscal 1990. By virtue of these projects the basic technology was established, and in order to promote subsequent accelerated introduction of this technology, a project entitled "Development of Urban Energy Center Fuel Cell Power Generation" has been in progress since fiscal 1991 with the objective of developing techniques for promoting practical use of the technology.

In regard to molten carbonate fuel cells, the first phase target for 10 kW-class power generation was successfully achieved, spawning the second phase, which was initiated in fiscal 1987. In pursuing the development of a megawatt class system, methods for increased stack capacity as well as technology for utilization of coal gas were developed. These accomplishments will be assessed in the interim evaluation of fiscal 1993 and 1994, following which development work and operational studies of a 1,000 kW-class power generation system will be conducted.

In the area of solid oxide fuel cells, in accordance with the plan for the period from fiscal 1989 to fiscal 1991, research was conducted on topics such as development of basic manufacturing techniques necessary for the optimization of cell structure and fabrication. In regard to the possibility of developing large-scale cells, final evaluation was completed, and on the basis of the results achieved up until the present, research and development work on the basic structure of modules with output capacities of several tens of kilowatts as well as on materials and substrates was commenced in fiscal 1992, along with system studies.

As for polymer electrolyte fuel cells, a new project was initiated in fiscal 1992, and the development of basic techniques as well as system configuration studies on 1 kW-class modules are to be completed by fiscal 1995.

1. Development of Fuel Cell Techniques for Urban Energy Centers and Other Applications

(1) Objectives and Work Program

In accordance with the national Moonlight Program, the studies conducted relating to phosphoric acid fuel cells yielded numerous noteworthy results during the period from fiscal 1981 to fiscal 1990. Owing to the successful completion of these studies, basic techniques concerning phosphoric acid fuel cells have been almost fully established.

Fuel cells are characterized by superior features with respect to environmental preservation, and they constitute an oil-alternative source which provides electric power and heat with high efficiency. Accordingly, the development and introduction of fuel cells as components of energy supply systems in municipal reconstruction zones or industrial building structures appears to be highly promising.

From this point, high reliability, compactness, low cost, and other improvements are necessary if full-scale introduction in the form of fuel cell plants for the electric power industry and for other industrial applications is to be achieved. To this end, research and development work will be devoted to the following projects:

Therefore, research and development work was conducted with respect to the following topics.

(a) 5MW class pressurized fuel cell plants of the urban energy center type for use by the electrical industry

(b) 1MW class unpressurized fuel cell plants of the on-site type for business and operational use

Other planned activities in this area include surveys directed toward the widespread introduction of 5MW class fuel cells as well as surveys and studies concerning the possibility of introduction of fuel cells for domestic use.

(2) Summary of Achievements During Fiscal 1994

(a) Technological development of urban energy center type 5MW class fuel cells

(i) Research on fabrication and operation of plant machinery

Fabrication and emplacement were completed, and power generating regulation tests were conducted. The power generating regulation tests implemented included performance verification at 100% load, start-up and stop-down tests, and load fluctuation tests, and the operational characteristics of the plant were thereby confirmed. Operation was subsequently commenced in March 1995.

(ii) Studies on practicalization of machinery and control techniques

In order to evaluate the reliability of cell stacks, short-stack tests using large-area, high current density cells of the same type as those used in the plant were continued, and the temporal operating characteristics of the cells were ascertained.

(iii) Evaluation studies

Studies were conducted concerning

plant cost reduction measures and the possibility of more compact design.

(b) Technical development of on-site type 1MW class fuel cells

(i) Fabrication of power plants, etc.

Emplacement of the component machinery of the on-site type fuel cell power plant was completed, power generating regulation tests were initiated, and 100% power output in the said regulation tests was attained in March 1995.

(ii) Studies on practical realization of machinery and control techniques

a. Short stack tests were continued, and the temporal operating characteristics of the cells were ascertained.

b. Performance evaluation tests of catalysts and reformers at low steam-carbon ratios were conducted, and prospects for sound maintenance of reformer and catalyst operation were obtained.

c. The soundness of IGBT inverter performance was verified.

(iii) Evaluation studies

Studies were devoted to measures for improvement of the actual machinery of the plant, and the possibility of achieving greater compactness as well as reducing costs was investigated.

(c) Surveys concerning optimal introduction

Quantitative prospects for introduction of urban energy center type 5MW class fuel cells in urban redevelopment districts were provisionally calculated, problems and measures relating to introduction and wide utilization were considered, and plans for subsequent implementation of measures related to introduction and extensive utilization were formulated and organized.

(d) Practical development of optimal systems for decentralized domestic power sources

In the area of small-scale fuel cells as decentralized power sources for domestic use, studies of economy and energy-saving characteristics were conducted through investigations of possibilities for application, and the scale of the potential market as well as the problems involved in practical realization, introduction, and extensive utilization were clarified.

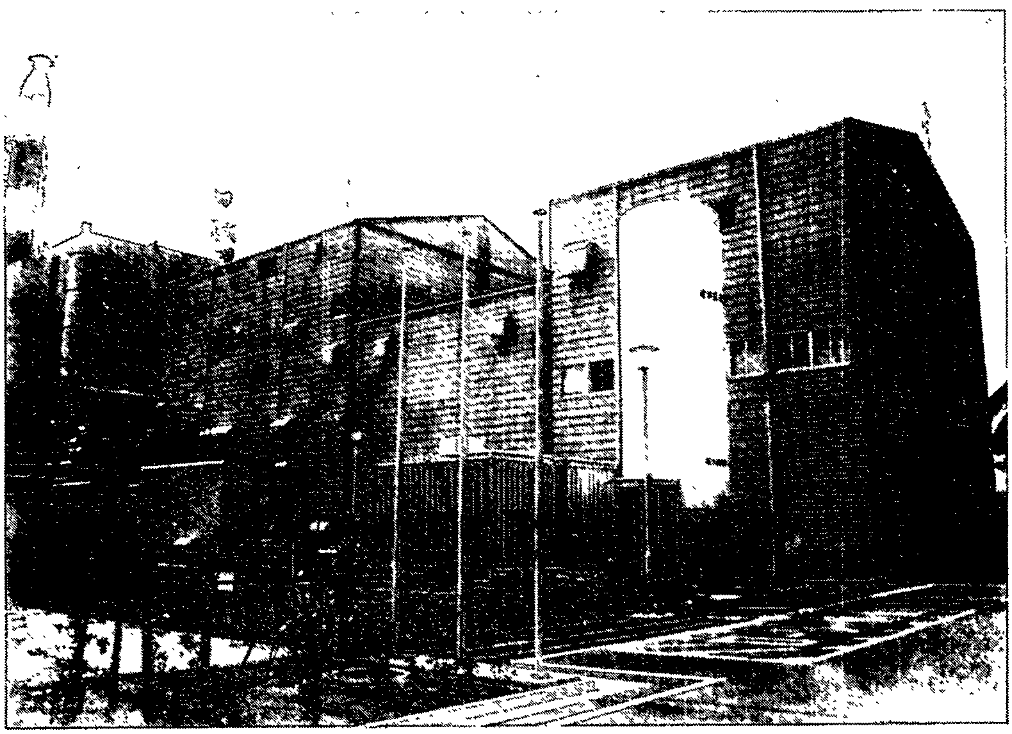
Furthermore, basic technical research was conducted with a view to size reduction of the mechanical components of reformers, which constitutes the major problem concerned in the achievement of greater compactness for applications to domestic use.

(3) Future Tasks

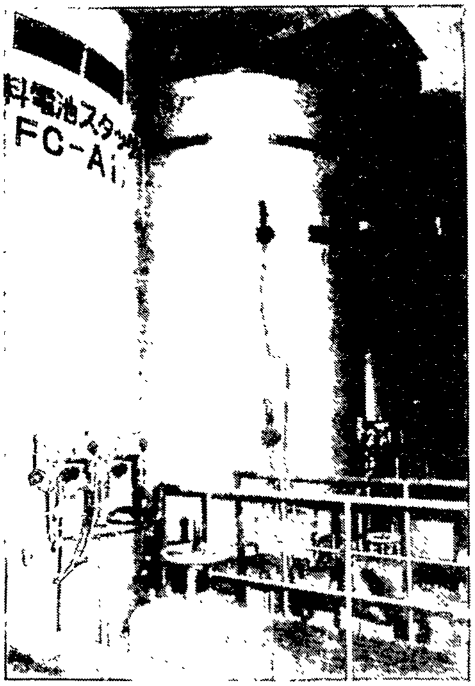
As regards the development of phosphoric acid fuel cells, continued efforts will be devoted to the project entitled "Technical Development of Urban Energy Center Type Fuel Cells," initiated with the objective of research on practical realization. Moreover, 5MW class pressurized type plants for the electrical industry as well as 1MW class unpressurized type plants for business operations will be subjected to operational tests over the forthcoming period of approximately two years, and with a view to genuine practical realization, validation studies of basic performance and mechanical reliability will be conducted, furthermore, studies will be applied to problems such as cost reduction and achievement of greater compactness.

Research and Development Schedule

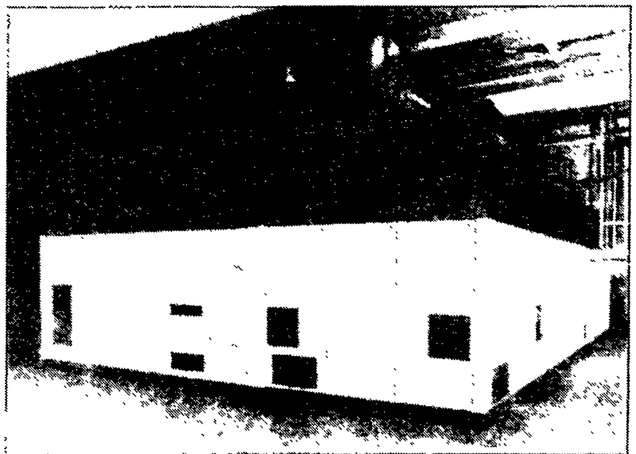
	1991	1992	1993	1994	1995	1996
5,000 kW class pressurized fuel cell plant	Design, fabrication and installation		Adjustment tests		Operating studies	
1,000 kW class unpressurized fuel cell plant	Design, fabrication and installation		Adjustment tests		Operating studies	



5 MW Plant Building



5 MW Plant Cell Stack



1 MW Plant Package

Moreover, fundamental technical research centered upon reformers will be continued as one aspect of the possibility of introduction in the domestic area of small-scale equipment of capacity several kilowatts or less.

In addition, with a view to steady progress toward full-scale practical realization, lifetime evaluation studies of phosphorus acid fuel cells will be initiated, while research and development work will be applied to elucidation of degradation mechanisms as well as accelerated testing methods for rapid evaluation of cell lifetimes.

2. Molten Carbonate Fuel Cell Power Generation

(1) Objectives and Work Program

Concerning the development of molten carbonate fuel cell, by fiscal 1997, liquid natural gas (LNG) is to be employed as fuel, and as the final target a pilot plant with AC output in the 1MW class and 45% power generation efficiency is to be developed and subjected to operating studies, while overall development work is to be applied not only to fuel cells but also to the various peripheral devices.

(2) Circumstances Preceding Interim Report

During the second phase plan commencing in 1987, proceeding on the basis of the results of the first phase plan extending from 1984 to 1986, development work was devoted to 100kW class stacks as well as individual techniques for major mechanical components and systems for 1MW class plants, which constituted the previous interim targets. According to the preliminary interim evaluation conducted in 1993, the stage for commencement of development work on 1MW class generating systems had arrived, and accordingly the latter half of the second phase was initiated in December of the same year.

However, since the stack performance was slightly inferior to the development targets, vigorous efforts were devoted to improvement of stack performance until October 1994, and as a result prospects for the technological development of a 1MW class generating system including these stacks emerged in the final interim evaluation conducted in November 1994.

(3) Summary for Fiscal 1994

(a) Technical development of stacks and 1MW class generating systems

(i) Development of high performance large capacity stacks

a. Cross-flow type

During fiscal 1993, in connection with the cross-flow pattern obtained by arranging four single square cells in a checkerboard pattern on the same plane as one approach to the formation of large-area cells, 100kW class stacks for use in interim evaluation were fabricated and subjected to operating tests.

As indicated in Table 1, the results revealed the necessity for improvement of initial voltage as well as the rate of degradation. Hence, during fiscal 1994, an improved 25kW class stack overcoming these problems was developed (Table 2) and subjected to operating tests, resulting in major improvement and the achievement of the interim targets (Fig. 1).

b. Co-flow type

During fiscal 1993, in connection with the co-flow pattern obtained by enlarging a single cell into a rectangular shape as one approach to the formation of large-area cells, 100kW class stacks for use in interim evaluation were fabricated and subjected to operating tests.

As indicated in Table 3, the results revealed the necessity for improvement with respect to the rate of degradation. Hence, during fiscal 1994, an improved 5kW class stack overcoming these problems was developed (Table 4) and subjected to operating tests, resulting in the achievement of the interim targets (Fig. 2).

c. Internal reforming type

During fiscal 1993, in connection with the internal reforming type of configuration characterized by the capability of reforming fuel within the cell stack when natural gas is utilized as fuel and offering the prospect of high generating efficiency, 30kW class stacks were developed, and the highly satisfactory results indicated in Table 5 were obtained.

Furthermore, as a result of continued operations in fiscal 1994, a total of 13,434 hours of operating time were obtained up to January 17, 1995 (Fig. 3).

(b) Development of 1MW class pilot plant

As a result of the preliminary interim evaluation conducted in October 1993, technical complement was sought in connection with still further improvement of stack performance. However, the results obtained on the technical aspects of peripheral devices, etc., were regarded as satisfactory. Therefore, the design of a 1MW class pilot plant was commenced in December 1993.

Table 1 Test Results of Cross-flow Type Stacks

	Interim evaluation stack	Improved 25 kW stack
Electrode effective area	1.2 m^2	1.2 m^2
Number of laminates	88 cells	22 cells
Output	110 kW	25 kW
Pressure	3 ata	6 ata
Cell initial performance	0.7V/150mA Fuel utilization rate: 80%	0.79V/150mA Fuel utilization rate: 60%
Degradation over time	17%/1,000 hours	0.5%/1,000 hours
Operating time	5,260 hours	4,011 hours (March 1, 1995)

Table 2 Major Improvements in Improved 25 kW Stack

Thickness of electrolyte plate	2.0 mm -> 1.1 mm
Cathode materials	SUS310S -> SUS316L
Cathode sintering temperature	700°C -> 750°C
Operating temperature	680 - 730°C -> 610 - 620°C (Max. 660°C)

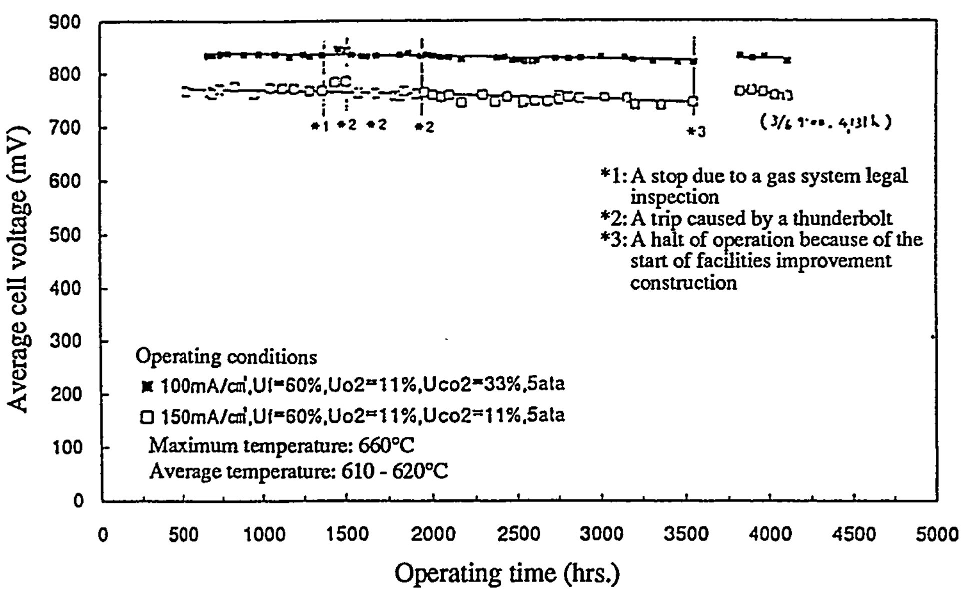


Fig. 1 Operating Status of Improved 25 kW Stack

Table 3 Test Results of Parallel Co-flow Type Stacks

	Interim evaluation stack	Improved 5 kW stack
Electrode effective area	1 m^2	1 m^2
Number of laminates	102 cells	5 cells
Output	124 kW	5 kW
Pressure	5 ata	Atmospheric pressure
Cell initial performance	0.8V/150mA Fuel utilization rate: 80%	0.80V/150mA Fuel utilization rate: 60%
Degradation over time	1.5%/1,000 hours	0.3%/1,000 hours
Operating time	5,118 hours	13,728 hours (March 1, 1995)

Table 4 Major Improvements in Improved 5 kW Stack

Thickness of electrolyte plate	LiA102 (fine grain/coarse grain) 50/50 -> 70/30
Materials of current collector and corrugate plate	SUS310S -> SUS316L

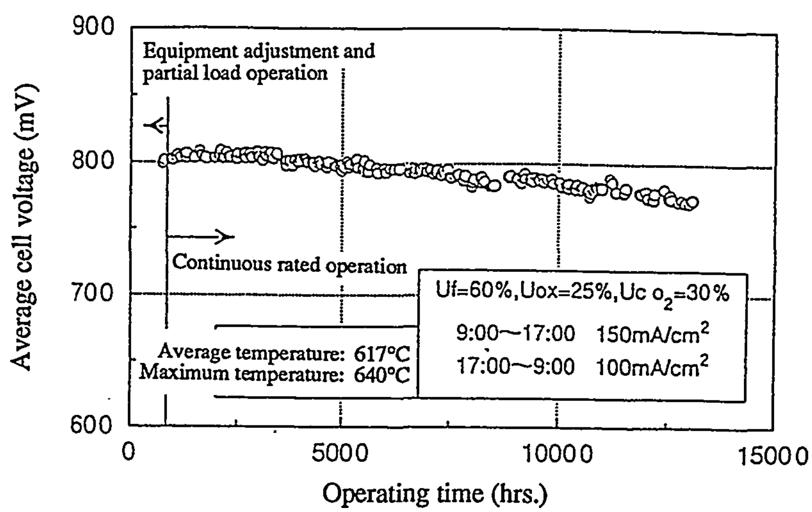


Fig. 2 Operating Situation of Improved 5 kW Stack

Table 5 Test Results of Internal Reforming Type Stack

	Interim evaluation stack
Electrode effective area	0.5 m²
Number of laminates	57 cells
Output	33 kW
Pressure	Atmospheric pressure
Cell initial performance	0.8V/150mA Fuel utilization rate: 80%
Degradation over time	0.6%/1,000 hours
Operating time	13,434 hours (January 17, 1995)

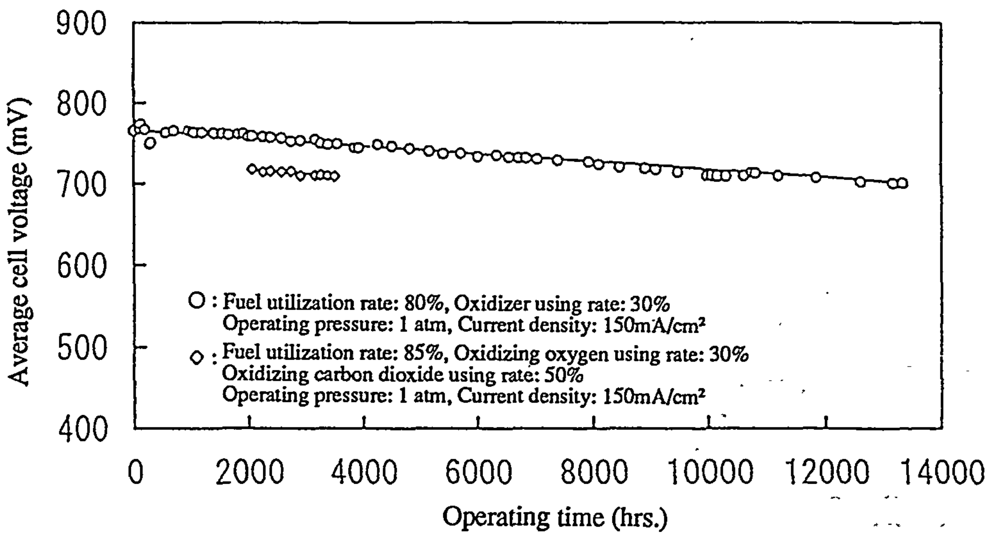


Fig. 3 Operating Status of 30-kW Class Internal Reforming Type Stack

During fiscal 1994, the design conditions of the pilot plant were subjected to detailed scrutiny, the basic specifications were formulated, and the basic and construction designs of individual devices were prepared accordingly (Table 6, Figs. 4 and 5).

(c) Supporting research

(i) Development of stack material techniques

In continuation of development activities conducted during fiscal 1993, further efforts were applied to the development

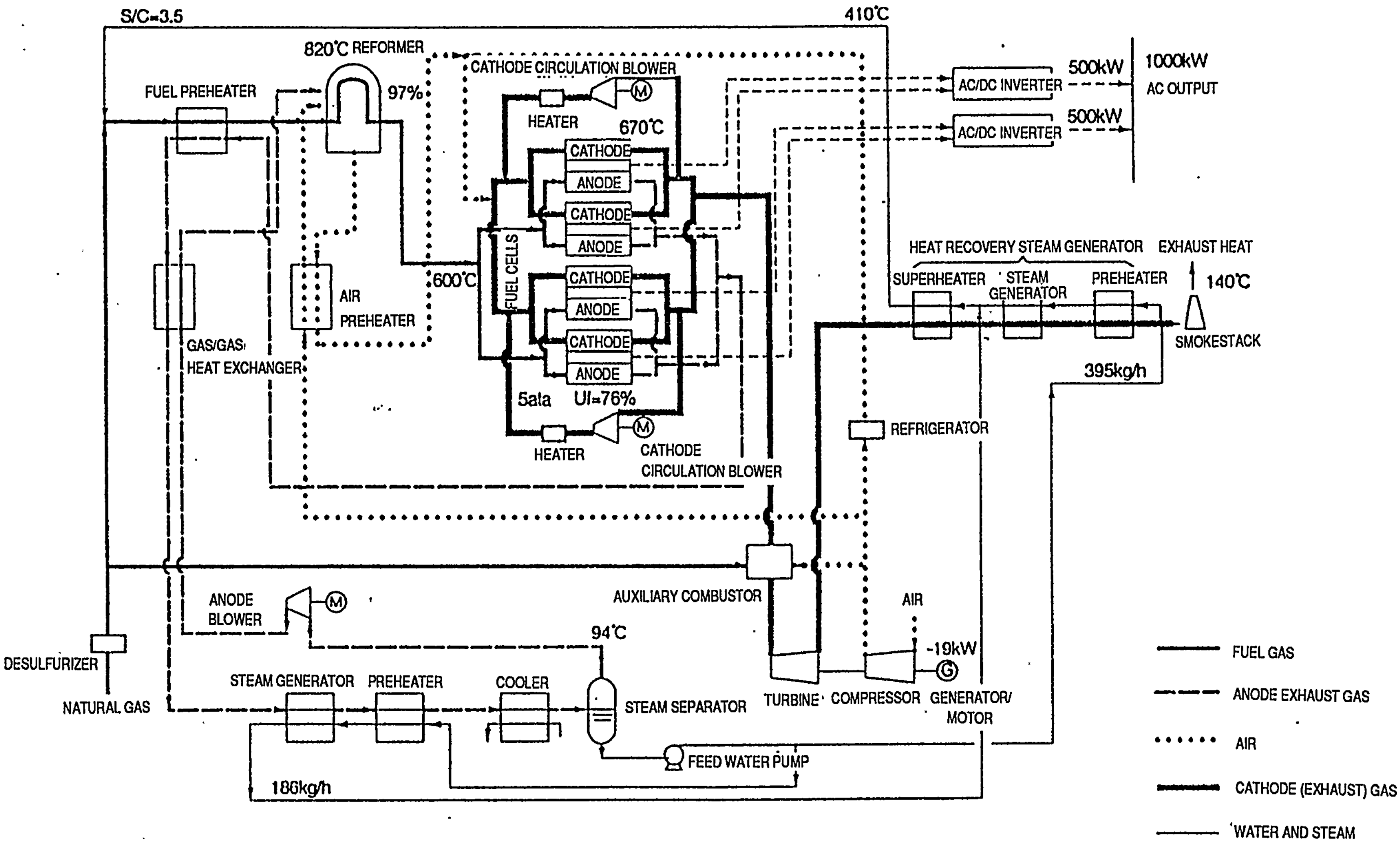
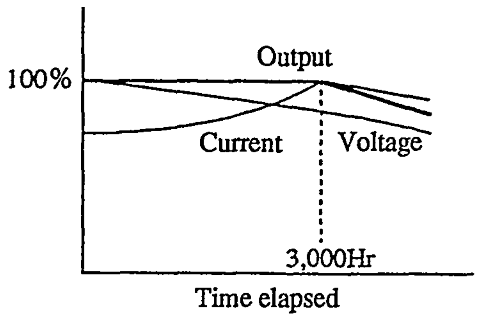


Fig. 4 Basic System Configuration of 1,000 kW Plant

Table 6 Design Conditions of 1,000-kW Class Pilot Plant

<table>
<tr><td rowspan="4">Design conditions</td><td>Operating time</td><td>5,000 hours</td></tr>
<tr><td>Output characteristics</td><td>1,000 kW x 3,000 hours</td></tr>
<tr><td>Stack operation temperature (cathode inlet/outlet)</td><td>580/670°C</td></tr>
<tr><td>Voltage degradation rate</td><td>1%/1,000 hours</td></tr>
<tr><td colspan="2">Output, voltage and current characteristics</td><td>
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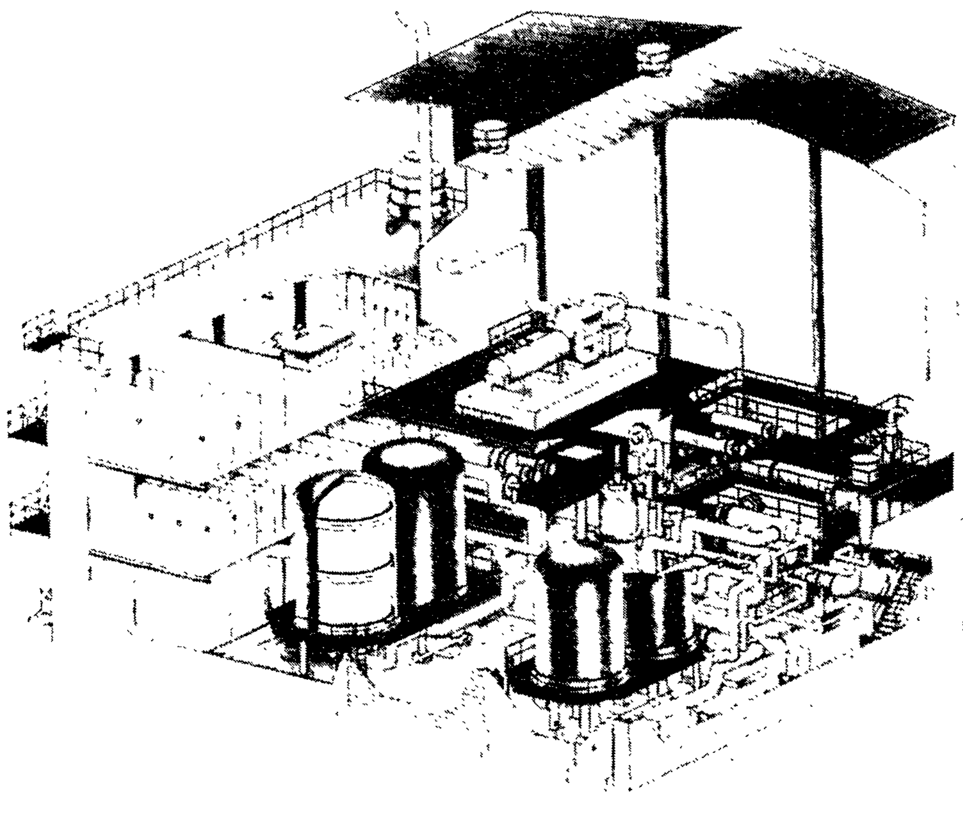


Fig. 5 Bird's-Eye View of 1,000 kW Plant

of new material techniques related to the future achievement of high performance characteristics, including long stack lifetime and low cost. As a consequence, steady results are being achieved with respect to multifunctional electrolyte plate and cell integration techniques.

(ii) Development of techniques for adaptation to coal gasification

With the objective of utilizing gasified coal, tests to assess the effects of impurities were conducted, with principal emphasis upon the effects of high concentrations of substances regarded as lowering performance, such as sulfoxides and halogen compounds.

Moreover, studies on gasified coal cleanup systems were implemented.

(4) Projects Scheduled for Future Implementation

(a) Technical development of stacks and 1MW class power generating systems

(i) Development of high capacity stacks

With a view to the implementation of operating tests of a 1MW class generating plant during fiscal 1997, parts will be fabricated in preparation for manufacture of 250kW cross-flow and co-flow external reforming type stacks.

Furthermore, in the field of internal reforming type systems, with a view to development of 200kW stacks, development of large-scale and high-lamination techniques is to be initiated.

(ii) 1MW class generating plant

With a view to implementation of operational studies during fiscal 1997, the fabrication of the principal peripheral devices will be initiated. Moreover, on-site construction work on the foundations of the plant building is to commence during the middle third of 1995.

(iii) Research on prolongation of lifetime

Research on lifetime prolongation will be conducted with the objective of establishing techniques permitting the achievement of stack lifetimes of about 40,000 hours by the end of fiscal 1997. In particular, studies on lifetime evaluation techniques will be pursued during fiscal 1995.

(b) Supporting research

(i) Development of stack material techniques

In continuation of work conducted during fiscal 1994, new material techniques will be developed in connection with future achievement of high performance characteristics including stack life prolongation and cost reduction.

Research and development work will be implemented with emphasis upon the solution of problems relating to the application of the results obtained with respect to each development topic, such as multifunctional electrolyte plate and cell integration techniques, to research on successive prolongation of lifetimes.

(ii) Research and development work on techniques for adaptation to coal gasification

With the objective of utilizing gasified coal, tests centered upon assessment of the effects of intermediate concentrations will be implemented on the basis of the results concerning high and low concentrations obtained in studies conducted during fiscal 1994 to ascertain the effects of impurities, with principal emphasis upon substances regarded as lowering performance, such as sulfoxides and halogen compounds.

Moreover, studies on gasified coal cleanup systems will be implemented in continuation of those conducted during fiscal 1994.

(iii) Research on total systems

With a view to practical realization of molten carbonate fuel cells, conceptual designs, schemes for introduction, and marketability will be considered in comprehensive studies of practical equipment suited to consumer requirements.

3. Research and Development Work on Solid Oxide Fuel Cells

(1) Development Targets

As one approach to the realization of high-capacity solid oxide fuel cells, studies concerning planar type cells will be pursued with a view to the achievement of large areas and high power density, and research will be devoted to basic module structures involving lamination, integration, etc.

Through these projects, modules in the several kilowatt class will be developed, operated, and evaluated, after which modules with outputs of several tens of kilowatts will be developed. In addition, research and development work will be devoted to material and foundational techniques and system configurations.

(2) Summary for Fiscal 1994

(a) Research and development work on modules

(i) Large-area cell lamination

The following improvements and studies were implemented during fiscal 1994.

a. Improvement of cell structure permitting uniform gas distribution within and between cell surfaces
b. Development and comparison of metallic fuel electrode substrates, promising as regards high mechanical strength and reliability, with ceramic air electrode substrates
c. Development of thin fine-grained electrolytes
d. Development of metal separators with low thermal expansion coefficients

Evaluation and study of the results of these improvements through tests of single cells 70mm in diameter revealed, in particular, that if metallic fuel electrode substrates were used, then absolutely no peeling or cracks would occur even after testing under four thermal cycles, thereby confirming the effectiveness of these techniques. Next, thermal cycle tests were performed using 200cm^2 single cells fabricated with metallic fuel electrode substrates, and no degradation of performance whatsoever was observed. These results are shown in Fig. 1 together with the corresponding results for previous types of cells.

(ii) Composite cell lamination type

The following improvements and studies were implemented during fiscal 1994

a. 160cm^2 x 30 cell modules were fabricated and subjected to power generation tests; the results demonstrated that an output of 1,064W, output density of 0.22W/cm^2, and fuel utilization factor of 40% were attained as initial characteristics. Subsequently, continuous operation was commenced, and opera-

Table 1 Development Targets of Modules

Item	Interim evaluation module	Kilowatt class module
Output Fuel (Pressure)	Several kW Reformed natural gas (Atmospheric pressure)	Several tens of kW Reformed natural gas (Atmospheric pressure)
Target cell average performance	(1) Initial characteristics: 0.18W/cm^2 (Fuel utilization: 70%)	(1) Initial characteristics: 0.20W/cm^2 (Fuel utilization: 75%) (2) Degradation over time: Less than 1%/1,000 hours

tion was sustained for 1,870 hours. Up to 1,030 hours, the rate of voltage decrease was 4.4%/1,000h. The lifetime characteristics of the module are indicated in Fig. 2.

b. Research and development work on material and foundational techniques and system studies

In the domain of research on material and foundational techniques, the activities conducted during this period included performance evaluation tests of cells fabricated by spray thermolysis and thermal spraying, internal reforming tests on fuel electrodes, fabrication and performance evaluation tests of electrolyte-electrode cosintered single cells, and studies on materials and microstructures of current collectors. Furthermore, in the domain of system research, simulation studies were conducted concerning both normal pressure and pressurized SOFC systems using liquefied natural gas as fuel, and also evaluation tests and other studies were conducted with respect to high-temperature heat exchangers, valves, and blower materials.

(3) Future Tasks

As regards module research and development, further improvement of cell technology is to be promoted, moreover, modules of the several kilowatt class will be fabricated and subjected to operational evaluation. As for materials and foundational techniques, research and development work will be pursued concerning material manufacturing methods, electrode structure, internal reforming methods, and current collection techniques. Also, technical performance will be verified by power generation tests using realistic cells. Further studies will also be pursued in the domain of system research.

Interim evaluation is scheduled for fiscal 1995. However, further establishment of basic technology such as cell structure, material, manufacturing and sealing techniques is necessary for the fabrication of several kilowatt class modules capable of long-term continuous operation to permit the attainment of the target performance of the interim evaluation as well as providing prospects for stable performance and practical realization. Therefore, during the present fiscal year, the subsequent development situation will be scrutinized and future orientation decided in connection with

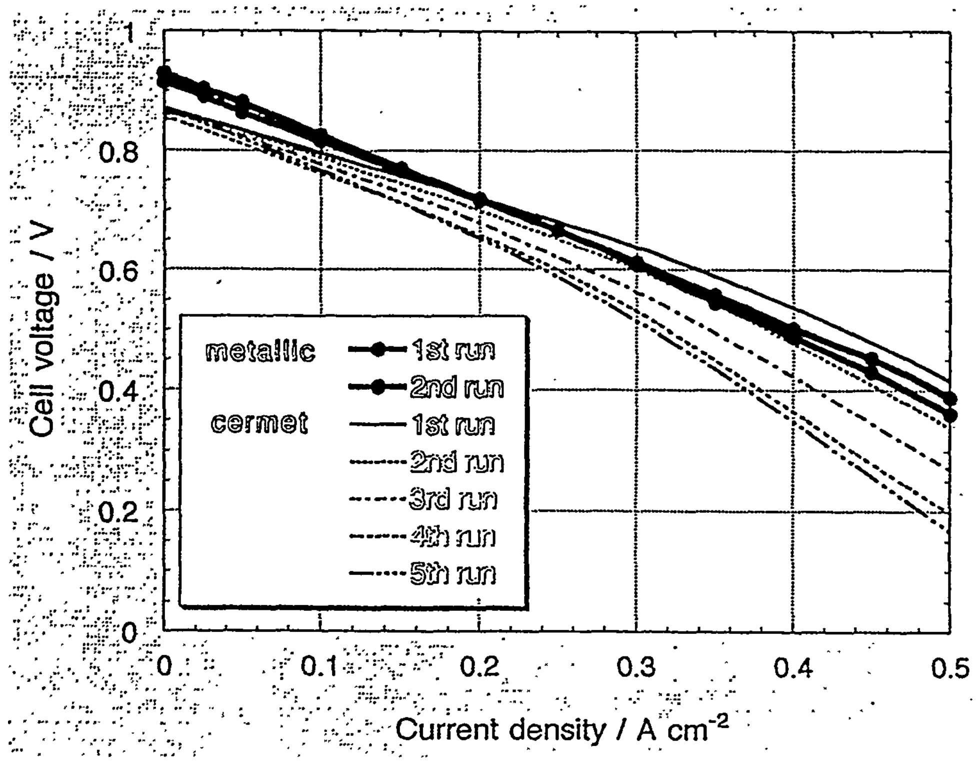


Fig. 1 Thermal Cycle Characteristics of Laminated Large Area Cell Type 200 cm² Cell

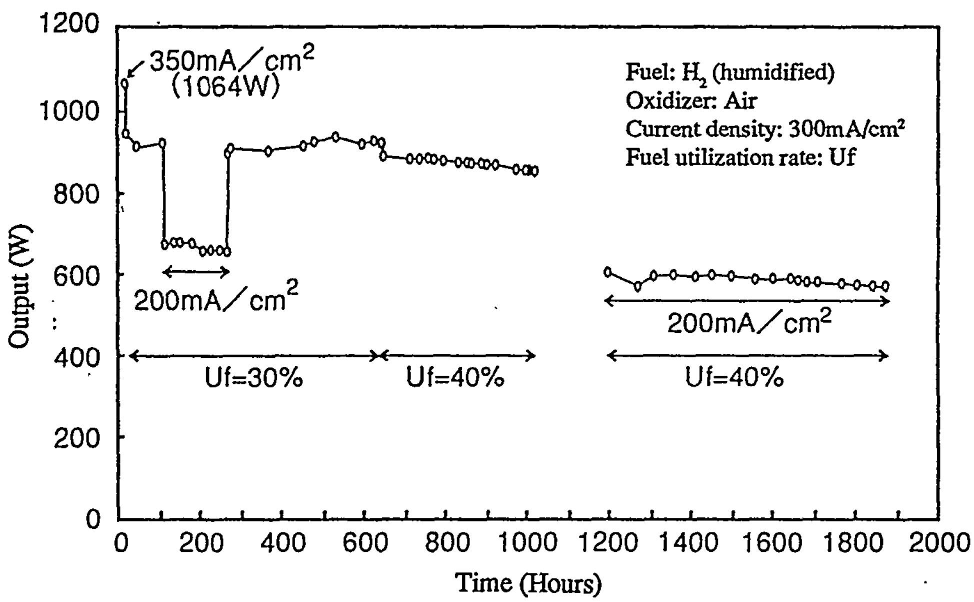


Fig. 2 Life Performance of Laminated Composite Type 160 cm² x 30 Cell Module

research and development work on several kilowatt class modules initially planned for implementation from fiscal 1996 onward.

4. Research and Development Work on Polymer Electrolyte Fuel Cells

(1) Objectives and Work Program

(a) Development targets

Research and development work was conducted on the basic technology necessary in order to realize power generation systems for private use in daily life as well as areas such as system design, etc., thereby demonstrating the technical feasibility of compact new power generating systems operating at normal temperatures and possessing excellent startup characteristics, as well as elucidating optimal methods of application and prospects for low cost production.

(b) Description of development work

From fiscal 1992 to fiscal 1995, basic technological development work included research on cell materials, cell structure, fabrication techniques, and stacking techniques suitable for application to private use as well as achievement of long life and low-cost production.

Furthermore, in the area of system research, various studies were conducted in connection with optimal configurations of power generation systems, including cells and peripheral devices, and the possibilities of practical applications to private use were clarified.

The development targets for 1 kW class modules are as follows.

Output	1kW class
Fuel	Hydrogen — Air (pressurized)
Average characteristics of target cells	Initial characteristics 0.3W/cm^2

(2) Summary for Fiscal 1994

(a) Basic technological development

(i) Development of high-voltage 1kW class modules

Stacks consisting of five cells each with an effective electrode area of 1,200cm^2 were fabricated, and provided an output of 1.8kW under the test conditions, i. e., hydrogen utilization factor 70%, air utilization factor 40%, and 3ata. The mean cell voltage in this test was 0.77V (at 400mA/cm^2), and the mean output density was 0.31W/cm^2, thereby achieving the development targets (Fig. 1).

(ii) Development of high-current density 1-kW class module

a. 3-dimensional electrode-membrane bonding joining method

Stacks consisting of sixteen cells each with an effective electrode area of 225cm^2 were fabricated, and provided an output of 1.1kW under the test conditions, i.e., hydrogen utilization factor 70%, air utilization factor 40%, and 3ata. The mean cell voltage in this test was 0.61V (at 500mA/cm^2), and the mean output density was 0.31W/cm^2, thereby achieving the development targets (Fig. 3).

b. High ionic conductivity electrode method

Stacks consisting of twenty cells each with an effective electrode area of 200cm^2 were fabricated, and provided an output of 1.2kW under the test conditions,

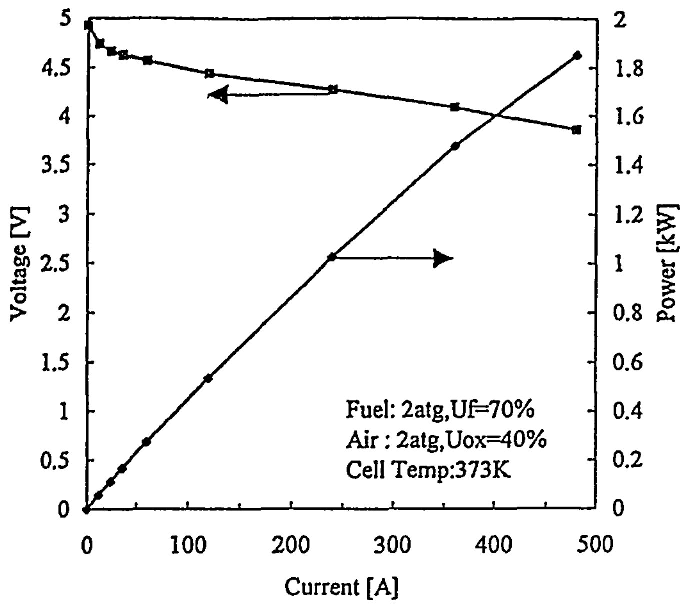


Fig. 1 Output Characteristics of High-voltage 1-kW Class Stack

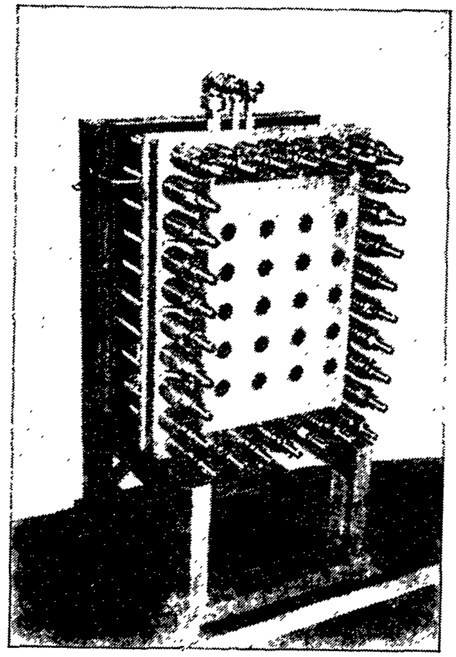


Fig. 2 Outside View of High-voltage 1-kW Class Stack

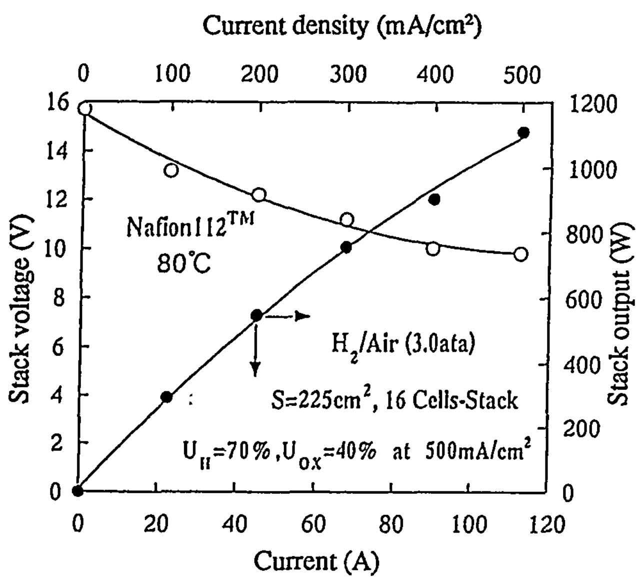


Fig. 3 Output Characteristics of High-current Density 1-kW Class Stack (3-dimensional electrode-membrane bonding joining method)

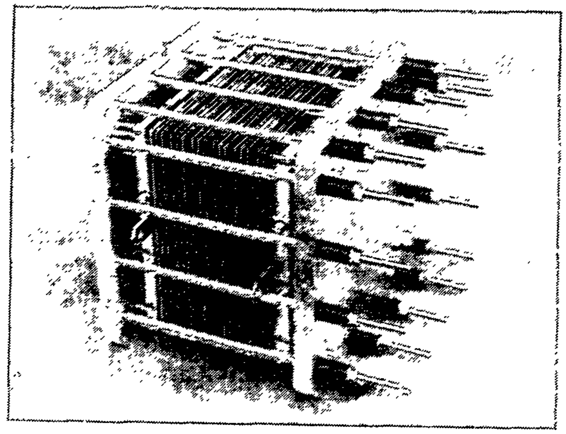


Fig. 4 Outside View of High-current Density 1-kW Class Stack (3-dimensional electrode-membrane bonding joining method)

i. e., hydrogen utilization factor 70%, air utilization factor 20%, and 3ata. The mean cell voltage in this test was 0.62V (at 500mA/ cm^2), and the mean output density was 0.31W/cm^2, thereby achieving the development targets (Fig. 5).

(iii) Research on polymer electrolyte membranes for fuel cells

a. Research on polymer electrolyte membranes for fuel cells

Studies of properties such as moisture content, moisture permeability, and gas permeability in humidified gases were conducted with emphasis upon ion exchange membranes possessing various different exchange capacities. On the other hand, as regards technical methods for electrode-membrane junctions, the applicability of the adhesive method was confirmed even when the effective electrode area was enlarged to 200cm^2.

b. Code position — coated membrane method

As regards electrode structures based upon, the code position — coated membrane method, with a view to improvement of aspects such as the coprecipitation conditions of the catalyst, power generation tests were conducted with cells of an effective electrode area of 10cm^2, and the results revealed that improvement of cell characteristics and air utilization factor is necessary as compared with conventional fabrication techniques.

c. Wave-formed catalyst layer electrode method

As regards electrode structures based upon wave-formed catalyst layer electrode method, electrodes with effective electrode area enlarged to 100cm^2 were prototypically fabricated and subjected to power generation tests, wherein an output

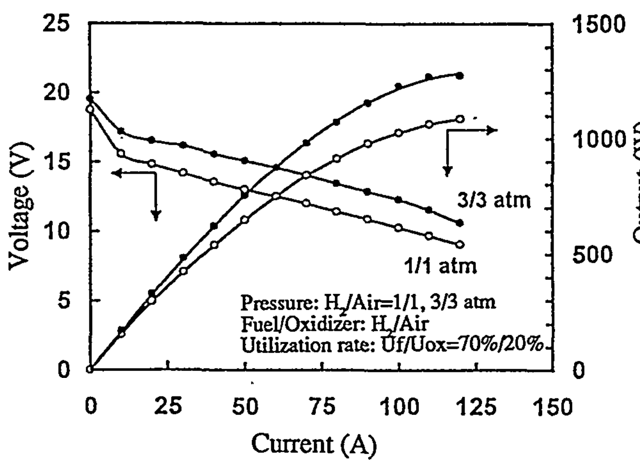


Fig. 5 Output Characteristics of High-current Density 1-kW Class Stack (High ionic conductivity electrode method)

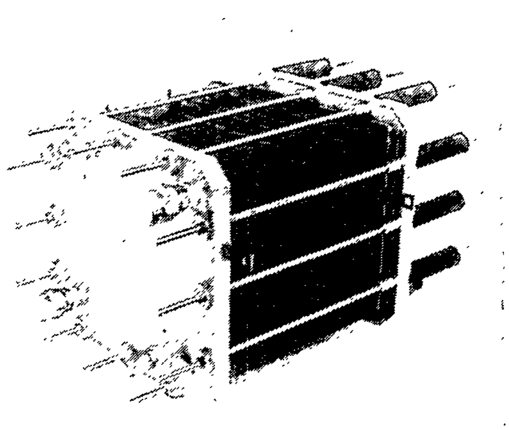


Fig. 6 Outside View of High-current Density 1-kW Class Stack (High ionic conductivity electrode method)

density of 0.24W/cm^2 was obtained. Moreover, as regards electrode constituent materials, with a view to rectification of methods and conditions for addition of water repellant materials, the quantity of platinum carrier was diminished by a factor of approximately 1/2 as compared with the previous fiscal year, and an output density of 0.34W/cm^2 was obtained from a cell with an effective electrode area of 10cm^2.

d. Thin-film methods

Prospects for the feasibility of electrode fabrication by thin-film methods were obtained, and therefore electrodes with an effective electrode area enlarged to 144cm^2 were prototypically fabricated and subjected to power generation tests. The results revealed that the cell performance was still low, but prospects emerged for higher performance provided certain future improvements are added.

(b) System studies

(i) Research of PEFC stationary systems

The surveys and studies initiated in fiscal 1992 were completed, and the prospects so obtained indicated that a combination of the methanol-steam reforming method and the carbon monoxide selective oxidation method is superior from the viewpoints of both compactness and efficiency. Moreover, 30kW class system analysis was conducted with respect to a system configuration combining a general purpose turbocompressor with methanol-steam reforming and carbon dioxide selective oxidation, and considering heat radiation as well as pressure losses. Provisional calculation on this basis indicated an AC transmitting end efficiency of 37.5% (HHV).

(ii) Research of PEFC systems for transportation applications

Survey studies were conducted concerning reforming techniques for methanol and other fuels, hydrogen and methanol storage techniques, carbon monoxide processing techniques such as carbon monoxide removal techniques, measures against carbon monoxide poisoning, etc., and peripheral devices such as air compressors and pumps. Furthermore, the results of survey studies concerning peripheral devices indicated that compact devices with low power consumption are most desirable for portable systems, but the specifications of existing peripheral devices are limited, and therefore the modification or development of such devices in a manner suitable for the output level of solid polymer fuel cells is desirable.

(3) Future Tasks

As regards module development, with a view to the further improvement of cell characteristics, studies on long-term performance characteristics will also be pursued. Moreover, as regards research on ion exchange membranes, the basic physical properties of the membranes will be measured and further improvement of electrode-membrane joining techniques will be sought.

In the domain of system studies, results concerning fuel reforming technology, techniques for removal of carbon dioxide from reformed gases, carbon dioxide poisoning mechanisms, and cell peripheral devices, etc., will be organized, and conceptual designs of both stationary and portable power generating systems will be prepared.

II

Development
of
Advanced Battery Electric Energy Storage Systems

1. Objectives and Work Program

Project objectives consist of development dispersed-type battery energy storage technology for both stationary and mobile (electric vehicles, etc.) systems, serving to store electric power (i. e., charging) during nighttime and release this power (discharging) during daytime on the demand side, thereby effecting so-called load leveling. To this end, research and development work will be devoted to lithium secondary batteries, said to constitute the ultimate in battery performance by virtue of their excellence with respect to properties such as energy density as compared with presently employed lead-acid batteries.

The research and development targets and schedule are as shown in the accompanying table. A total of 14 billion yen has been allocated for this research project.

[Research and Development Areas]

(1) Research and Development of Advanced High Performance Batteries

Cell development and basic research work will be devoted to ambient temperature lithium secondary batteries in the class with capacities of several tens of kilowatt hours, characterized by long life and high energy density. In this connection, the basic research and prototypical fabrication work involved in cell development will be conducted with a view to securing high-capacity single cells as well as performance improvement in both single cells and battery assemblies. Moreover, in addition to cell development, research and development work will be applied to utilization technology including devices such as charging equipment and residual capacity meters. Furthermore, operating studies of prototypically fabricated advanced high performance batteries will be conducted, and the batteries subjected to testing studies for overall evaluation.

Development Targets

Type		Long Life Type	High Energy Density Type
Energy density	(Wh/kg)	120	180
Specific density	(Wh/l)	240	360
Cycle life	(cycle)	3,500	500
Energy efficiency	(%)	90 or more	85 or more
Other		Consideration for environment and safety, maintenance free	

(2) Total Systems Studies

Multifaceted overall studies will be applied to the required performance characteristics, optimal form, safety, economy, and modes of introduction of dispersed-type battery energy storage systems.

[Procedures for Promotion of Development Work]

At present, the use of lithium secondary batteries is limited to small cells. Increased size and development of large-capacity single cells as well as substantial improvements in the energy density and cycle life of both single cells and battery assemblies are required, and to this end many technical obstacles must be surmounted.

Accordingly, research and development work will be applied to various types of battery systems offering possibilities for achieving the development targets, and in addition, studies of basic materials will be conducted. In particular, the various aspects of research and development in this area are to include development of cell component materials for anodes, cathodes, electrolytes, etc., as well as improvement of the safety and reliability characteristics of single cells and battery assemblies. Furthermore, in order to achieve effective utilization of the completed lithium secondary batteries from the viewpoint of resources, studies will also be devoted to the establishment of total systems including recycling functions as well as economy of other factors involved in future practical realization and a wide field

Schedule for Research and Development of Dispersed-type Battery Energy Storage Technology

Fiscal year / Research items	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
	First term (basic technology research)				Second term (scale-up)			Third term (reliability enhancement)		
1. Advanced high performance battery	Design, basic technology development and fabrication of cells			First interim evaluation	Fabrication of modules		Second interim evaluation	Fabrication of set batteries/ overall test		
2. Total system	Required ability, optimum form, safety, cost performance, investigation and examination of application method									

Outline of the Plan

Objects	Battery system			Characteristics
	Positive electrode	Electrolyte	Negative electrode	
Long life type	Metallic oxide	Organic electrolyte	Carbon	(Cobalt type) • Employing high-voltage cobalt oxides as cathode materials to lengthen the life of batteries and to reduce their size, a newly-developed electrode structure with an electrolyte reservoir is used.
				(Carbon type) • Improvement of graphite-type carbon, which is superior in capacity and voltage characteristics, as anode material is being conducted to develop a long-life battery.
			Lithium-lead alloy	(Composite alloy type) • Carbon is mixed with Li-Pb alloy, which has superior cycle characteristics, and is used as an anode material to lengthen battery life.
		Polymer solid electrolyte	Carbon	(Polymer type) • Polymer solid electrolytes make batteries highly reliable, safer, more maintenance-free, and capable of more cycles.
High energy density type	Metallic oxide	Organic electrolyte	Carbon	(Carbon type) • Optimized large single-cell structures and a homogenized LiNiO2 crystal structure (an easily obtainable material) are quite suitable for high-energy density batteries.
				(Cobalt type) • Energy density is improved by optimizing the composition and structure of cobalt oxides, a material whose operating voltage is high, and by using long-life carbon materials for the anode.
			Lithium alloy carbon complex	(Composite alloy type) • This type of battery has a lithium alloy anode for high voltage and high energy density. Moreover, carbon is composited for safety and to further increase the energy density. Manganese materials are mainly used for the cathode, depending on resource and environmental issues.
			Lithium	(Metal type) • Cathode materials are created with nanometer-scale microstructure control, and metallic lithium is used for the anode for high energy density.
Materials	—	—	Carbon	• To create an optimum crystal structure, new carbon precursors are being investigated and, as new synthetic technologies are developed, new long-life and high-energy density carbon materials are being produced and put to practical use.
	—	Organic	—	• Not only is the ion conductivity being improved and performance being stabilized, but organic electrolytes, which can curb the formation of lithium dendrites, are being developed.
Total system	• Study on the strategy for introduction • Study on multicell technology			• Safety, cost performance, marketability, load leveling effect in practical use, and performance sought to match that of other machines in use are being examined. • To determine the information that should be considered in the design of single-cell and multicell batteries, overcharging and overdischarging tests of multicell batteries are being conducted. The information is then sent to battery makers as feedback that assists in the more effective development of batteries. Operating tests of multicell batteries are also being conducted to fully examine performance and to determine areas for improvement.

of applications.

Pursuant to the above, the essentials of the plan are as indicated in the table. In this research and development of advanced high performance batteries, development studies are to be conducted on four different varieties of battery systems in the areas of both long life and high energy density type batteries as well as cell materials in both the carbon and liquid electrolyte categories.

2. Summary for FY1993

The project designated as "Research and Development of Advanced High Performance Batteries," in continuation from fiscal 1993, will be devoted to long-life and high energy density type ambient temperature lithium secondary batteries, and in this connection cell component materials (high-performance electrodes, stable electrolytes, etc.) will be developed, their performance characteristics ascertained, and reaction and degradation mechanisms elucidated. Moreover, single cells will be designed, fabricated, and tested with a view to development of 10Wh class single cells in preparation for interim evaluation in fiscal 1995.

In the project designated as "Total Systems Studies," studies on approaches to introduction of dispersed-type battery energy storage systems were implemented through research directed toward clarification of the efficacy of introduction and required performance of small-scale load-leveling apparatus (or load conditioners (LCs)) for home use as well as portable batteries for purposes such as electric vehicles. Furthermore, methods for evaluation of battery assemblies were studied as one facet of research on battery utilization technology.

2.1 Research and Development Work on Long-Life Lithium Batteries

(1) Research and Development Work on Long-Life Lithium Batteries (Cobalt Type)

(a) Research on improvement of battery performance

(i) Elucidation of degradation mechanisms and studies on accelerated life testing methods

a. Studies on cycle degradation correlation formulae

In order to predict cycle life, cycle degradation correlation formulae were investigated on the basis of data on cycle life tests under various charging and discharging conditions using small cylindrical cells (capacity 500mAh). The results of measurements of changes in mean voltage differences between charging and discharging or cyclic variations in electrode impedance revealed that cycle degradation is due to increased reactive resistance of the anodes and cathodes.

b. Studies on accelerated life testing methods

The reactive resistance of the anodes and cathodes is considered to increase as a result of ambient temperature, overcharge, or overdischarge; this prompted the study of methods for accelerated life testing based upon the imposition of stresses such as temperature changes or impulse currents during the charging-discharging cycle, thereby increasing the reactive resistance.

(ii) Development of high-capacity cobalt oxides and high-capacity carbon materials

a. Optimization of conditions for synthesis of high-capacity cobalt oxides

In order to achieve stable charge-discharge capacity with only slight cycle degradation, a portion of the cobalt in the active material $LiCoO_2$ of the cathode was replaced by nickel, synthesizing compounds with the stoichiometric formula LiCo(1-x)NixO_2 for various values of x. The X-ray diffraction patterns of these compounds were analyzed by Rietvelt analysis, and the results revealed that increasing the value of x tends to increase the rock salt phase, and if x = 0.8, then a product with a purity of approximately 90wt% can be formed. When the material was synthesized in an air atmosphere, which would be most promising as regards cost reduction in industrial production, the value x = 0.8 provided the highest practical initial capacity of 150mAh/g.

b. Development of high-capacity carbon materials

In order to decrease the irreversible capacity of carbon anodes, the reactivity of the carbon surface was evaluated by measurement of the heat of contact with organic solvents. This revealed that the heat of contact differed with the degree of surface oxidation treatment of graphitized MCMB and with the type of organic solvent, and the irreversible capacity was found to be high when the heat of contact with benzene was large.

(iii) Evaluation of active materials by Raman infrared spectroscopy

The changes in the chemical bonds of the active materials due to charging and discharging were assessed by measurement of the Raman infrared spectra of the anodes and cathodes. The intensity of the Raman infrared spectrum of $LiCoO_2$ was observed to diminish concomitantly with the imposition of successive charging-discharging cycles. This indicates that changes occurred in the chemical bonds involving oxygen in $LiCoO_2$.

(b) Research on essential technology ofsingle and compound cell structures

(i) Prototypical fabrication and evaluation of cells with folding electrode structures

10Wh class cells with folding electrode structures were prototypically fabricated and charge-discharge cycle tests of these cells were initiated. The prototypically fabricated cells are of dimensions 45mm x 42.5mm x 20mm, with four superposed pairs of 10-times folded electrodes. In a simple sealed state, the energy density per unit weight was 106Wh/kg, the energy density per unit volume 240Wh/l, the discharge capacity 3Ah, the mean voltage 3.6V, and the power capacity 10.8Wh. Some statistical dispersion of the capacity was observed during the initial period of cycling, but by adjusting the bearing pressure, the interelectrode contact was stabilized, and subsequently the charge-discharge cycle was stably continued.

(2) Research and Development Work on Long-Life Lithium Batteries (Composite Alloy Type)

(a) Elemental technological development of lithium secondary batteries

(i) Achievement of high proportions of lithium in anodes

a. Development of materials for composite anodes

Materials permitting lithium intercalating were applied to carbon-based powder mixed with lithium-lead alloys, and the volume capacity was found to vary greatly with the packing density, the discharge capacity of the carbon, and the compounding ratio. On the basis of these results, "new composite anodes" were devised through reconsideration of the carbon-metal compounding ratio and addition of minute quantities of metals capable of forming lithium alloys during the charging process. Lead, tin, aluminum, silver, and other candidates were considered as metals capable of forming lithium alloys.

b. Achievement of long life in composite anodes

Precipitation reactions of lithium onto particles of electrodeposited lead were observed with a quartz crystal microgravimeter (QCM). The results revealed that surface inactivation reactions were suppressed, as in the case of deposition onto platinum substrates forming alloys with lithium.

With the objective of raising the capacity density of composite anodes composed of lithium-lead alloys, increases in the proportions of lithium used in these alloys were considered. For proportions of lithium exceeding 35%, intense degradation occurred during charge-discharge cycles. This is attributed to large increases and decreases in the volume of the alloy during charging and discharging, resulting in rapid crystallization and destruction of electrode structure.

(ii) Achievement of high performance in cathodes

a. Development of metallic oxide materials for cathodes

The charging and discharging characteristics of vanadium, manganese, cobalt and nickel oxides were compared. The results revealed that vanadium oxide active materials were characterized by lower discharge potential as compared with others and were also somewhat disadvantageous as regards energy density. Manganese, cobalt, and nickel oxide active materials displayed nearly identical discharge potential, and cobalt and nickel oxide materials were superior to manganese oxide materials as regards discharge capacity. Moreover, the conditions for preparation of nickel oxide active materials for cathodes were studied, and a stable discharge capacity of approximately 170Ah/kg was obtained.

b. Analysis of intercalation reactions

A horizontal type goniometer permitting continuous measurement of changes in the crystal structure of active materials during the charging and discharging processes as well as an in situ X-ray diffraction apparatus employing a chargeable and dischargeable measuring cell of the adherent polyethylene film type were developed, and these were used to investigate structural changes in manganese oxide active materials ($LixMn_2O_4 \longrightarrow LiMn_2O_4 \longrightarrow LiMnO_2$) during charging and discharging. Concomitantly with the progress of discharging, a transition from cubical to tetragonal crystal structure was observed, and the lattice volume change between these structures was approximately 13%.

(b) Prototypical fabrication of cells

(i) Prototypical fabrication of hermetically sealed single cells

Hermetically sealed stainless steel cell containers were fabricated by deep drawing. The inner volume of these containers is 41ml and their specifications permit the packing of a 10Wh cell. Studies of manufacturing techniques such as the coating and molding of electrodes necessary for prototypical cell fabrication were also pursued. Also, a 10Wh class cell employing $LiCoO_2$ as active material in the cathode as well as a new tin-carbon based composite anode was prototypically fabricated. The cell is composed of 17 cathodes and 18 anodes, the electrode dimensions being 55mm x 70mm.

(3) Research and Development Work on Long-Life Lithium Battery (Carbon-Type)

(a) Achievement of high performance in battery materials

(i) Achievement of high performance in electrodes

a. Studies of various oxide materials

The influence upon charging and discharging characteristics of the Co/Ni ratio of lithium-containing cobalt-nickel composite oxides ($LiCo_1$-$xNixO_2$) was investigated. The results demonstrated that discharge capacities exceeding 140mAh/g were obtained when x = 0.3 - 0.9. Furthermore, the results of charging-discharging cycle tests revealed that the total discharge capacity during 30-cycle operation was comparatively large for x = 0.3 and x = 0.7. As regards $LiCo_{0.7}Ni_{0.3}O_2$ and $LiCo_{0.3}Ni_{0.7}O_2$, charging and discharging tests of small-scale cylindrical cells (equivalent to JIS T3) were conducted, and the results demonstrated that if natural graphite A is used as the anode, then discharge capacities of 440mAh ($LiCo_{0.3}Ni_{0.7}O_2$) and 430mAh ($LiCo_{0.7}Ni_{0.3}O_2$) can be obtained. Thus, the discharge capacity was slightly greater for $LiCo_{0.3}Ni_{0.7}O_2$, but the discharge voltage was slightly less for $LiCo_{0.7}Ni_{0.3}O_2$. Also, the respective capacity degradation rates when 200 cycles had been completed were 0.073%/cycle ($LiCo_{0.3}Ni_{0.7}O_2$) and 0.183%/cycle ($LiCo_{0.7}Ni_{0.3}O_2$). Thus, $LiCo_{0.3}Ni_{0.7}O_2$ was superior in this respect.

b. Studies of various carbon materials

For the purpose of optimizing the composition of materials compounded from low-crystallinity coke and high-crystallinity natural graphite, the relation between the natural graphite A to coke A ratio and the discharge characteristics was investigated in the range of ratios 1:3 to 4:1. The results revealed that the discharge capacity tended to increase concomitantly with increasing proportions of natural graphite A, whereas the potential rise during the final stage of discharging became more gradual concomitantly with increasing proportions of coke A.

With respect to both the mixed anode with a graphite A to coke A ratio of 4:1, which provided the highest discharge capacity of 330mAh/g, and that with a graphite A to coke A ratio of 3:2, which displayed a discharge capacity exceeding 300mAh/g and a gradual potential rise during the final stage of discharge, small cylindrical cells (equivalent to JIS T3) were fabricated, and the initial discharge characteristics of the cell were investigated. The discharge capacity obtained was 448mAh for the graphite A/coke A ratio of 4:1, and 419mAh for the ratio 3:2; thus, the discharge capacities were greater than that obtained using coke A alone (361mAh) and lower than that obtained using natural graphite A alone (504mAh), but in either case the potential changes during the final stage of discharge were more gradual as compared with that occurring when natural graphite A was used.

The respective proportionate capacity degradations when 200 cycles had been completed were 0.091%/cycle (natural graphite A/coke A = 3/2), 0.069%/cycle (natural graphite A/coke A = 4/1), 0.098%/cycle (natural graphite A alone) and 0.147%/cycle (coke A alone), thus, the natural graphite A to coke A ratio of 4:1 provided superior results in this respect.

c. Achievement of high performance in electrolytes

As regards mixed electrolytes composed of ethylene carbonate (EC) and diethyl carbonate (DEC) as solvents and with $LiPF_6$, possessing confirmed high conductivity, as the solute, the influence upon conductivity of the $LiPF_6$ concentration and the EC/DEC ratio was investigated. The results indicated that at 25°C the highest conductivity is associated with an EC/DEC ratio of 1:1 and with a $LiPF_6$ concentration of 1mol/l, which provided the high electrical conductivity of 8.46mS/cm.

(b) Optimization of cell composition

Small cylindrical cells (equivalent to JIS T3, with $LiCoO_2$ or $LiNO_2$ cathodes), fabricated using copper or aluminum cores (electrode substrates) and polyethylene separators were subjected to charge-discharge tests over 1,000 cycles, and the observed capacity degradation rate was 0.039 - 0.058%/cycle.

Furthermore, 7Wh class small cylindrical cells (diameter 22cm, height 65cm) employing $LiCoO_2$ in the cathodes were prototypically fabricated and tested. The results demonstrated that the energy densities obtained were 116Wh/kg or 264Wh/l when natural graphite A was used as the anode, as compared with 114Wh/kg or 261Wh/l when anodes of mixed natural graphite A and coke A (mixing ratio 4:1) were used.

(4) Development of Long-Life Lithium Battery (Polymer Type)

(a) Research on battery element technology

(i) Research on polymer solid electrolytes

Investigations of chemical and electrochemical stability were conducted in order to elucidate the mechanisms of degradation of polymer solid electrolytes. After thermally accelerated degradation tests of a randomly copolymerized polymer of ethylene oxide and propylene oxide (SPE(B)), changes in tensile strength were slight, and almost no thermal degradation was recognized. Furthermore, the same degradation tests were applied to a polymer (SPE(C)) with ethylene oxide as the monomer of the principal chain and with improved side chains, and again the results revealed almost no degradation.

Moreover, after accelerated degradation tests of both SPE(B) and SPE (C), the resulting changes in ion conductivity were measured, and likewise almost no thermally-induced changes were recognized.

Next, the potential window was measured in order to investigate anti-oxidation and reduction performance of electrolytes containing supporting salts. Since the stable potential window varied with changes in the supporting salt, anti-oxidation and reduction performance of the polymer alone was high, but due attention must be devoted to the stability of the supporting salt. Among the four varieties of supporting salts investigated up to that time, $LiN(CF_3SO_2)_2$ displayed a comparatively wide potential window.

(ii) Development of cathodes

With the objective of improving reversibility by employing composite active materials, a portion of the cobalt in $LiCoO_2$, a compound the synthesis of which was initiated during the previous fiscal year, was replaced by boron, thereby obtaining a new active material with the stoichiometric formula $LiCo_1$-xBxO_2, and the cycle characteristics of this material were assessed using organic electrolytes. The results confirmed that reversibility could indeed be improved by replacing a portion of the cobalt by boron, and in particular the most desirable cycle characteristics were obtained when the proportion replaced was 5mol%. On the other hand, however, increases in the proportion of cobalt so replaced were found to be accompanied by decreases in conductivity, and in particular replacement by 5mol% of boron caused a drop of several percent in the utilization rate at high discharge rates.

(iii) Development of anodes

Studies on selection of carbon materials were continued from the previous fiscal year. The studies revealed that artificial graphite displays high initial Coulomb efficiency, but its capacity density is comparatively low, while conversely natural graphite displays low initial Coulomb efficiency but comparatively high capacity density. Furthermore, the charge-discharge cycle characteristics of these materials were evaluated, and natural graphite displayed excellent reversibility.

(b) Research on large-scale electrodes

With respect to the technology for manufacture of the anode and cathode pastes which play an important role in the fabrication of thin electrodes using film-forming apparatus, first of all, studies were directed toward optimizing the composition of joining materials. In the cathodes, in addition to the active material and the solid electrolyte, conductive carbon was added as an electrical conducting agent to supplement the low conductivity of the active material. Differences in the physical properties of the conductive carbon were associated with large variations in the electrical properties of the electrodes and changes in the physical properties of the paste. Moreover, the proportion used also influenced the electrode performance characteristics and physical properties of the paste.

In research conducted up to the present time, more stable electrode performance has been obtained using chain-like conductive carbon as compared with granular conductive carbon.

2.2 Research and Development Work on High Energy Density Lithium Batteries

(1) Research and Development Work on High Energy Density Lithium Batteries (Cobalt-Type)

(a) Research on element technologies

(i) Development of high-performance cathodes

a. Influence of substituent elements upon charge-discharge characteristics

With the objective of preventing collapse of crystal structure, a portion of the cobalt or the lithium in $LiCoO_2$ was replaced by a third element, and the charge-discharge characteristics of the resulting compound were evaluated. Oxides formed by replacing a portion of the cobalt by magnesium or a portion of the lithium by sodium in proportions not exceeding 5% displayed almost the same discharge capacity.

b. Influence of substituent elements upon thermal stability

Oxides such that lithium has been deintercalated by charging have been found to develop unstable crystal structure and display decreased thermal stability (i. e., a decrease in the temperature at which heat emission commences under thermal treatment). Therefore, a portion of the cobalt was replaced by a third element, and the resulting effects upon the thermal stability of the compound were assessed. The oxides formed by replacing a portion of the cobalt by gallium, manganese, magnesium, iron, or aluminum all displayed a higher temperature of commencement of heat emission as compared with $LiCoO_2$, and their crystal structure tended to become stabilized.

(ii) Development of high-performance anodes

a. Influence of removal of functional groups upon charge-discharge characteristics

Functional groups such as =O or -OH are presumed to exist on carbon surfaces. These groups are reduced during the initial charging and this is inferred to cause a decrease in Coulomb efficiency. Hence, vacuum heat treatment and hydrogen heat treatment were applied for the purpose of removing these functional groups, the effects upon initial Coulomb efficiency were assessed, and the results revealed that the respective initial Coulomb efficiencies were raised by approximately 2%.

b. Influence of surface modification

The surfaces of carbon anodes were modified by coating with films of silane compounds possessing lithium ion conductivity or with polymeric compounds, thereby attempting to inhibit film formation reactions during initial charging and thus raising Coulomb efficiency. The results demonstrated that carbon materials modified with silane compounds display an approximately 3% rise in initial Coulomb efficiency, but their initial discharge capacity is diminished. Moreover, carbon anodes coated with the polymer PAN (polyacrylonitrile) displayed a rise of approximately 3% in initial Coulomb efficiency, but their initial discharge capacity tended to decrease.

(iii) Development of stable electrolytes

a. Analysis of decomposition reactions in electrolytes during initial charging

With respect to open-system cells employing $LiCoO_2$ for the cathode and graphite-type carbon materials for the anode, the constituents of the gases generated by decomposition of the electrolyte during initial charging were analyzed. The electrolytes employed consisted of four varieties with one component, i. e., EC (ethylene carbonate), DMC (dimethyl carbonate), EMC (ethylmethyl carbonate), and DEC (diethyl carbonate), three varieties with two components, i. e., mixtures of EC with DMC, EMC, and DEC, respectively, and one variety with three components, i. e., a mixture of EC, DMC, and DEC, while $LiPF_6$ was used as the electrolyte solute. The results suggested that reduction of EC was the principal reaction occurring in the 2-component and 3-component mixed electrolytes during the initial charge.

Moreover, the results of analysis using the 3-component electrolytes demonstrated that ester exchange reactions occur during initial charging.

b. Analysis of decomposition reactions in electrolytes during overcharging

Using the same combination of anodes and cathodes, the constituents of the gas generated during overcharging by decomposition of the above-mentioned two-component and three-component electrolytes were analyzed. The results suggested that the decomposition reactions principally consisted in the oxidation of DMC, EMC, or DEC.

(b) Development of cells

(i) Research on basic cell configuration

a. Prototypical fabrication of 10Ah single cells

10Ah prismatic cells were fabricated and subjected to evaluation of initial charge-discharge characteristics. The results demonstrated that the energy density of the cells was 82Wh/kg or 253Wh/l, and that an energy density of the order of 115Wh/kg would be attainable by designing a light weight container.

b. Evaluation safety and reliability of 3Ah cells

i. Nail puncture tests

Nail puncture tests of cells without safety vents revealed that the sealing plate of the cell base opened and the elements were ejected immediately after puncture. When cells with safety vents (diameter 3mm) were used, the electrolytes spurted out in the form of white smoke, but no rupture was detected. Moreover, when the number of safety vents was increased, the swelling as well as the maximum temperature attained by the cell were decreased, and the sealing area of the vents was found to exert a major influence upon the safety of the cells.

ii. External short-circuit tests

External short-circuit tests were conducted using two varieties of cells having different separators, i. e., uni-axial oriented microporous polyethylene films and non-oriented microporous polyethylene films. However, the different separators were not associated with differences in short-circuit behavior; a 70A current flowed immediately after shorting, but several seconds later this decayed to the level of 20-30A. After approximately 5 minutes, when the cell temperature reached 120°C, the short-circuit current decreased abruptly, and subsequently the cell temperature also gradually diminished.

(2) Research and Development Work on High-Energy Density Lithium Batteries (Metallic Compound Type)

(a) Research on battery materials

(i) Research on anode materials

a. Research on essential techniques for dendrite suppression

i. Analysis of effects of surface films

The superfine structure of the lithium surface and deposition morphology changes in various types of electrolytes were analyzed by atomic force microscope (AFM), scanning auger microscope (SAM), and X-ray photoelectron spectroscopy (XPS). The lithium surface was composed of 100-200 μm particles surrounded by grain boundaries of 1-2 μm in thickness, but AFM measurements further revealed the presence of many convex lines of width 100-300nm on these particles, and the presence of level portions several μm in size surrounded by such lines. Furthermore, the structure of the level portions were found to consist of overlapping ellipsodial particles 50-100nm in size. Next, when the changes in surface morphology resulting from immersion in electrolytes were measured, indistinct (buried) line portions were observed to change into distinctly convex portions.

Next, the chemical composition of the lithium surfaces and state of deposition in various types of electrolyte were investigated, and the data so obtained were studied in conjunction with the results of macroscopic observations. In lithium perchlorate ($LiClO_4$) - propylene carbonate (PC) electrolytes, characterized by conspicuous needle-like growth, the development of particles 200-1,000nm in size was observed in the line portions as a change occurring during the initial stage of deposition, thus, the initial changes were manifested by granule formation. On the other hand, changes in some of the line portions were observed in $LiCO_4$-PC + 1,2-dimethoxyethane (DME) electrolytes, characterized by preponderantly lumplike growth. Moreover, partial changes (2 x 10 µm) were also observed in the line portions in lithium hexafluoroarsenate ($LiAsF_6$) - PC electrolytes. Thus, in such electrolytes, characterized by a preponderance of lumplike growth, the initial changes were found to be changes of line and surface form, and thus the results revealed that the initial state of deposition varies according to the type of electrolytes.

ii. Development of materials for compound anode

Studies were initiated concerning metal-carbon compound anode employing fine metallic powders forming alloys with lithium. The highest mean charge-discharge efficiency of 96% was obtained when gallium was used as an additive element in the carbon materials, and accordingly this metal was considered as optimal for compound metal-carbon anodes.

Furthermore, binder materials were evaluated on the basis of properties such as coating performance, filling density, electrode plate adhension strength, activated material utilization ratio, etc., and the fluoropolymer polyvinylidene fluoride (PVDF) was found to be the most suitable binder material among those investigated.

(3) Research and Development Work on High Energy Density Lithium Batteries (Metallic Lithium Type)

(a) Nanometer-scale structural control of active materials for cathodes

(i) Determination of relevant physical parameters of active materials for cathodes

In order to determine the relevant physical parameters requiring optimization in ideal active materials for cathodes, work was commenced on the gas phase synthesis of lithium-manganese oxides, using a material synthesizing apparatus permitting morphological control on a nanometer scale. Lithium oxide and manganese oxide were used as vapor deposition sources, and films were formed by vapor deposition onto a stainless steel substrate in an atmosphere of oxygen radicals. This was followed by heat treatment, thereby creating $LixMn_2O_4$ with a spinel structure. Small-scale cells were assembled using the aforesaid $LixMn_2O_4$ material for the cathodes, and the electrode performance of these cells was evaluated. The results verified that charging and discharging were possible even in the absence of other conductive materials or binder.

(ii) Studies of material synthesis conditions and electrode performance

With the objective of raising the charge-discharge cycle of $LixMn_2O_4$ cathodes, research was commenced on the experimental clarification of the effects of addition of various chemical elements in order to control crystal structural changes concomitant with doping or undoping of lithium ions. $LixMn_2O_4$ with added copper was subjected to charging-discharging tests, and X-ray diffraction analysis was also applied after discharging. The findings revealed that the peak intensity associated with tetragonal crystals with lower as compared to the material without added copper, indicating that changes in crystal structure had been effectively reduced.

(b) Suppression of charge-discharge cycle degradation in anodes

(i) Studies on lithium surface composition and electrode performance

Phosphorus ion injection was employed for surface modification of metallic lithium anodes, and the dendrite suppressing effects of this treatment were studied.

Samples injected with phosphorus ions were treated once by electrodeposition of lithium, and the resulting surfaces were observed, but no regions of dendrite precipitation were seen.

(4) Research and Development Work on High Energy Density Lithium Batteries (Carbon-Type)

(a) Research and development work on cathode materials

(i) Analysis of $LiNiO_2$ microstructure

a. Research on preparation of $LiNiO_2$ films

In order to investigate the factors determining the capacity and cycle life of cathode materials, studies were conducted on the theme of elucidating the microstructure of thin film crystals. Using an apparatus for the manufacture of crystalline films for cathode (sputtering apparatus), trial films were prepared by various film-forming processes, and a thin film of $LiNiO_2$ with precise stoichiometric composition and possessing excellent crystallinity was successfully formed. This film contained almost no compounds other than $LiNiO_2$, and also contained no crystal particles with unordered crystal orientations.

b. Structural analysis of thin-film crystals

Thin films formed on magnesium oxide substrates were subjected to X-ray diffraction analysis, which revealed that the film was composed of $LiNiO_2$ crystallites having a rhombohedral crystal structure of α-$NaFeO_2$, and that the C-axis of the $LiNiO_2$ crystals was perpendicular to the substrate surface. Moreover, diffraction peaks corresponding to higher index lattice planes appeared, indicating that the degree of C-axis orientation was extremely high. As regards the lattice parameter of the $LiNiO_2$ crystals composing these films, the lattice parameter was found to be 1.42nm, comparable with the powder X-ray data recorded in the literature (i. e., C = 1.419nm).

c. Research on synthesis of bulk-form materials

The addition of a fourth element to $LiNiO_2$ was considered with a view to improving charge-discharge cycle characteristics. In order to suppress changes in crystal structure resulting from separation of lithium during charging, materials with portions of the nickel replaced by a classical trivalent element (boron or aluminum) were synthesized and assessed. The results of evaluation of charge-discharge cycle characteristics showed that materials with 3 mol% of added boron or aluminum displayed cycle life 40 to 70 cycles greater than that of $LiNiO_2$ without additives. In order to investigate the reasons for the improvement of performance characteristics, the changes in crystal structure occurring during the charging process of the first cycle were investigated, and the results indicated that the lattice parameter C of the crystals had increased and the lattice parameter a had decreased concomitantly with charging, a tendency similar to that observed in the material without additives; however, the transition from a rhombohedral phase to the monoclinic phase displayed by the material without additives did not appear. Thus, the addition of boron or aluminum was found to effectively suppress changes in crystal structure concomitant with charging or discharging, and thereby contribute to improvement of cycle characteristics.

(b) Research on prototypical fabrication and evaluation of cells

(i) Research on cell specifications

a. Studies on specifications and composition of prismatic cells

In order to study the process of prototypical cell fabrication as well as the specifications of 10Wh class cells, a 3Wh class cylindrical cell (diameter 18mm, height 50mm) was prototypically fabricated and evaluated. An electrode formed by coating $LiNiO_2$ with 3 mol% of added boron onto aluminum foil was used for the positive pole, and an electrode formed by coating carbon onto copper foil for the negative pole. An initial discharge capacity of 1Ah was obtained, and the energy density was 275Wh/l or 118Wh/kg.

2.3 Research and Development Work on Battery Materials

(1) Research and Development Work on Battery Materials (Carbon Materials)

(a) Research on elucidation of carbon-lithium reaction mechanisms

(i) Quantification of lithium

Selecting acenaphthalene (abbreviated below as AN) as a graphitizable carbon material and phenolphthalein (abbreviated below as PhP) as a nongraphitizable carbon material, model carbon was formed by heat treatment of these materials at temperatures of 800°C, 1,000°C, and 2,780°C, respectively. In order to elucidate the mechanisms of carbon-lithium reactions, quantitative analysis of the lithium content of products from in the charging and discharging of model carbon anodes was performed by inductively coupled plasma emission spectrometry (abbreviated below as ICP).

The AN and PhP samples treated at 800°C and at 1,000°C displayed a nearly linear relationship between actual charge-discharge capacity and the lithium content quantified by ICP. The results suggested that the flat portion conspicuously observed in the vicinity of 0.8V in the discharge curves of the AN samples treated at 800°C corresponded to the de-intercalation of lithium from the carbon material. On the other hand, in the AN samples treated at 2,780°C, the results obtained indicated that irreversible reactions (e. g., film formation reactions) concomitant with increased lithium content occur to a considerable extent during the charging process. Similarly, in the PhP samples treated at 2,780°C, the results obtained indicated that irreversible reactions (e.g., decomposition of electrolytes) concomitant with increased lithium content occur to a considerable extent during the charging process.

(ii) Small-angle X-ray scattering measurements of carbon materials for anodes

Carbon samples obtained from AN and PhP were subjected to small-angle X-ray scattering measurements, the distance distribution functions were calculated by Fourier transformation from the scattering intensity data so obtained, and the cavities existing within the carbon were analyzed.

a. PhP-based materials

The results of calculation of the distance distribution functions of PhP samples sintered at various different temperatures revealed that two types of voids, of respective dimensions 0.7-2.4 nm and roughly 35 nm, were present in all cases. Since the cavities roughly 35 nm in size were observed not only in PhP-derived but also in AN-derived samples, their formation is attributed to interparticle grains created by processes such as secondary aggregation, etc. On the other hand, the cavities of size 0.7-2.4 nm were markedly larger in graphitized samples, were therefore considered as particularly susceptible to the influence of structural changes concomitant with heat treatment, and were presumed to be intercrystallite.

b. AN-based materials

The results of calculation of the distance distribution functions of graphitizable carbon samples obtained by sintering AN at various different temperatures revealed that, as in the case of PhP, two types of cavities were present, i.e., relatively large cavities roughly 35 nm in size and extremely small cavities roughly 0.8-1.1 nm in size. The former type were presumed to be cavities present in the intercrystallite. The results of small-angle X-ray scattering analysis of charging products demonstrated that charging was accompanied by progressive intercalation reactions and diminishing cavity size owing to expansion of crystallite caused by increased interlayer spacing.

(iii) X-ray diffraction analysis

Carbon materials obtained by heat treatment of ANC at the respective temperatures 800°C, 1,000°C, and 2,780°C were used as samples for observation of cycle degradation by X-ray diffraction analysis.

Upon comparison with the samples analyzed prior to charging, no changes were observed in the half-value width of the (002) peak of any of the carbon sample materials after 1, 4, 7, or 10 cycles, thereby demonstrating that these carbon materials are free from degradation for at least up to 10 cycles. Moreover, shifts in the main peak were obtained in all the samples after full charging, thereby verifying that lithium is intercalated between the carbon layers.

(b) Development of high-performance carbon materials for anodes

(i) Synthesis of crosslinking agents

Studies were conducted on methods for the synthesis of dimethyl paraxylene glycol (abbreviated below as DMPXG) as a crosslinking agent for the control of carbon structure. The silver nitrate method and the sodium hydroxide method, involving one-stage reactions, as well as the sodium acetate method, involving a two-stage reaction, were considered as methods for the production of DMPXG at a high yield from 1,4-dimethyl-2,5-dichloromethylbenzene. Comparison of yields obtained in the synthesis of DMPXG at the laboratory level revealed that the yields were 48.7% for the silver nitrate method, 26.4% for the sodium hydroxide method, and 40% for the sodium acetate method.

(ii) Synthesis of precursors

Studies were conducted concerning the synthesis of carbon precursors by reactions between the crosslinking agent DMPXG synthesized as described above and the aromatic compound pyrene as the main ingredient.

(iii) Optimization of carbon manufacturing process

The precursors obtained as described above were coarsely pulverized, infusibilized, and then subjected to heat treatment at specified temperatures. The structures of all these carbon materials were found to exhibit optically anisotropic organization. In the carbon materials obtained by heat treatment of the precursors at 800°C, the amount of cavities as calculated from X-ray diffraction and density measurements tended to increase concomitantly with increasing proportion of crosslinking agent.

The discharge capacity of the carbon materials obtained by heat treatment at 800°C tended to increase as the molar ratio of DMPXG increased from 1/1.05 to 1/3.0. This was attributed to an increase in cavity content concomitant with increasing quantities of crosslinking agent in the synthesis of the precursor, and the utilization of these cavities in the charge or discharge of lithium species.

(2) Research and Development Work on Battery Materials (Electrolytes)

(a) Research and development work on carbonate-based electrolytes

(i) Evaluation of primary characteristics of electrolytic solutions

a. Improvement of solvent characteristics

With respect to seven varieties selected from among various electrolytes, composed of $LiPF_6$ — ethylene carbonate (EC) combinations plus a subsidiary solvent on the basis of evaluations of primary characteristics such as potential windows, conductivity, and boiling point, as well as three electrolytes composed of $LiPF_6$-EC plus a subsidiary solvent (containing the subsidiary solvents propylene carbonate (PC), dimethyl carbonate (DMC), or γ-butyl lactone (GBL)), improvement of conductivity characteristics was sought through studies of solute concentrations and proportionate solvent composition, and the range of optimal compositions was determined.

Moreover, similar studies were also applied to electrolytes composed of $LiPF_6$-PC mixtures plus a subsidiary solvent, using PC as the principal solvent.

b. Quests for new electrolytes

Electrolytes composed of $LiPF_6$-EC combinations plus a new subsidiary solvent (mixing ratio 1:1), the latter solvent being selected from among two varieties of new linear carbonate compounds (new solvent No. 4 and new solvent No. 5) as well as three varieties of carboxylic acid ester compounds (new solvent No. 6, new solvent No. 7, and new solvent No. 8), were subjected to evaluation studies concerning thermal characteristics of conductivity.

Furthermore, the electrolyte stability tests described below were performed, and relations with the molecular structure of the solvents were assessed. The results obtained demonstrated that two varieties of carboxylic acid ester compounds (new solvent No. 6 and new solvent No. 8) were superior as regards evaluation of primary electrolyte fluid characteristics and electrolyte stability characteristics.

(b) Stability tests of electrolytes

(i) Accelerated degradation tests of electrolytes

The charging-discharging efficiency of lithium was measured by electrodeposition and dissolution of lithium on nickel working electrodes, and the stability of electrolytes with respect to lithium electrodeposition was assessed. The results revealed that subsidiary solvents of the carbonate and carboxylic acid ester types displayed comparatively high efficiency (70-80%), while nitrile type solvents displayed low efficiency (40-60%) and comparatively poor electrochemical stability.

(ii) Analysis of thermal behavior of electrolytes

a. Thermal stability tests of electrolytes by head space-attached gas chromatography

Thermal stability tests (80°C sustained for 100 hours) of electrolytes in the presence of metallic lithium were performed, and in the analysis of the gaseous phase by-products formed concomitantly with degradation, the components of the generated gases were analyzed. The results revealed that extremely slight generation of gaseous components occurred when the subsidiary solvent was isobutyronitrile, 2-methoxypropionitrile, or PC.

b. Thermal stability tests of electrolytes using calorimeters

Thermal stability tests of electrolytes composed of $LiPF_6$-EC mixtures plus subsidiary solvents were performed using calorimeters. The results demonstrated that in view of the observed relations between thermal stability and the molecular structure of the carbonates and carboxylic acid esters used as subsidiary solvents, the stability of cyclic and methyl esters as chemical structures of subsidiary solvents was superior to that of the other types considered. However, electrolytes with $LiPF_6$ as solute were found to undergo abrupt exothermic reactions due to the decomposition of $LiPF_6$ in the vicinity of 250°C.

Regarding the thermal behavior of electrolytes in the presence of metallic lithium, the heat of reaction (enthalpy) was 2.5 to 6 times greater as compared with electrolytes alone.

(c) Analysis of basic phenomena involved in solid-liquid interface reactions

Analysis of basic phenomena included application of spectroscopic methods such as Fourier transform infrared spectrometry (FTIR) and laser Raman spectrometry to the study of the chemical species of the films formed on the surfaces of lithium anodes. The results of these studies verified that the films formed when metallic lithium is immersed in ethyl acetate solvents consists of organic compounds.

(d) Proportionate of high-purity electrolytes

(i) Improvement of performance characteristics through high purity

The production of high-purity solvents by precise fractionation was considered, and high purity refining techniques were established, permitting both the organic impurities and the water content in solvents for electrolytes to be reduced to a level below 10ppm.

(e) Design and synthesis of new materials

Using molecular orbital calculations (MOPAC-PM3), the molecular orbital energy levels (HOMO and LUMO energy levels) involved in oxidation and reduction of existing solvent molecules were calculated, and the results indicated that carbonate and some carboxylic acid ester type solvents possessed favorable characteristics in this respect.

2.4 Research on Total Systems

(1) Studies on Measures for Introduction of Dispersed-Type Battery Energy Storage Systems

(a) Sectors, efficacy, and methods of introduction

(i) Provisional calculation of efficacy assuming quantities and patterns of introduction

Studies were conducted concerning the optimal capacity and optimal operating procedures to be adopted when load leveling equipment (or load conditioner (LC)) for home use is installed. The results revealed that for a nearly ordinary home with a mean electric power consumption of roughly 500kWh per month, LC systems with an AC power of approximately 2kW and capacity of about 14kWh would be optimal.

Assuming the installation of a LC with the aforesaid optimal capacity, the limiting cost of the LC was calculated, and found to be ¥30,000 to ¥40,000 per kilowatt hour for the battery component of the system.

As regards the load leveling efficacy which might be expected from dispersed-type battery energy storage systems, the situation during the representative future year 2030 was envisaged, and the load leveling efficacy obtainable by introduction of LCs and electric vehicles was considered. According to the results of this analysis, under the assumption that LCs would be introduced into roughly 10% of ordinary homes and that electric vehicles would comprise roughly 10% of all operating automobiles, the annual load factor would be raised from 58.6% before introduction to 62.1% after, an increase of 3.5%. Moreover, the analysis indicated that the introduction of electric vehicles and LCs, in addition to reducing the required energy storage facilities capacity on the power supply side, would also contribute to decreasing the unit cost of power generation, permitting a reduction of roughly 0.1 yen per kilowatt hour.

(ii) Survey on legal regulations involved in introduction of dispersed-type battery energy storage systems

During the initial period of introduction, load leveling equipment (or load conditioner (LC)) for home use would, depending upon the operating methods employed, be subject to the regulations stipulated by the presently existing Electricity Enterprises Law or the Law for Control of Electrical Appliances. Moreover, depending upon the battery capacity (i.e., if the product of the rated capacity and the number of battery casings exceeded 4,800Ah-cells), the regulations concerning electrical storage equipment stipulated by the Fire Services Act could also be applicable, and the materials constituting the lithium batteries might be subject to the regulations concerning specified numbers of hazardous articles.

As regards electric vehicles, conformity with the same legal regulations as those applicable to conventional internal combustion automobiles will be required. That is, the security standards, etc., stipulated by the Road Transport Vehicles Act must be satisfied. The combined loading of metallic lithium and organic solvents is not prohibited, but since quantitative restrictions are applicable, improvement of battery reliability constitutes an essential topic for further study.

(iii) Surveys on battery material resources

Among the projects concerned with technical development of dispersed-type battery energy storage systems, the material composition and quantities of lithium secondary batteries has not been decided, but surveys were conducted with central emphasis upon the materials constituting the principal components under consideration at the present time as well as the resources which could constitute a restrictive factor. Assuming introduction of the quantity of dispersed-type battery energy storage systems attaining the scale necessary to contribute substantially toward power load-leveling (approximately 10^7kWh/year), then if cobalt alone were used, the available resources would be limited, moreover, production of lithium may also be regarded as restrictively low. In the case of cobalt, recycling techniques would be necessary to preserve valuable metal resources, and in the case of lithium, expanded production would be necessary as a concomitant of increased demand.

(b) Studies on system technologies

(i) Performance of electric vehicles and performance requirements for lithium batteries

a. Studies on methods of testing batteries for electric vehicles

The performance of electric vehicles is determined by the performance of the secondary batteries used in these vehicles. In general, the performance demanded in secondary batteries is that required in order to satisfy the electric vehicle performance demanded by the consumer. The important characteristics determining the performance of batteries for use in electric vehicles are as follows.

i. Capacity (energy density)
ii. Power density
iii. Lifetime.

These characteristics are directly related to the following performance characteristics of electric vehicles.

i. Range per charge
ii. Acceleration performance
iii. Cumulative distance travelled

Therefore, evaluation tests designed with consideration for these three characteristics are desirable. Surveys on the methods of testing the lifetime of batteries for use in electric vehicles proposed up to the present time covered lifetime testing methods employing constant current discharges. However, in addition to constant current discharges, an L-shaped discharge pattern, taking into consideration the accelerated running of electric vehicles, was adopted in the large-scale project implemented from 1971. In recent years, the trend has been toward adoption of more complex patterns designed with a view to simulation of actual running conditions, including regenerative braking.

b. Areas for widespread introduction of electric vehicles

At the present time, the performance of electric vehicles is gradually improving, but nevertheless as compared with gasoline vehicles, etc., one must acknowledge that the range per charge is still low. The potential areas for introduction of electric vehicles in Japan were considered from the viewpoint of range per charge. One possible area would be utilization for traveling to the nearest railway station. At present, this is accomplished by walking or by employing conveyances such as bicycles, motorcycles, private automobiles, buses, and taxis; electric vehicles could replace these conveyances to a certain extent. The average trip for private automobiles used for such purposes is roughly 10km, and an electric vehicle equipped with a 10kWh battery, assuming an energy consumption rate of 4km/kWh, would have a range per charge of at least 40km, fully adequate for this purpose. In such a case, if a lithium secondary battery were used, and if the energy density were assumed to be 120Wh/kg or 280Wh/l, the weight of the battery would be 85kg and the volume of the battery would be 35 l, and thus an extremely compact electric vehicle could be constructed on this basis.

(ii) Studies on safety

Studies were conducted concerning the physical and chemical properties of lithium battery materials.

The oxides of cobalt, nickel, manganese, etc., used as active materials for the cathode are subject to the regulations concerning permissible concentrations of metals in working environments stipulated by the Labor Safety and Hygiene Act and other relevant statutes, and therefore cannot be used in an arbitrary and unrestricted manner during the manufacturing processes.

The metallic lithium used as an active material for the anode is intensely reactive with water, and is therefore considered a potentially dangerous material.

Moreover, the salts used as electrolytes, if their decomposition products are also taken into consideration, include many compounds known to be carcinogenic, neurotoxic, or otherwise deleterious to health. Furthermore, in view of the fact that lithium batteries are assumed to be fabricated with a hermetically sealed structure, although no problems would arise under the conditions of ordinary use, due attention must be given to safety problems in discarding, disposing of, or recycling lithium batteries.

(2) Research on Battery Application Technology

With a view to the application of lithium batteries to LCs, electric vehicles, etc., the topics requiring further study and problem points involved were identified. Furthermore, tests were conducted for the purpose of estimating single cell cycle life, one of the cell development target parameters most difficult to assess and validate. In order to apply these studies to the development of lithium secondary batteries, various tests and studies were devoted to the following topics.

(a) Operating tests of small capacity cells incorporating into assembled batteries and studies on performance improvement measures

(i) Tests concerning effects of operating methods

The results of studies conducted up to the present time on the relation between rapid charging conditions and discharge capacity indicated that application of the constant-current constant-voltage method, with the establishment of an appropriate constant voltage time, permitted the attainment of the rated capacity (1Ah). During the fiscal year under review, several conditions were selected for the purpose of ascertaining the cycle characteristics under these conditions, cycle tests were performed, and the results confirmed that this charging method manifests no adverse effects upon cycle life.

(ii) Tests during overcharging and overdischarging conditions and studies on measures for performance improvement

Up to the present time, tests of overcharging and overdischarging under constraints on capacity and voltage have revealed the following facts concerning ultimate failure modes for overdischarging.

• Forced discharge to voltages below 0V results in low impedance (1-3Ω), although this varies according to the magnitude of the current.

• Imposition of a voltage constraint of 0V results in high impedance, that is, in an open circuit mode, stable voltage cannot be obtained, and passage of current may become impossible.

(iii) Series connection tests

Adopting the multistage series-connected simulated float connection method, and using four series, cycle tests were continued for the main purpose of assessing the influence of heterogeneity in the charging state, and at the present time 400-700 cycles have been performed.

(b) Tests to estimate single cell cycle life

In addition to the basic conditions (i. e., the four conditions conforming with the first interim evaluation testing method proposal plus the three conditions specified in the maximum scope of operating voltages, or a total of seven conditions), three conditions for each of the five acceleration factors (i. e., (i) discharge depth, (ii) charging rate, (iii) discharging rate, (iv) charge-discharge rate and (v) temperature), or a total of fifteen conditions, were also imposed, and cycle tests were commenced with n = 3 cells in order to estimate cell cycle life.

III

Technical Development of Ceramic Gas Turbines

1. Objectives and Work Program

Ceramic gas turbines are to be developed with the objective of improving thermal efficiency, decreasing pollutant emission, and promoting multi-fuel capability in the operation of small-scale gas turbines employed in cogeneration systems and mobile power generation.

The following aspects of technical development will be pursued in order to achieve these objectives:

(a) Research and development of heat resistant ceramic components with superior high-temperature strength, toughness, and corrosion resistance.

(b) Research and development related to improvement and assessment of the performance of various components of ceramic gas turbines (CGTs), including turbines, combustors, heat exchangers, and others.

(c) Design, fabrication, and testing of 300kW-class ceramic gas turbines integrating the results obtained in the above-mentioned research and development work on ceramic components and component technology (two types of CGTs for cogeneration and one type of CGT for mobile power generation).

In order to achieve the objectives, the current plans envisage that this research will be conducted in the following three phases:

Phase 1: Basic gas turbine (same structure as pilot CGT; i.e., metal, with turbine inlet temperature (TIT) of 900°C)

Phase 2: Basic CGT (same structure as pilot CGT, with TIT of 1,200°C)

Phase 3: Pilot CGT (with TIT of 1,350°C)

2. Summary of Results for Fiscal 1994

Development Targets

Thermal Efficiency	Turbine Inlet Temperature	Axial Output	Exhaust Emissions
42% or more	1,350°C	300 kW class	Below the standard level specified by law

Concerning the results achieved up to the end of fiscal 1993, interim evaluation was implemented during the period from the spring through the summer of 1994, and the following assessments were indicated.

• Research and development work on ceramic components:

The targets can be attained, international high standards can be achieved, and the development of parts for the pilot CGT will be pursued according to plan.

• Research and development work on component technology:

The targets have nearly been attained, but validation of engine performance is necessary.

• Research and development work on engine systems:

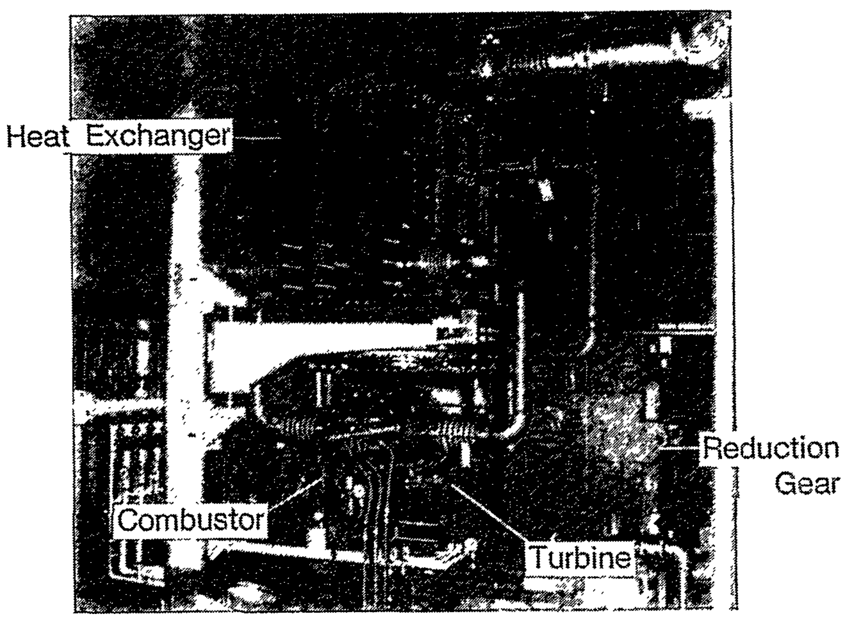
Three types of engines were successfully operated for brief periods at a TIT (turbine inlet temperature) of 1,200°C. However, the topics requiring further study in connection with engine systems were not fully identified, and therefore continued operating studies with a view to accumulating further data will be necessary during fiscal 1994.

During fiscal 1994, on the basis of these evaluation results, intense efforts were devoted to operating studies on a basic type of CGT (TIT 1,200°C), moreover, research and development work was conducted in connection with fabrication techniques for parts of the pilot CGT, improvement of component characteristics, etc.

The results achieved in research and development work on two types of CGT for cogeneration and one type for mobile power generation as well as supporting research such as studies of adaptability to social needs will be briefly described below.

2.1 Regenerative Single-Shaft Ceramic Gas Turbine for Cogeneration (CGT 301)

(1) Research and Development on Heat-



Outside View of Basic CGT (CGT301)

Resistant Ceramic Parts

(a) Parts fabrication techniques

In the area of ceramic parts for the pilot CGT (TIT 1,350°C), studies were conducted concerning molding, sintering, and machining of new materials with improved characteristics such as high-temperature strength and oxidation resistance.

(i) Turbine blades

Using new materials, and with a view to improving the reliability and dimensional accuracy of pilot CGT parts, studies were conducted concerning uniform molding, sintering techniques, and machining techniques. Through these studies, the correlations between dimensional accuracy or the strength of sintered bodies and molding or machining conditions were ascertained, prospects for feasibility of parts manufacture were obtained, moreover, cut-out-test pieces were subjected to strength evaluation, and the superiority of the new materials was verified.

(ii) Turbine nozzles

Adapting to design changes introduced to avoid stress concentrations during the process of attaching the inner and outer circumferential parts of turbine nozzles, machining techniques in particular were improved, and manufacturing methods satisfying the prescribed precision requirements were established.

(iii) Combustors

Prospects were obtained for the feasibility of integral combustor liner manufacturing through appropriate procedures for machining after CIP molding. Moreover, a technique for machining the inner cylindrical surfaces of the fuel injection valves (inner diameter 20mm, length 60mm) was developed. Furthermore, as regards combustor materials, evaluation of erosion characteristics using an arc heating device was initiated in order to ascertain the nature of degradation phenomena in high-temperature and high-velocity air flow.

(iv) Heat exchanger

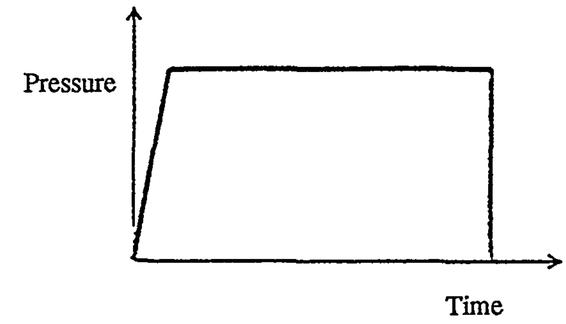
For the purpose of improving dimensional accuracy and decreasing the failure rate in heat exchanger tubes, attention was focussed upon the adjustment conditions of raw materials for extrusion molding, L9 orthogonal array experiments were performed, and the factors governing transverse cracks and cross-sectional shape characteristics in heat exchanger tubes were clarified.

(v) Gas conduit parts

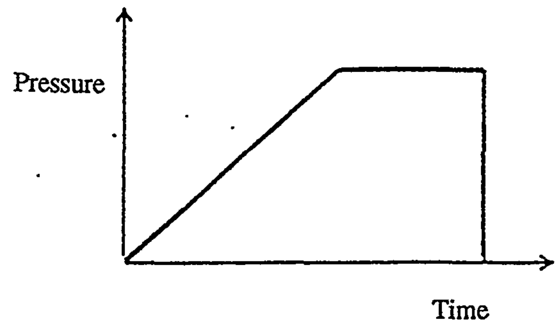
In order to establish appropriate molding conditions for thick annular nose cones, molding patterns obtained with high-pressure slurry injection apparatus were investigated using thick disciform models (ϕ90mm x 25mmt). According to the results so obtained, decreased-pressure molding patterns (gradual pressure reduction) displayed the lowest incidence of cracks, and these studies are to continue and optimal conditions are to be established.

(b) Parts assembly techniques

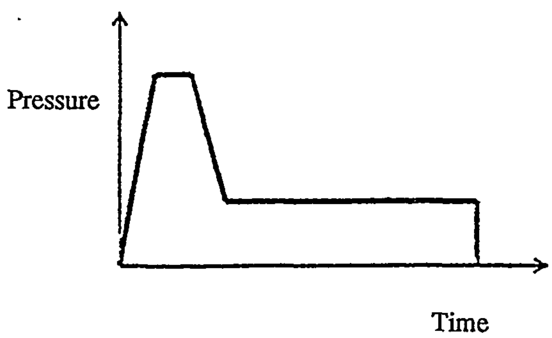
Concerning the joins between the heat exchange tubes and perforated plates of heat exchangers, with the objective of shortening the manufacturing process, tests were performed on the joining of the attachment sites of the heat exchange tubes in an unmachined state (as-fired surfaces), and such a procedure was found to be feasible. Hereafter, sealing tests and strength tests are to be conducted, and applicability to ceramic heat exchanger tube blocks is to be assessed.



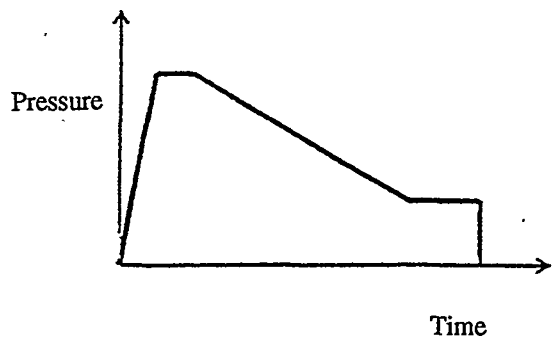
(1) Constant-pressure molding pattern



(2) Increased-pressure molding pattern



(3) Decreased-pressure molding pattern (1)
(Rapid pressure decrease)



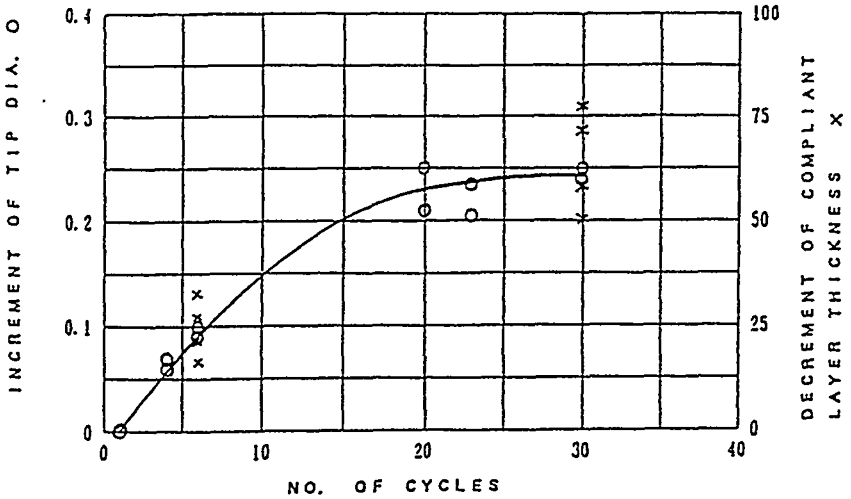
(4) Decreased-pressure molding pattern (2)
(Gradual pressure decrease)

Basic Slip Cast Molding Patterns

(2) Research and Development on Component Technology

(a) Turbines

In connection with the strength and reliability evaluation of hybrid rotors (ceramic blades and metallic disks), attention was focussed upon the action and durability of the buffer material inserted in order to relax the stress nonuniformities between the dovetail portions of the blades and the embedded portions of the metallic disks, and appropriate tests were conducted. According to the patterns of stop-down from operation at a TIT of 1,200°C and at the rated rotational speed (56,000rpm), differences were obtained in the residual stress generated in the joints, but even after 30 cycles of start-up and stop-down over 20 hours, no damage had occurred in the compliant layer, and thus the efficacy of this feature was verified.



Changes in Rotor Diameter and Compliant Layer Thickness According to Start and Stop Cycles

(b) Combustors

Owing to improvements of the fuel injection site and ratio, a NOx exhaust concentration of 54ppm was attained at the rated operating conditions of the basic CGT (combustion air/dilution air = 70kg/kg), thereby satisfying the target of NOx exhaust concentration below 70ppm.

(c) Heat exchangers

Two sets of a partial unit heat exchanger with a high-temperature portion consisting of a ceramic heat exchange tube block and a low temperature portion consisting of a metallic U-tube block, equivalent to 1/6 of the heat exchanger scheduled for installation in the pilot CGT, were joined and subjected to validation tests relating to mutual buffering of thermal expansion absorbing functions and bias in flow distribution. The results obtained indicated the feasibility of fabricating large scale heat-exchangers by parallel connection.

(d) Compressor

Efforts were devoted to raising the efficiencies of both the axial flow compression and centrifugal compression stages, and to extending the stable operation range; in addition, experiments and analysis were performed in order to rationalize the proportions of the pressure ratio allocated to the two stages, and a 79% compressor efficiency was obtained.

(3) Design, Fabrication and Test

(a) Operating studies of basic CGT (TIT of 1,200°C)

Concerning the thermal behavior of the engine system, soundness of the ceramic parts, optimum clearance between the parts, and the support, shock absorption, and fastening structure for the hybrid turbine rotors, validation studies and preliminary tests were performed with a view to further improvement, the results so obtained were successively reflected in the engine structure, and operational studies were conducted. At a TIT of 1,200°C and at the rated rotational speed of 56,000rpm, operation was continued for more than 20 hours with all ceramic parts incorporated other than the low pressure stage turbine blades, and for 1 hour in a fully ceramic state of assembly. A maximum efficiency of 12.3% and a maximum output of 79.4kW were obtained.

2.2 Regenerative Two-Shaft Ceramic Gas Turbine for Cogeneration (CGT302)

(1) Research and Development on Heat-Resistant Ceramic Parts

(a) Parts fabrication techniques

As regards ceramic components for the basic CGT (TIT 1,200°C), and in particular concerning studies directed toward optimization of manufacturing and machining techniques and the development of components for the pilot CGT (TIT 1,350°C), molding studies of gas generator turbine rotors (GGT rotors) using new materials and related topics were initiated. Moreover, researches were conducted in relation to topics such as ceramic-metal joining techniques, improvement of oxidation resistance by CVD coating of intricately shaped components and joints, etc.

(i) GGT rotors

Molding studies were conducted with respect to GGT rotors composed of new materials (SN-S) for use in the basic CGT, and the target tolerance (-0.1mm – +0.2mm) was attained. Moreover, prototypical fabrication studies were conducted with respect to thick-vaned rotors intended to avoid damage due to FOD (foreign object damage), and prospects for feasibility of fabrication were obtained.

(ii) Scrolls

The outer scroll are large-scale thin members with irregular shapes, and in order to cope with problems such as shrinking or deformation during sintering, a method of integrating the joints by filament windings has been adopted. However, for purposes such as shortening of the manufacturing process, technical studies of integrated fabrication were undertaken, and provision of the necessary parts proved possible.

(iii) GGT nozzles

Fabrication studies were pursued concerning GGT nozzle segments, inner supports, and outer supports using new materials (SN-S), and the target precision (-0.1mm – +0.2) in the vane shapes of the nozzle segments was attained.

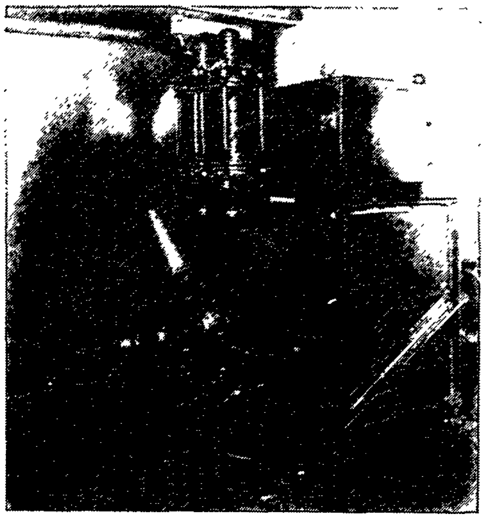
(iv) Joining techniques

Post-heat cycle strength evaluation studies of the joins of GGTs for the basic CGT were continued, and the absence of degradation was confirmed. Regarding the joins for the pilot CGT, brazing methods and HIP thermal treatment cycles were improved, techniques permitting HIP treatment without vacuum sealing were developed, and strength checks were performed.

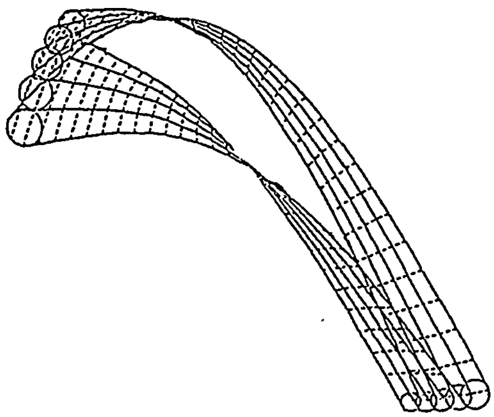
(2) Research and Development on Component Technology

(a) Compressors

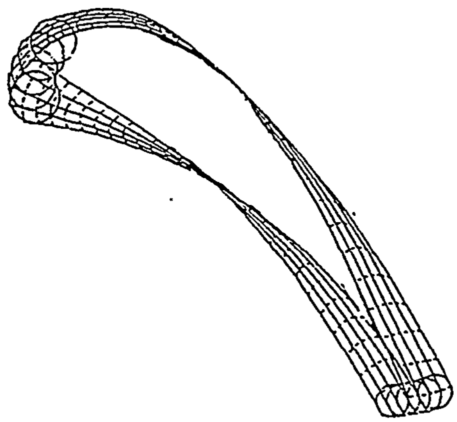
On the basis of numerical analytical studies, vane and gas-passage shapes were selected and prototypically fabricated, assembly tests of impellers and diffusers were performed, and assemblies permitting attainment of the planned performance levels



Outside View of Basic CGT (CGT302)



(a) Normal blade



(b) Thicker blade coping with FOD

Comparison of Shapes and Thickness of GGT Rotor Blades

were discovered.

(b) Turbines

Hot spin tests of GGT and PT were performed with turbine testing apparatus, and thermal shock tests of stationary members were conducted. Performance measurements of the basic CGT demonstrated a performance of 84% as compared with the target performance of 82.2%.

Moreover, thick blades were designed with the objective of raising impact resistance against FOD.

(c) Combustors

With a view to size reduction and simplification of variable mechanisms of combustors, medium pressure and medium temperature tests of combustors with one variable valve were conducted, and prospects were obtained for attainment of the target NOx exhaust levels.

(d) Heat exchangers

With respect to plate fin type heat exchangers, using the ultra-heat-resistant alloy HA230, 35-stage (1/2 actual size) laminated partial heat exchanger elements were prototypically fabricated, and strength was verified by pressure tests. Furthermore, actual size 79-stage elements were prototypically fabricated, and the relevant topics for further study were identified.

(e) Control equipment

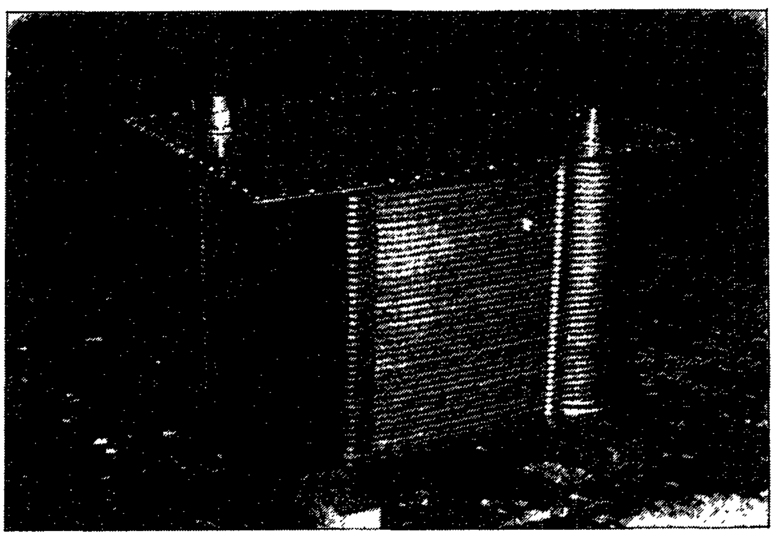
With respect to premixed lean-burn equipment, the start-up schedule and operating control parameter with gas fuels were adjusted, and trip by functions were augmented, etc.

(3) Design, Fabrication, and Test

(a) Operating studies of basic CGT

After verifying the soundness of the ceramic parts, metal parts were replaced by ceramic parts in successive stages, and engine operating tests were successively performed in this manner. A maximum thermal efficiency of 29.2% and maximum output of 172kW were attained during continuous operation for more than 38 hours at a TIT above 1,200°C. The achievement of a performance close to 30% with an engine of this output level constructed an internationally unprecedented accomplishment.

Hereafter, results obtained by operation of ceramic power turbines must be accumulated, and progressive research and development work directed toward the realization of a pilot CGT.



Prototype of Heat Exchanger Core Made of HA230 (79 layers)

2.3 Regenerative Two-Shaft Ceramic Turbine for Mobile Power Generation (CGT303)

(1) Research and Development on Heat-Resistant Ceramic Parts

(a) Parts fabrication techniques

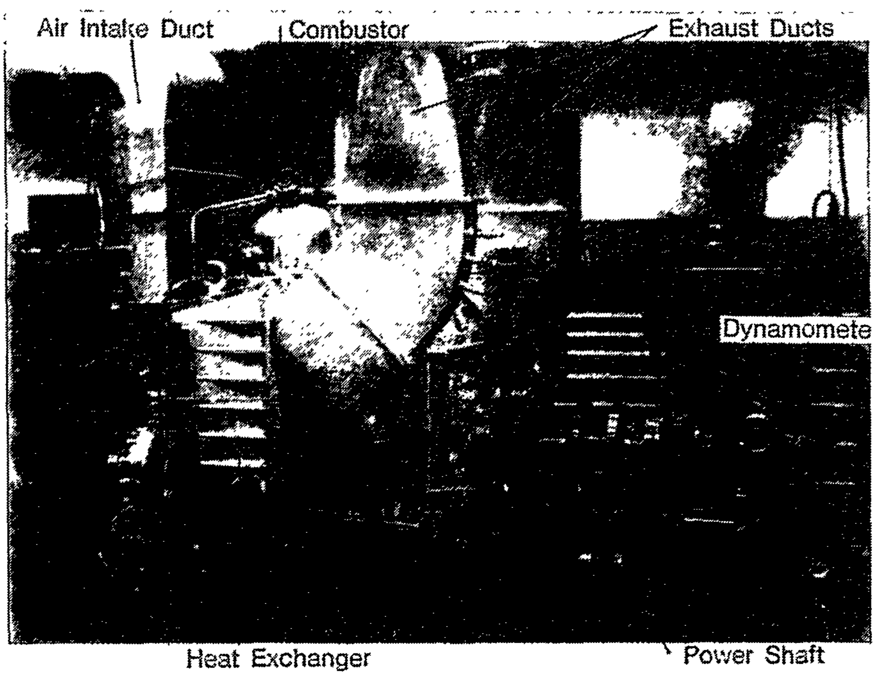
In the area of ceramic members for the basic CGT (TIT 1,200 degrees Centigrade), efforts were principally devoted to improvement of dimensional precision and reliability as well as optimization of manufacturing and machining techniques with due consideration for assembly and fitting processes. Moreover, as regards parts such as GGT rotors and GGT nozzles requiring resistance to high-temperature oxidation and high stress, research and development work was applied to fabrication techniques using new materials, while collision tests were performed to provide data for measures to cope with FOD.

(i) Scrolls

With a view to improvement of dimensional accuracy, optimization of fabrication techniques was pursued in order to cope with structural changes from the taper type to the in-row type in three-component assembled parts formed from basal, outer circumferential, and inner circumferential portions.

(ii) GGT rotors

In order to improve the reliability of the joins between rotors and metallic shafts, the design of the metal portion was altered, and after undergoing proof tests at 120% of the rated rotational speed (55,000rpm), the rotors were subjected to actual engine tests. Moreover, molding studies of new materials (SN - S) were conducted in order to improve the reliability of GGT rotors, and prospects



Outside View of Basic CGT (CGT303)

for the feasibility of fabrication were confirmed.

(iii) PT nozzles and PT blades

Although the target dimensional accuracy of both nozzles and blades has been attained with existing materials, the relevant studies were continued with a view to further improvement. Furthermore, research on fabrication techniques was conducted with a view to the application to nozzles of ST-2 materials, characterized by greater oxidation resistance as well as the application to blades of ST-1 materials, possessing improved high-temperature strength. In each case, molds were improved, and the attainment of a dimensional accuracy of ±0.1mm in the blade shape is planned.

(iv) GGT nozzles, shrouds, and back shrouds

Effective from the present fiscal year, the material composing these three parts was changed from β sialon to silicon nitride, the development of fabrication techniques with assurance of dimensional accuracy as the primary objective was undertaken, and the fabrication of parts with the required precision proved to be possible.

(2) Research and Development on Component Technology

(a) Heat exchangers

In order to improve the seal characteristics of rotary regenerative heat exchangers, the core material was changed and studies were conducted concerning optimization of seal shapes and spring force. As a result, the leakage rate in static leakage tests was reduced to 4.2%. Furthermore, high-temperature rotational tests are to be performed, and the parts showing high performance are to be incorporated into engines.

(b) Combustors

With respect to premixed lean-burn combustors, studies were conducted concerning the position of the fuel injection valve suitable for a fuel-air temperature of 900°C on the basis of test results with the inlet air temperature as parameter.

(c) Compressors

A pressure ratio of 5 and an efficiency of 82% were attained by altering the vane angle and outer diameter of the impeller (φ 183mm —> φ185mm). Hereafter, reflecting the results of engine tests, impeller diameters and diffuser areas are to be appropriately selected to permit optimal matching.

(d) Turbines

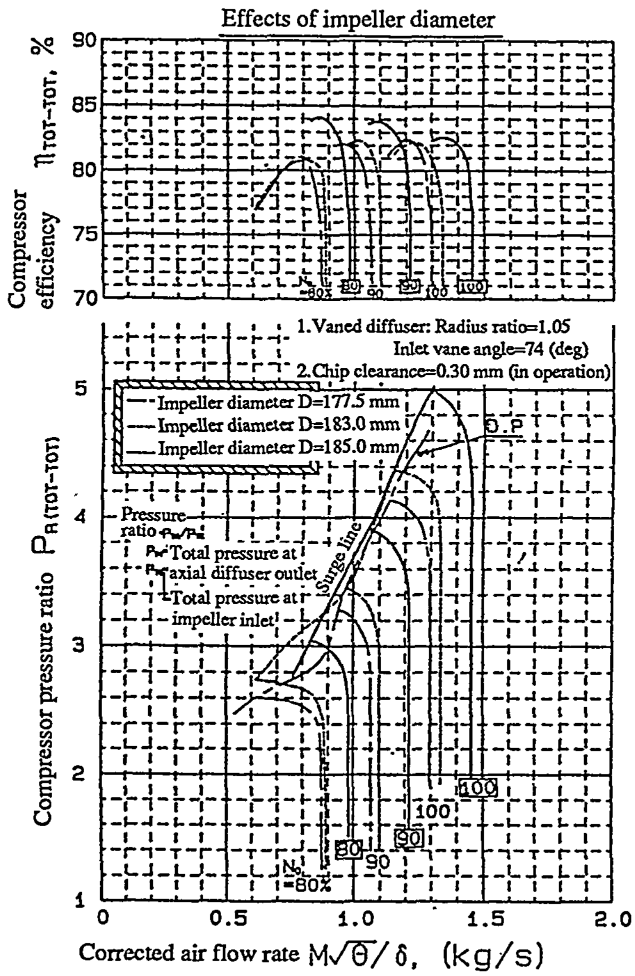
Hot spin tests of GGT rotors and PTs were performed, and efforts devoted to measurement of oscillatory modes and tip clearance.

(3) Design, Fabrication and Test

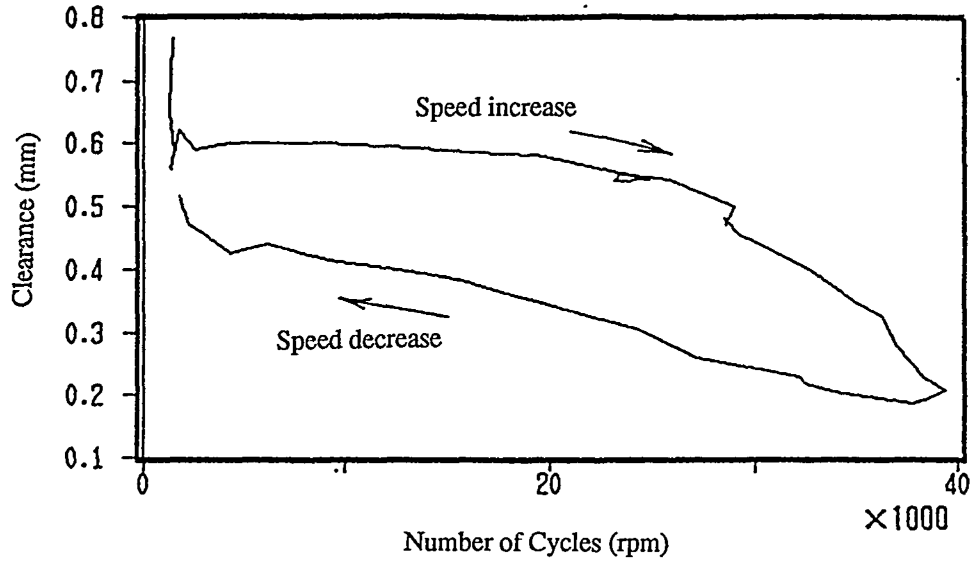
(a) Operating studies of basic CGT

Operating tests of the engine were performed in accordance with the procedure of replacing metallic parts by ceramic parts after verifying the soundness of the latter. Operation for more than 20 hours at TIT of 1,200°C was achieved with all of the ceramic parts incorporated except for the PT blades, and without installation of a heat exchanger. The highest performance attained up to the present time consisted in an output of 165kW and a thermal efficiency of 12.3% at a TIT of 1,200°C.

Hereafter, it is necessary to continue operating studies and accumulate operational data as well as extraction of problem points and improvements with respect to the engine



Compressor Characteristics with ϕ185 mm Impeller



Measurements of Hybrid PT Rotor Tip Clearance

system.

2.4 Supporting Research

(1) Testing Method to Confirm the Reliability of Ceramic Components

(a) Studies on creep rupture validation tests

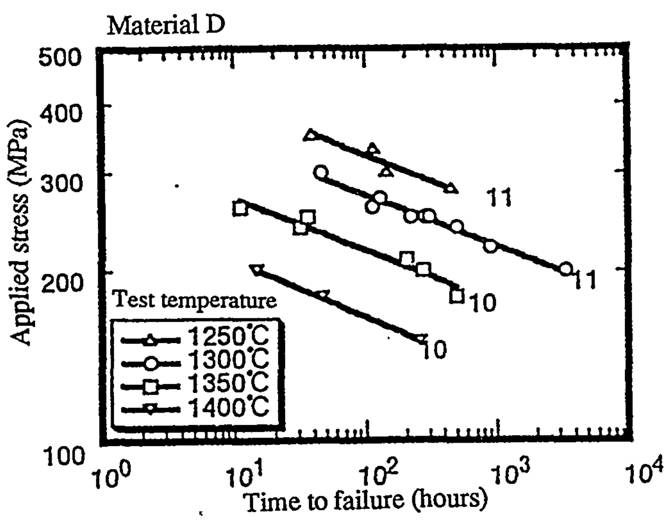
Efforts were applied to the accumulation of data on the relation between load stress and rupture time in order to evaluate the high-temperature creep rupture strength of materials for CGTs operating at 1,350°C.

By plotting the data for each test temperature on a logarithmic axis, the relations between load stress and rupture time can be expressed by linear graphs with a single slope. Therefore, if the test temperature is given, then the creep rupture time of a test piece can be estimated. Application of the Monkman-Grant method, used for prediction of the creep rupture time of metallic materials, was attempted. In this method, the lifetime is analyzed in terms of the minimum strain rate and the strain rate at the instant of rupture is estimated.

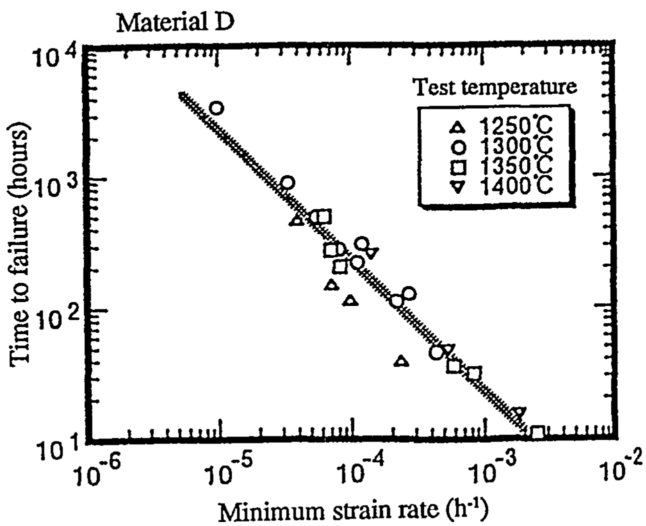
(b) Studies on non-destructive inspection methods

Using model testpieces of various shapes with artificial flaws, studies were conducted to ascertain the flaw detection performance limits of microfocus X-ray CT, and the flaw recognition factor (equivalent circular flaw diameter/test piece diameter) was determined. Moreover, an investigation was conducted concerning the applicability of high-energy x-ray CT to large ceramic parts, and the results confirmed that the positions, shapes, and sizes of flaws undetectable by conventional methods could detected by this technique.

(2) Testing and Evaluation Method for Joint Technology of Ceramic Component



Creep Test Results



A Test Method for Early Stage Lifetime Prediction and Assurance

The correlation between residual stress and durability (stress corrosion fracture strength characteristics) of joins was studied by various tests and analytical procedures, and the following results were obtained concerning the relation between residual stress and stress corrosion fracture strength.

• Changes resulting from stress corrosion cracks due to residual stress in joints can be assessed by X-ray stress measurements. Stress corrosion cracks cause reduction of the residual stress in the join interface and on the ceramic side in the vicinity of the free end.

• Under constant stress conditions, time-dependent rupture occurs when the stress is below the bending strength. Lifetime increases concomitantly with decreasing stress. The fractures originate in the interface between the ceramic and the brazing filler metal.

• Under constant loading speed conditions, an extreme strength drop occurs at high loading speeds (500mm/min) as compared with other conditions (below 0.5mm/min).

(3) Studies on Social Adaptability

An existing composite facility comprising office buildings, shopping buildings, and centralized residential facilities (jointly constructed shops, offices, and hotels) equipped with 300kW class cogeneration systems (CGS) was adopted as a model, and simulation calculations were performed on the basis of optimal design envisaging the introduction of CGTCGS. As regards energy saving, environmental impact, economy, and other aspects, the simulation results were compared with CGS based upon gas and Diesel engines as well as facilities without introduction of CGS.

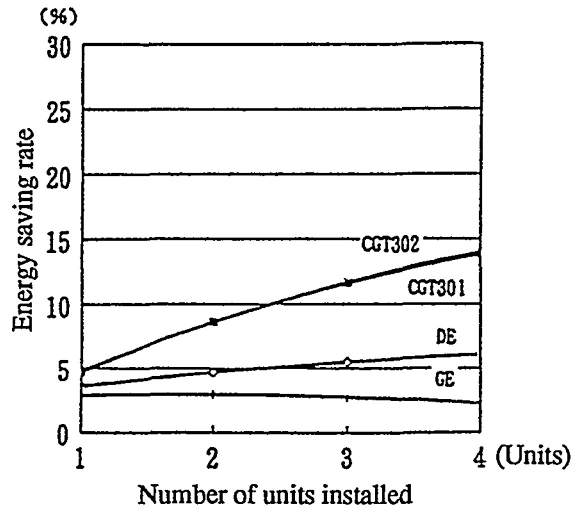
Regarding the office buildings, the following results were obtained.

• Energy efficacy increases with the number of CGTCGS units introduced (up to a maximum of 4 units).

• CGTCGS is most advantageous as regards environmental impact (except for systems using grade A heavy oil).

• CGTCGS is also most advantageous as regards running costs.

Hereafter, simulation studies must presumably be pursued with respect to buildings with long operating time such as hotels and hospitals, where the introduction of CGS is said to manifest highest efficacy.



Energy Saving Rates by Number of Units Installed (Office building)

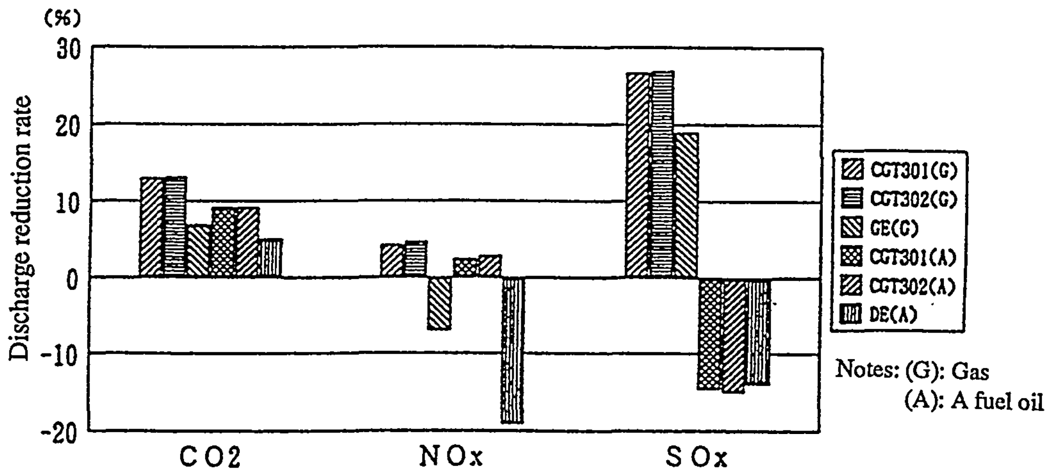


Fig. 3 Environment Load Reducing Effects (Number of units: 2, office building)

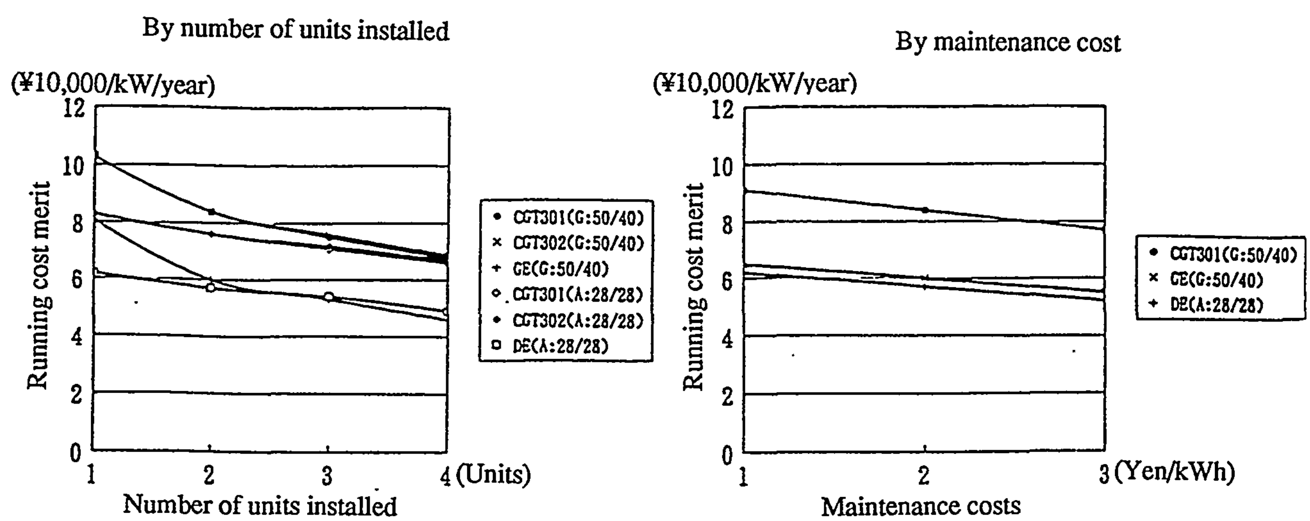


Fig. 4 Running Cost Merits (Office building)

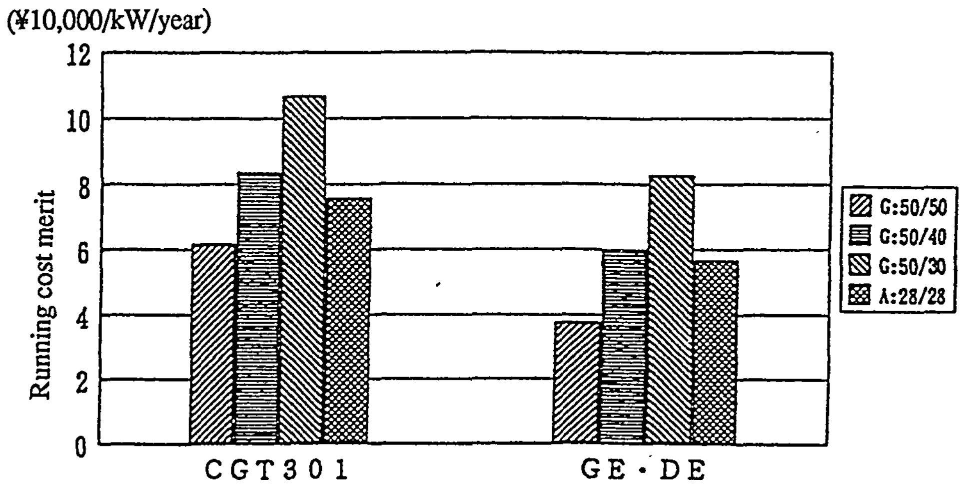


Fig. 5 Running Cost Merits by Difference of Gas Charges (Office building)

IV

Research and Development Work
on
Superconductive Technology for Power Applications

1. Objectives and Work Program

Power generation equipment as well as transmission and transformer equipment are constantly being augmented and expanded in order to cope with ever increasing electric power demands. However, concomitantly with the increasingly greater capacity and remote location of power stations, problems involving difficulties in acquisition of site for installation of transmission lines as well as power system stability are becoming more evident; moreover, a further reduction in power losses is becoming necessary. In order to cope effectively with these problems, superconductive technology must be introduced into power apparatuses with a view to raising efficiency, energy density, and power system stability. To this end, superconductive technologies for the power application are being developed with reference to the following topics:

(a) Research and development on superconducting wires

(b) Research and development on superconducting generators

(c) Research on total systems

(d) Research and development on refrigeration systems

(e) Verification tests

(f) International cooperation projects

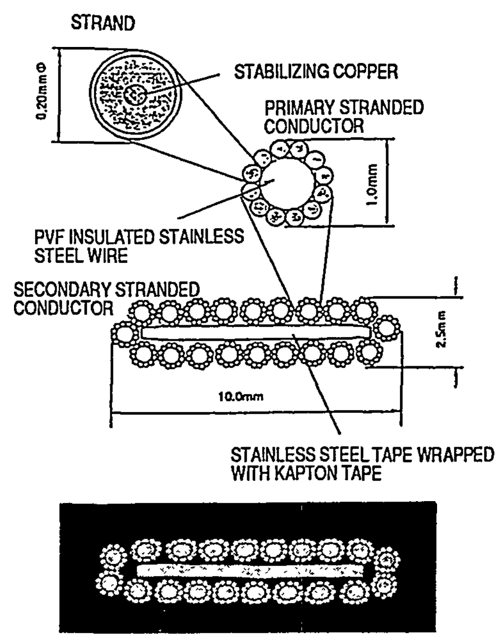


Fig. 1 NbTi AC Conductor (Rectangular-shaped stranded)

2. Summary for FY1994

2.1 Research and Development Work on Superconducting Wires

(1) Research and Development Work on Metallic Materials

(a) Research on enhancement of strand performance

(i) In the area of niobium titanide (NbTi) wires, with specific power application devices such as generator armature windings as development targets, research and development efforts were directed toward improvement of superconductive characteristics in the respective magnetic fields involved.

As regards wire for generator armature windings, rectangular-shaped strand conductors and round-shaped multi-stranded conductors with varying matrix ratios were prototypically fabricated, their respective current transmission characteristics in 1 - 5T fields were measured, and current transmission levels of 3kA class (DC) or 5kA class (AC) were attained. Reduction of AC losses in wires used in shunt reactors was achieved by adjusting the stabilizing copper content ratio, reducing the filament diameter, and improving the twist pitch. As a result, a performance level of 8 - 10kW/m^3 (at 0.5T and 50Hz) was obtained; moreover, the studies revealed that increases in the copper content ratio of the strands are effective in raising the conductor quench current Iq. Furthermore, as regards wires used in current limiters, the manganese concentration of the matrix and the stabilizing copper content ratio were optimized, which permitted a reduction of total AC losses, and a critical current density 1.4 times the previous value was obtained.

(ii) In the area of triniobium stannide (Nb3Sn) wires, striving for reduction of AC losses and achievement of high current densities, research and development work was performed by the following fabrication methods with a view to raising the performance characteristics of strands.

As regards the internal tin method, small coils with filament diameter decreased to 1/2 and twist pitch decreased to 8/6 as compared with previous coils were prototypically fabricated and compared to coils with the same structure but with niobium titanide conductors, and AC currents approximately twice those transmitted by the NbTi coils were obtained.

As regards the external diffusion method, the germanium concentration, matrix ratio, filament diameter, and thermal treatment conditions were optimized, and as a result AC losses (hysteresis losses) of 330J/m^3 were attained, lower by one decimal digit as compared with previous levels. Moreover, the reversible critical bending strain of Nb_3Sn wires was improved to 3.8%, approximately 4 times the previous level.

As regards the bronze method, filament diameter and filament spacing were optimized, and as a result reduction of critical current density was suppressed while the AC losses of the strands were reduced to 900J/m^3, approximately 1/8 of the previous level. The studies revealed that increasing the filament spacing is effective in reducing hysteresis losses.

As regards the in situ method, structural designs of wires were prepared with consideration for the tin diffusion process and strain characteristics, heat treatment conditions were investigated, strands and small coils were prototypically fabricated and studied, and a 0.5T field was obtained during AC transmission.

As regards the tube method, wires with various filament spacings and tin concentrations were prototypically fabricated and tested, and the results demonstrated that increasing the tin concentration raises critical current density, and that widening the

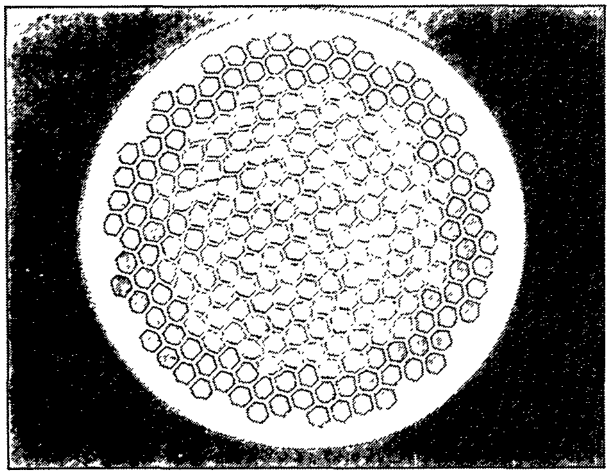


Fig. 2 Cross Section of External Diffusion Method Nb_3Sn Wire Rod

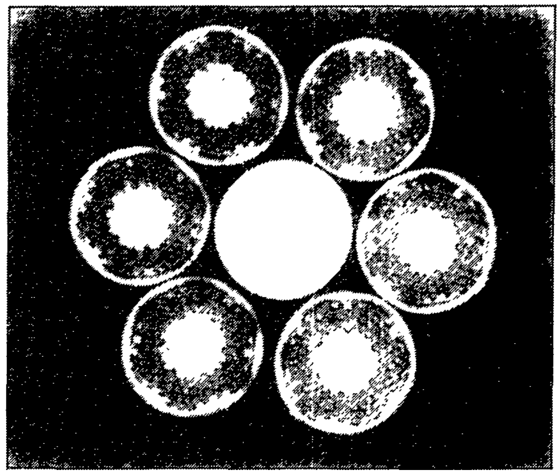


Fig. 3 Cross Section of Tube Method Small Coil Conductor

filament spacing diminishes AC losses (hysteresis losses).

As regards the powder method, strands with increased niobium concentrations were prototypically fabricated, and provided critical current densities approximately 3 times the previous levels, moreover, prospects were obtained for decreasing hysteresis losses while maintaining high critical current densities. Furthermore, molding and machining of up to 70% of the metallic part of the wire cross-section were performed, and test results revealed almost no degradation with respect to hysteresis losses after machining.

(b) Research and development on oxide materials

As regards oxide materials, research was applied to improvement of the superconductive characteristics of materials in wire form as well as mechanical and chemical stability. Moreover, studies were pursued with emphasis upon techniques for formation into wires, including elongation and incorporation in composite conductors, etc.; in particular, development of basic technology necessary for formation into wires, such as improvement of critical current densities and critical current, was further promoted with the objective of application to various apparatuses utilizing electric power.

(a) Research and development on multilayer wires by the composite machining method

Higher critical current density and greater length by virtue of a decreased silver ratio and larger base material dimensions as compared with the previous rolled tape winding method were sought through the development of a multilayer pipe configuration with bismuth (2223) and silver arrayed in a concentric cylindrical manner. This permitted the achievement of a critical current density (Jc) of 14,000A/cm^2 with superconductive core tape wires of thickness 10 microns. Moreover, the AC losses were measured in a sample obtained by lamination of 5 strips of multilayer tape, and the results revealed that coupling losses occurred between the tapes at currents below Ic.

(b) Research and development on high-performance large-area film forming methods by plasma spraying and other methods

The substrates of thallium (2223) plasma-sprayed wires were reinforced, and the substrate thickness was reduced to 200 microns, thereby increasing the overall critical current density. Moreover, silver-sheathed wires obtained by laminating four thallium (2223) wires displayed improved bending strain characteristics.

(c) Research and development work on high-performance film formation by ionized cluster beam method

Formation of films with composition shifted from yttrium (123) and application of heat treatment was shown to permit stronger pinning and improvement in the magnetic field characteristics of the critical current density. Studies were conducted concerning laser irradiation of superconductive films, and a critical current density $Jc = 2 \times 10^4 A/cm^2$ was obtained on strontium titanate ($SrTiO_3$) substrate, and $Jc = 2 \times 10^6 A/cm^2$ in silver tape. Furthermore, the temperature dependence of current limiting characteristics was investigated, and the

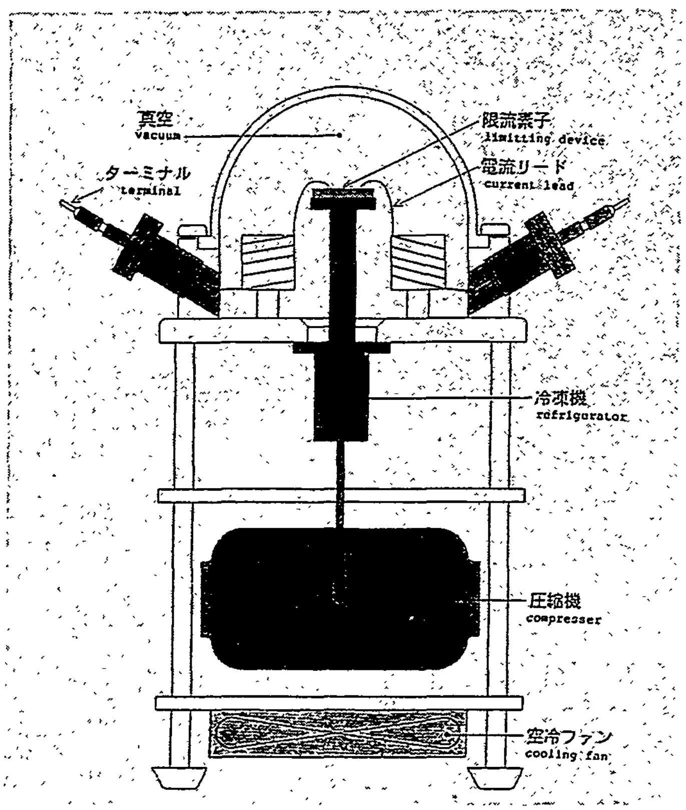


Fig. 4 Model of Refrigerator Cooling Type Current Limiting Equipment

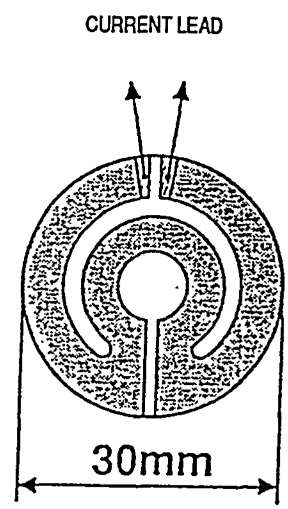


Fig. 5 Current Limiting Device

results verified that the current-limiting initiation current (i. e., transmittable current) could be increased by lowering the operating temperature.

(d) Research and development on high-performance wires by physical vapor deposition method

Yttrium-based superconductors were created by continuous vapor deposition, and prototypical tapes of length 10cm and film thickness 2.0 microns were formed at a shifting speed of 0.8m/h. This process was successful in attaining high performance characteristics, i.e., the critical current density and critical current for the entire length of the tape were Jc = 2.6 x 10^5/cm^2 and Ic = 52A, respectively, while the corresponding figures for short intervals were Jc = 6.2 x 10^5A/cm^2 and Ic = 103A, respectively. No drop in critical current density concomitant with increased film thickness was observed up to a thickness of 2.0 microns, and prospects for the achievement of larger capacities were obtained.

(e) Research and development on high-performance wires by chemical vapor deposition method

Studies were conducted concerning film forming methods for high-quality buffer layers, and the prior deposition of YSZ on the substrate permitted the creation of an a-axis oriented YSZ layer by a high-speed film formation process. Moreover, the provision of a platinum barrier layer at the boundary between the substrate and the film inhibited diffusion and permitted the attainment of a critical current density of 1.5 x 10^5A/cm^2.

(f) Research and development on high-performance wires by melt processing method

A bismuth (2212) fiber sample produced by the laser pedestal method was annealed under a tension on the order of 1 - 3MPa, thereby obtaining a wire with a critical current density of 5,030A/cm^2, representing an increase of 60% as compared with wires produced without application of tension. As regards large diameter wires, annealing processes were optimized, thereby permitting a increase of 60% in the critical current

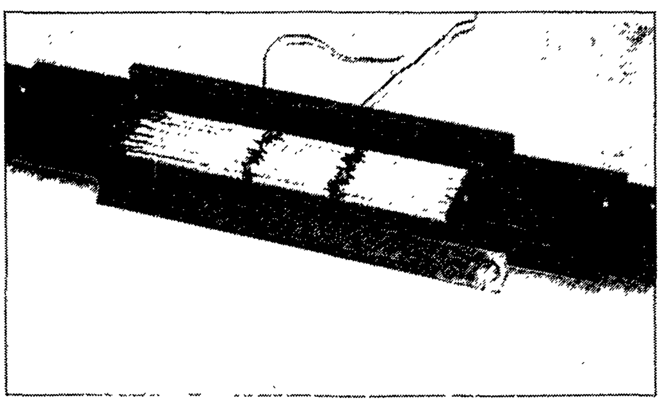


Fig. 6 Laser Pedestal Wire Rod (Combination of 12 strands)

density of sample strands 270mm in length, and in one such strand the value Ic x L = 125 was obtained. Furthermore, the performance characteristics Ic x L = 338Am, Jc = 1,350A/cm^2 were obtained in 12-strand aggregated conductors 250mm in length.

(g) Studies on improvement of superconductive characteristics by crystal structure control

Vapor deposition conditions were optimized with a view to improvoing the observational precision of the magnetic flux distribution in superconductors by the bitter decoration technique, and the result demonstrated that nickel particles, previously prone to flocculate, could in fact be vapor deposited without flocculation. Moreover, as regards yttrium-based thin films prepared by the ionized cluster beam method, decoration patterns were determined, and numerous nickel particles were observed in the a-axis oriented particles regarded as pinning points.

2.2 Research and Development Work on Superconducting Generators

(1) Research and Development Work on Slow Response Excitation Type Generators

(a) Research on a multicylindrical rotor

Concerning a multicylindrical rotor, internal piping was manufactured, and partial assembly of a rotor including the incorporation of piping into the interior of the rotor shaft was performed.

As regards the field windings, after the insertion of wedges into the slots of the winding support shaft, the shaft was placed in a stationary cryostat and static excitation tests were performed. Excitation tests at the rated field current as well as the maximum

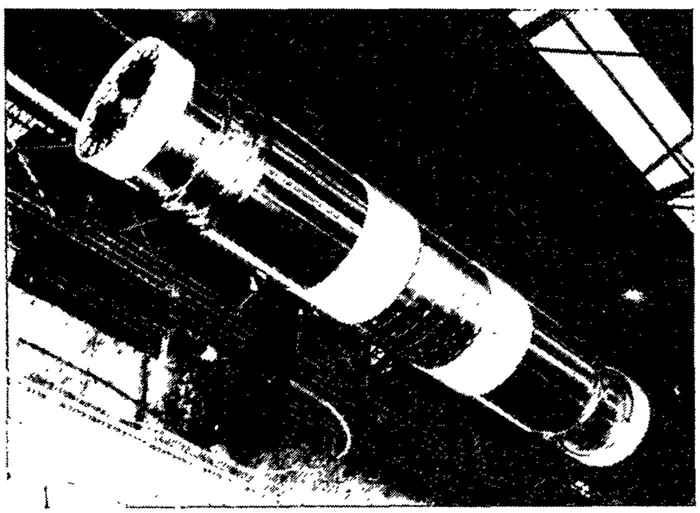


Fig. 7 Winding Support Shaft of Multicylindrical Rotor Model

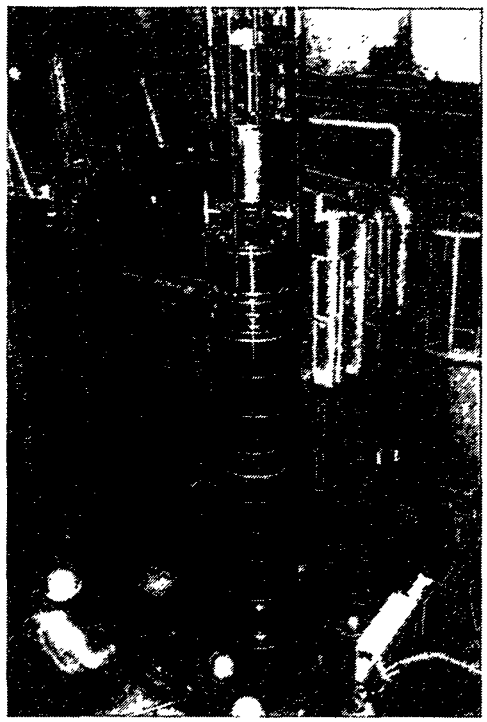


Fig. 8 Winding Support Shaft in Cryostat Inserting Process

transient field current, heater induced quench tests employing heaters installed in the field windings at the rated field current were performed, and the robustness of superconducting field winding directed toward cryostable winding was demonstrated.

(b) Design and manufacture of a rotor for a model generator

As regards rotors for model generators, on the basis of a fundamental design of a model generator as well as test results concerning partial rotor models, etc., static excitation tests were continued from the previous fiscal year, moreover, portions of the rotor were assembled and various parts were manufactured. As regards static excitation tests, current quench tests, heater-induced quench tests using a heater, and pulsed-excitation tests were conducted, and excellent results were obtained. Moreover, the efficacy of analytical methods was verified by comparison with measured values.

Furthermore, the low-temperature portion of the rotor was completed, assembling with components such as the helium piping in the interior of the rotor as well as the current leads, vessel and the winding support shaft. Among the principal components, materials were manufactured for the cold damper, warm damper retaining ring, wedges, and other components, while the final mechanical machining of the warm damper support was performed. In addition, the end shafts were installed, rotational balance tests were conducted at normal temperatures, and excellent test results were obtained.

(c) Design and manufacture of a stator for model generators

As regards stators for model generators, design and fabrication were pursued on the basis of the previously achieved research and development results on various essential techniques, stator winding model, etc., and some component parts were manufactured and assembled. After installation of wiring supports for measurement in a stator frame disassembled during the previous fiscal year, the lamination work for embedding magnetic shielding materials (laminated iron core) in cylindrical form into keys mounted on the inner diameter side and also the installation of the measurement sensor were completed. Furthermore, the lamination and other tasks required for embedding FRP teeth materials in cylindrical form into this magnetic shield were performed.

(2) Research and Development on Quick Response Excitation Type Generators

(a) Research on a partial rotor model

As regards partial rotor models, design and manufacture work was performed with consideration for the essential technologies previously developed. Moreover, superconducting field windings wound during the previous fiscal year were cured, fixed, and subjected to static excitation tests including DC excitation tests and pulsed-excitation tests, thereby establishing prospects for full attainment of the target specifications for the model generator. After that, rotor assembly, including helium vessel and other components, was implemented, and balance adjustments were performed. Furthermore, various parts such as flexible supports and internal piping was manufactured, and the finishing work preliminary to assembly of the end shafts composed of materials produced during the previous fiscal year was performed.

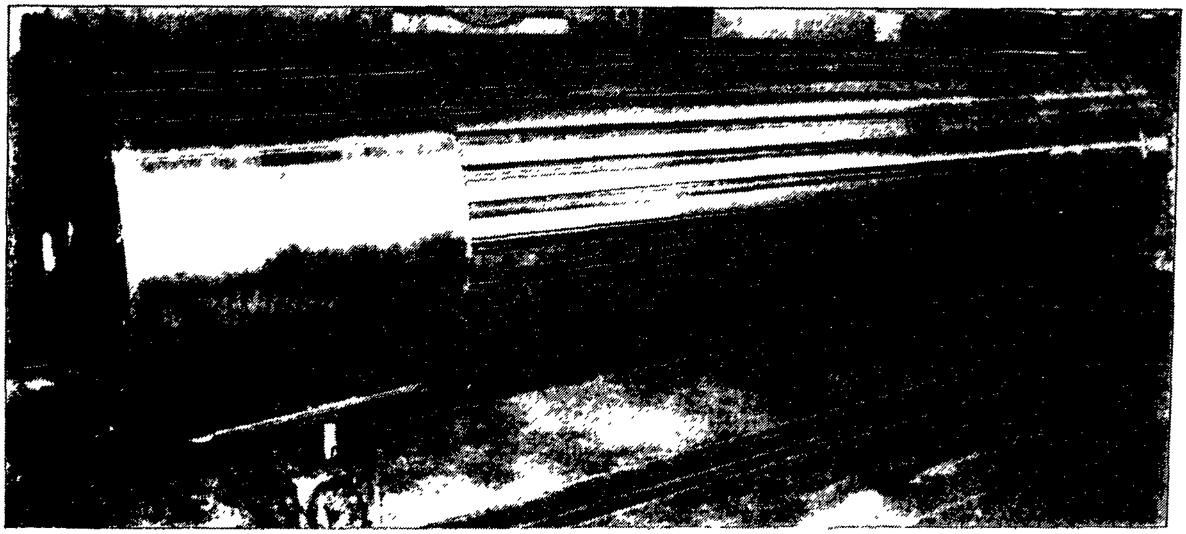


Fig. 9 Warm Damper Support of Slow Response Excitation Type Model
(after final mechanical processing)

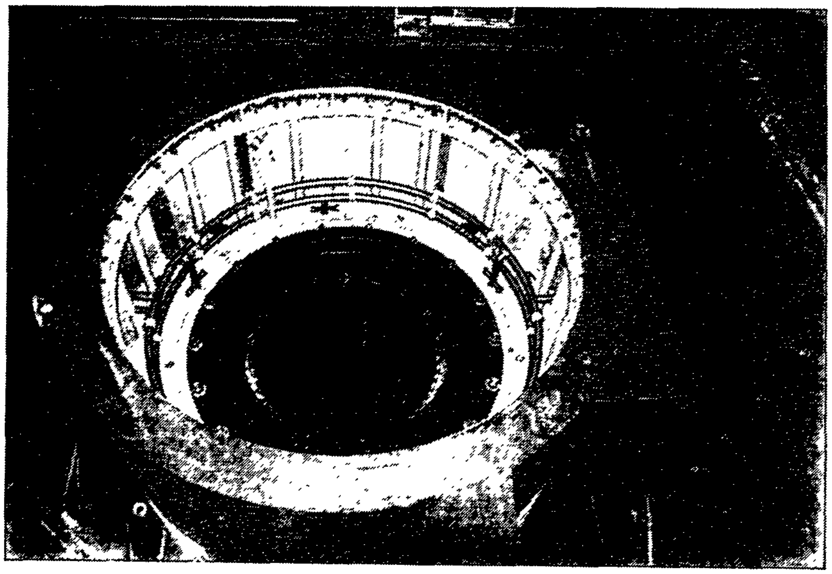


Fig. 10 Stator of Model Generator
(after magnetic shield lamination)

(b) Design and manufacture of a rotor for a model generator

Manufacture of the materials for the winding support shaft of a rotor for a model generator was completed, and machining preliminary to aging treatment of various components including the peripheral cooling grooves and winding slots was per-

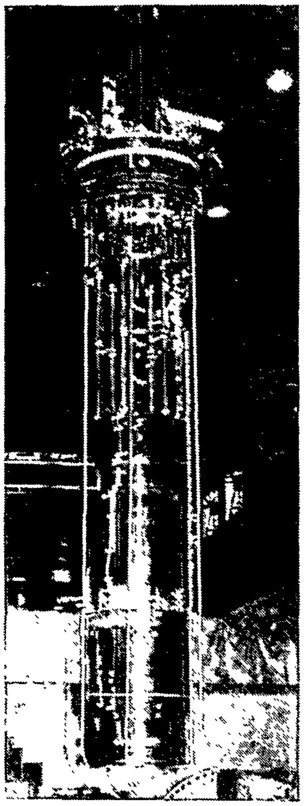


Fig. 11 Quick Response Excitation Type Partial Rotor Model

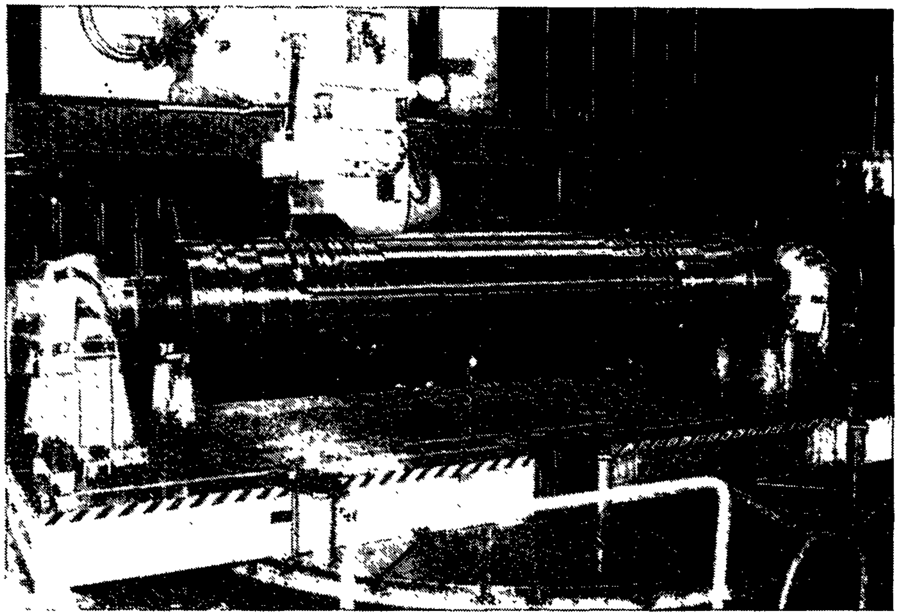


Fig. 12 Winding Shaft of Quick Response Excitation Type Model Rotor (in process)

formed. Also, as regards the principal component materials such as the warm damper and radiation shield, specifications were decided and manufacture was implemented. Moreover, the intra-slot parts for insulation and fixation of windings were designed and some were manufactured. Furthermore, a part of the basic structural design, three-dimensional magnetic flux analysis of the field windings and convection analysis of the helium gas in the internal piping of the rotor were performed with a view to raising design precision, while some of the manufacturing designs were prepared.

2.3 Research on Total Systems and Other Aspects

(1) Studies on Testing Methods for Model Generators

With a view to precise clarification, detailed studies were devoted to the testing conditions in various severity tests such as three-phase sudden short-circuit tests and negative-phase-sequence phase overcurrent tests as well as load tests such as long-term reliability tests.

• The conditions for three-phase sudden short-circuit tests were specified as a combination of the no-load reduced voltage method and the off-phase reconnection method established during the previous fiscal year. On the basis of fault analysis on a three-phase short-circuit system, the terminal voltage and other parameters of the model generator were decided and the fault duration time was determined.

• As regards negative-phase-sequence overcurrent test conditions, the continuous and short-time negative-phase-sequence withstand current capacities were established with due consideration for factors such as multi-phase reclosing operation and increases of consumer loads utilizing various switching.

• As regards long-term reliability tests, DSS and continuous operating time, etc., were established with the objective of investigating initial faults and weak points.

(2) Improvement of Design Analysis Methods on the Basis of Model Generator Test Results

In connection with the superconducting generator models for power system analysis proposed at the CIGRE conference, the literature was surveyed, and in conjunction with previous investigational results, the models were organized and classified, and topics requiring further investigation were identified.

(3) Development of Control, Protection, and Operating Techniques for Superconductive Power Generation Systems

In order to establish the protective mechanisms demanded in superconducting generators, including pilot generators, under the assumption of introduction into electric power systems, studies were devoted to the progression, detection, and prevention of troubles and failures, possible protective mechanisms were organized, and protective coordination with power systems was considered.

(4) Studies on Efficacy of Introduction of Superconducting Generators into Electric Power Systems

As regards the capability of superconductive synchronous phase modifiers for maintaining voltage during drops in system voltage, the superiority of superconducting synchronous phase modifiers was demonstrated by comparison with existing synchronous phase modifiers as well as SVCs and SVGs.

(5) Survey Studies Concerning Devices for Application of Superconducting Power Apparatuses

Conceptual surveys and economic feasibility studies were conducted with respect to medium capacity superconducting generators, etc., and the nature of the research and development work necessary for their practical realization was considered. Studies were also devoted to the economic assessment, development subjects, developmental approaches, and other aspects related to practical realization of superconducting cables.

2.4 Research and Development Work on Refrigeration Systems

(1) Research and Development Work on Establishment of High Reliability in Conventional Type Refrigeration Systems

In order to ascertain operating methods for refrigeration systems suitable for the starting, stopping, and DSS operation of superconducting generators, in-factory studies were conducted on a refrigeration system for model generators using a dummy load apparatus which simulates the generator, and the following points were verified; moreover, the causes of faults occurring in the factory tests analyzed and measures to prevent recurrence were adopted with a view to raising system reliability.

- As regards methods for liquid supply rate adjustment, this can be effected in due response to the thermal load of the generator by properly controlling the pressure within the Dewar vessel and the degree of opening of the liquid feed valve.
- With respect to the thermal load change of the generator, prospects for automatic and stable system operation was obtained for conditions when the liquid surface was maintained at a constant level and the liquefaction rate was equal to the liquid supply rate.

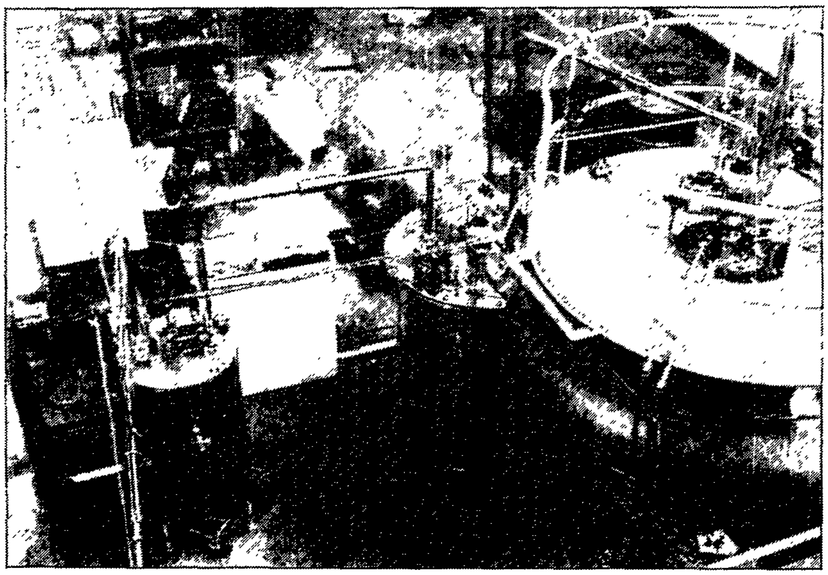


Fig. 13 Conventional Refrigeration System (in test)

(2) Research and Development on Advanced Refrigeration Systems

(a) Oil-free screw compressors

Using element testing apparatus with normal-temperature atmospheric air as the working fluid, pressure conditions were established and comprehensive operating tests from start-up to stop-down were conducted in order to establish compressor operating procedures. The results verified that no problems arose even if the compression ratio was raised within the target time (15 minutes) with a view to shortening the time required for setting the pressure conditions. Moreover, operating tests of the helium compressor were performed from start-up to stop-down with a series of various operating patterns, methods of compressor operation including capacity control by rotational speed were determined, and basic performance characteristics such as seal performance were checked.

(b) Oil-free turbocompressors

Second-stage compressors for coupling tests were designed and a compressor casing was fabricated in order to study the operating characteristics of multi-stage turbocompressors. Moreover, a compression unit was assembled with the driving unit manufactured during the previous fiscal year, thereby completing the compressor construction. Using low-temperature testing apparatus, unit performance tests were conducted, and the results verified that stable operation was possible up to the rated rotational speed of 100,000 rpm. Furthermore, the performance as regards pressure-flow rate characteristics and adiabatic efficacy were shown to fully exceed the specifications.

2.5 Verification Tests

(1) Design and Manufacture of Equipment for Verification Tests of Model Generators

Design as well as procurement and machining of materials and equipment were successively implemented with respect to mechanical apparatuses such as auxiliary equipment for superconducting generators, the main unit and accessory components of synchronous machines for loading, principal circuit equipment, common equipment, etc. Moreover, manufacturing designs and detailed drawings for major equipment were prepared.

(2) Construction of Equipment for Verification Tests of Model Generators

Basic construction was implemented with respect to the various equipment such as M-G foundation as well as electrical work such as ground wiring and illumination facilities, piping work for efflux of oil-bearing waste water, etc. Furthermore, a mobile frame was installed, and using this frame the synchronous machines for loading were mounted on the M-G foundation.

(3) Governmental Agency Procedures and Arrangements with Relevant Authorities

Equipment for verification testing, including the refrigeration system, is subject to integrated control as nonutility electrical work in accordance with the Electricity Enterprises Act. Accordingly an "Application for Approval of Construction Plan" was filed in accordance with the act and due approval was obtained from the Minister of International Trade and Industry on June 13th. Moreover, the procedures necessary for construction work were duly completed, including a "Notification of Appointment of Chief Electrical Engineer."

Construction methods for the equipment receiving the power supply were decided in collaboration with the electrical utility company concerned, full cooperation with the relevant organizations was sought in order to ensure unimpeded implementation of the construction work, and the various tasks involved were effectively executed.

2.6 International Cooperative Projects

Various implementation agreements relating to the IEA-CRD sponsored "Assessment of Impact of High-Temperature Superconductivity upon the Electric Power Sector" have been proposed or concluded with the objective of multinational exchange of relevant information such as data on assessment of superconductive application techniques. As regards this area of activity, our representatives participated in the Eighth Meeting of the Implementation Committee convened in October 1994 and the Ninth Meeting convened in April 1995, and exchanged information concerning the state of progress of research and development work related to superconductive application techniques with various nations, as well as conducting deliberations on the items of activity in this area during the present and future fiscal years.

3. Future Prospects

In the present project, up until now, items such as superconducting wires and refrigeration systems have been developed, the relevant activities being principally centered upon 70MW class superconducting generators. Plans for the period from fiscal 1996 through fiscal 1998 include the implementation of verification tests of the 70MW class superconducting generators (model generators). During the present fiscal year, as the final stage in the development of the 70MW generators, model generators are to be fabricated and subjected to factory tests. Moreover, the verification test facility is be constructed and other preparations completed with a view to assuring the perfect and unimpeded commencement of the verification tests.

V

Establishment of a Comprehensive Promotion System for the Popularization of Electric Vehicles (EVs)

1. Objectives and Work Program

Electric vehicles (EVs) are expected to become widely popular, and daytime charging and particularly rapid charging of EVs is expected to cause an even greater drop in the load factor. Accordingly, utilizing nighttime power supplies, EV charging systems employing power storage systems are to be developed with a view to load leveling. Furthermore, surveys and research on total systems and related topics are to be conducted in preparation for the widespread introduction of EVs.

(1) Research and Development Work on Electric Vehicle Charging Systems

(a) Development of charging systems

Proceeding on the basis of the results of research and development work on advanced type battery power storage systems, efforts will be devoted to the development of EV charging stations utilizing systems for storage of nighttime electric power. Moreover, data on various methods of utilizing charging stations, collected by fleet tests, will be analyzed and performance evaluation studies of charging systems will be conducted with reference to the adaptability of charging methods, performance characteristics, etc.

(b) Fleet tests with electric vehicles

Fleet tests using EVs are to be implemented in designated operational fields in which the large-scale introduction of EVs is expected, and actual running data is to be collected, analyzed, and assessed.

(2) Surveys and Studies on Large-Scale Introduction of Electric Vehicles and Total Systems

(a) Surveys and studies on infrastructural preparation and related areas

Overall studies are to be conducted with a view to the systematic organization (infrastructural preparation) required for widespread introduction of EVs with particular reference to forms of charging appropriate for the locations of various charging facilities as well as both ordinary and rapid charging systems.

(b) Surveys and studies on social systems

Methods of utilizing EVs in the transport and distribution sectors, where widespread introduction of EVs is expected, are to be thoroughly investigated, and the state of utilization of nighttime power supplies is to be studied.

(3) Survey Studies on High-Performance Energy Storage Systems for Electric Vehicles

Studies were conducted on the feasibility of application to electric vehicles of future energy storage systems including high-performance futuristic batteries.

2. Summary for FY1994

(1) Research and Development Work on Electric Vehicle Charging Systems

(a) Development of charging systems

Rapid charging stations utilizing systems for storage of nighttime power supplies were developed, and methods of supplementary daytime charging were introduced, thus permitting increases in the mileage of electric vehicles. The configuration and specifications of the rapid charging system are as follows.

(b) Fleet tests with electric vehicles

(i) Implementation of fleet tests

Fleet tests using the facilities established in fiscal 1992 and 1993 were continued, the following two business establishments were newly created with due consideration for business sectors, regional factors, and climate, etc., commercially marketed electric vehicles with proven market achievements were selected, and rapid charging stations were established.

(ii) Measurement of electric vehicle driving performance and battery characteristics

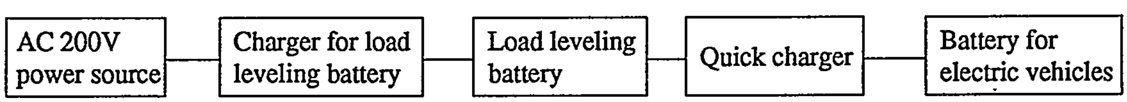
With the objective of evaluating the performance history of electric vehicles initial characteristics and temporal changes in vehicle performance were measured using vehicles procured in fiscal 1992 and 1993 as well as those newly procured in fiscal 1994.

(2) Survey and Studies on Systems for Mass Introduction of Electric Vehicles

Surveys and studies conducted in this area included measurements of running power consumption of electric vehicles and studies of new type load-leveling batteries, as well as surveys of actual electric vehicle fleet tests and rapid charging facilities in Japan and abroad, legal regulations concerning the establishment of rapid charging stations, and relevant technical problems.

(3) Surveys and Studies on High-Performance Energy Storage Systems for Electric Vehicles

Surveys were conducted concerning high-performance storage batteries for electric vehicles and other futuristic energy storage systems.



Configuration of Quick Charging System

Specifications of Quick Charging System

	Specifications	
Load leveling battery (LL battery)	Charging method:	Controlling charge start time according to remaining capacity of battery and using midnight power applying from 23:00 till 7:00.
	Battery type:	Enclosed lead acid battery
	Data management:	Data processing using personal computers
Quick charger	Output power:	150A (1C)
	Charging capacity:	About 50% of the full capacity
	Charging time:	About 30 minutes

State of Electric Vehicles and Installation of Quick Chargers

Company/organization	Business field	Location	Electric vehicles	
Mie Prefectural Office	Municipal office	Tsu-shi, Mie Prefecture	Nissan Cedric	1
			Toyota Town Ace	2
			Daihatsu Hi-Jet Van	2
Kyushu Electric Power Co., Ltd.	Public utility	Fukuoka-shi, Fukuoka Prefecture	Toyota Town Ace	2
			Daihatsu Hi-Jet Van	2
			Suzuki Alto	1

VI

Technological Development of a Wide-Area Energy Utilization Network System (Urban Eco-Energy System)

1. Objectives and Work Program

Although energy-saving measures have been actively promoted in the industrial sectors of Japan, considerable quantities of low-temperature heat are still being discharged. This is partially due to the fact that the effective utilization of this exhaust heat in plants is difficult owing to its low temperature level (under 200°C).

Utilization of this exhaust heat in urban areas with high heat demand would result in a significant savings of energy consumed. However, in view of the present state of steam and hot water transport technology, efficient long-distance transport cannot be expected owing to a large amount of heat loss. From this viewpoint, the objective of the present area of research and development work will consist in the development of high-efficiency, long-distance heat transport technology and the establishment of techniques for efficient utilization of thermal energy.

2. Development Schedule

Research and development work in this connection is to be continued over an eight-year period, commencing in fiscal 1993, and will undergo interim evaluation in fiscal 1996 (Table 1).

3. Description of Research and Development Work

As regards the content of research and development work, studies are to be conducted on themes including heat recovery techniques, heat transport and storage techniques, heat supply and utilization techniques, and systematization techniques. Research and development work has been conducted on basic technologies for the system from fiscal 1993.

3.1 Heat Recovery Techniques

Research and development work is to be conducted on techniques for recovery of sensible and latent heat with a view to waste-free multistage recovery of industrial waste heat discharged from steel plants, chemical plants, and LNG thermal power plants, etc., in accordance with the temperature range concerned up to the vicinity of atmospheric temperature.

[Content and Topics of Research]

(1) Research and Development Work on Techniques for Recovery and Utilization of Heat from Facilities for Manufacture of Granulated Slag at Steel Plants

Table 1 Research and Development Schedule

R & D item \ Fiscal year	1993	1994	1995	1996	1997	1998	1999	2000
Heat recovery technologies	Development of basic technologies and fabrication of bench unit →				Interim evaluation	Design and fabrication of pilot plant and operating study →		
Heat transportation and storage technologies	Development of basic technologies and fabrication of bench unit →				Interim evaluation	Design and fabrication of pilot plant and operating study →		
Heat supply and utilization technologies	Development of basic technologies and fabrication of bench unit →				Interim evaluation	Design and fabrication of pilot plant and operating study →		
Peripheral technologies	Development of basic technologies and fabrication of bench unit →				Interim evaluation	Design and fabrication of pilot pland and operating study →		
Systematization technology	Basic study and optimum desing of subsystem →				Interim evaluation	Optimum design of total system →		

Development work will be applied to techniques for stable recovery of latent and sensible heat from the polluted waste gases and thermal effluents discharged from facilities for manufacture of granulated slag at the blast furnaces of steel plants.

(2) Research and Development Work on Exhaust Heat Reforming and Recovery Systems at Chemical Plants

Technological development work will be devoted to systems capable of recovering waste heat from the heads of internal heat exchange type distillation columns in the form of steam at a temperature on the order of 150°C.

(3) Research and Development Work on Heat Recovery Utilizing Hydrogen-Absorbing Alloys

Technological development work will be applied to systems for recovering and utilizing low-temperature waste heat from the condensers and LNG cooling equipment of LNG thermal power plants in order to elevate the pressure of low-pressure hydrogen by means of hydrogen absorbing alloys and convey the resulting high-pressure hydrogen to heat transport lines.

(4) Research and Development Work on Systems for Recovery of Waste Heat from Exhaust Gases, etc.

Technological development work will be directed toward recovery of latent and sensible heat from sources such as the combustion exhaust gases of power plants and the polluted thermal effluents of steel plants.

(5) Research and Development Work on Air Cycle System Techniques for Waste Heat Recovery

Techniques will be developed for recovery of heat at a temperature of approximately 80°C from combustion waste gases at temperatures below 200°C, using air cycle heat recovery systems formed by combining compressors and expanders.

(6) Research on Techniques for Recovery of the Latent Heat of Steam from the Combustion Waste Gases of Electric Power Plants in the Form of Hot Water

As regards systems for the recovery of the latent heat of steam from the combustion waste gases of electric power plants, studies will be conducted in connection with the practical feasibility and energy-saving merits of waste heat utilization.

(7) Research on Systems for Recovery of the Latent Heat of Steam in Combustion Waste Gases of LNG Thermal Power Plants

Studies will be conducted on the feasibility as well as problem points and measures for their solution in connection with the techniques necessary for effective utilization of waste heat from LNG thermal power plants.

3.2 Heat Transport and Storage Techniques

Research and development work will be applied to the efficient long-distance transport of industrial waste heat to urban residential and business districts several tens of kilometers distant from the industrial zones where the heat is generated.

3.2.1 Technical Development Work on Processes Employing Waste Heat at Temperatures Above 150°C to Decompose Methanol, Etc., Transport the Generated Hydrogen-Carbon Monoxide Gas Over Long Distances (of the Order of 30km), and Supply the Heat by Chemical Reactions at the Demand Sites

[Research Topics and Their Content]

(1) Research and Development Work on Methanol Energy Systems

Development work will be devoted to the techniques necessary for construction of an energy system for heat recovery, transport, and supply using two-stage methanol decomposition reactions with ethyl formate as an intermediate.

(2) Research and Development Work on Techniques for Non-Equilibrium High-Efficiency Methanol Decomposition Reactions

Technological development work will be conducted in connection with non-equilibrium high-efficiency methanol decomposition reactors incorporating selective hydrogen separation membranes.

(3) Research and Development Work on Equilibrium Type High-Performance Methanol Decomposition Reactors and Methanol Synthesis Catalysts

Technical work will be devoted to the development of catalysts for decomposition and synthesis of methanol by gaseous phase methods as well as equilibrium type reactors for methanol decomposition and synthesis.

3.2.2 Technical Development Work on Processes for Utilizing Hydrogen-Absorbing Alloys to Convert Waste Heat at Temperatures above 80°C into Hydrogen Pressure, Transporting the Hydrogen over Long Distances (on the Order of 10km), and Supplying the Heat by Means of the Alloys at the Demand Sites

[Topics and Content of Research]

(1) Research and Development Work on Heat-Hydrogen Recovery, Transport, and Utilization Techniques

Technical development work will be applied to systems for utilizing waste heat at temperatures on the order of 80-150°C, releasing high-pressure hydrogen by means of hydrogen-absorbing alloys, using this hydrogen to transport energy, and generating thermal outputs of 80°C and -20°C at the demand sites.

(2) Research and Development Work on Heat and Cold Supply Systems for Daily Living

Four types of hydrogen-absorbing alloys will be developed, i.e., high-temperature (150°C), intermediate temperature (80°C), and low-temperature (45°C, 7°C), and double-effect waste heat utilization systems supplying both heat and cold will be developed by combining these types of alloys.

(3) Research and Development Work on High-Response Hydrogen Absorption and Release Systems Utilizing Hydrogen-Absorbing Alloys

Technological development work will be conducted in connection with reactors packed with hydrogen-absorbing alloys for heat storage, possessing high-response hydrogen absorption and release characteristics.

(4) Research on Network Systems Utilizing Hydrogen

As regards hydrogen networks for heat transport, development work will be applied to techniques for pressure control and safety management systems.

3.3 Heat Supply and Utilization Technology

Development work will be devoted to techniques for utilizing transported heat and supplying this heat in accordance with demand characteristics in a multifunctional and high-efficiency manner for purposes such as regional heat and cold supplies, hot water supplies, and refrigerated warehouses at urban demand sites.

[Topics and Content of Research]

(1) Research and Development Work on Multi-temperature Heat Supply Systems

Technical development work will be applied to gas engine heat pump systems for decomposition of methanol, permitting output of various grades of hot and cold heat from a single system.

(2) Research and Development Work on Heat Utilization System of the Hybrid Compression and Absorption Type

Work will be directed toward developing a CFCs-free heat pump system of the compression and absorption hybrid type that produces a cold output of -10°C using heat of about 100°C.

(3) Research and Development Work on Cooling System of the Cold-Generating and Exhaust Heat-Using Absorption Type

Effort will be directed at developing technology for a refrigeration system combining two sets of absorbers and evaporators that generates cold heat (-6°C) utilizing heat of some 150°C.

(4) Research and Development Work on Bidirectional Heat Siphon Heat Pipe

Heat pipes will be developed that can transport heat and cold about 100 meters vertically in both directions.

3.4 Peripheral Technologies

To efficiently develop basic techniques and systematization technology, work will be carried out to develop techniques common to all these and to develop peripheral technologies.

[Topics and Content of Research]

(1) Research and Development Work on Porous Structured Thermoelectric Power Generation System

Technological development work will be devoted to systems for recovering electric power by including autocombustion of low-calorie exhaust gases within porous structures incorporating high-efficiency direct thermoelectric exchange elements.

(2) Research and Development Work on Flow Measurement Technology for Polluted Fluids

Work will be devoted to the development of technology for non-contact, continuous and accurate measurement of polluted exhaust gas and warm effluent flows.

(3) Research and Development Work on Cold Supply System Using Microspheres

Technological development work will be conducted in connection with systems permitting high-density cold transport using microsphere/liquid slurries with low solidification, low cohesion characteristics and a melting point in the vicinity of 0°C.

3.5 Systematization Technology

Development work will be directed toward techniques for ensuring conformity of the various basic constituents of thermal systems (heat recovery, transport, storage, and utilization, etc.) and permitting their incorporation into overall systems, as well as design techniques for optimization of broad systems networking multiple heat sources and heat consumption sites.

[Topics and Content of Research]

(1) Research on Design and Evaluation of Total Systems

Studies will be conducted on the construction of thermal energy models and their use for the introduction of energy network systems into actual localities in urban areas where multiple heat sources and heat demands are present.

(2) Overall Adjustment of Basic Techniques

Technological investigations will be made and comprehensive adjustment will be effected in connection with the content of basic technological research and development work relating to heat recovery, transport, storage, and utilization, etc., with a view to permitting the establishment of well-balanced networks as energy systems.

(3) Research on Systematization and Evaluation Techniques

Concerning basic techniques for establishing an energy network system, evaluation methods for the overall system will be developed. Furthermore, studies will be conducted on technology for establishing a total system by combining the basic techniques.

(4) Surveys on the Current state of Waste Heat Discharge and Heat Requirements

Surveys will be conducted with reference to the quantitative data on waste heat discharge and heat demand necessary for studies on the design and feasibility of introduction of an energy network system, and a database will be established.

(5) Surveys on Advanced Basic Technologies Related to Wide-Ranging Energy Utilization

Surveys will be conducted in order to ascertain domestic and foreign trends relating to advanced basic technologies regarded as feasible with respect to incorporation into future generations of energy networks, and the relevant technical evaluation studies will be implemented.

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CHAPTER 7

DEVELOPMENT OF HYDROGEN, ALCOHOL AND BIOMASS TECHNOLOGIES

DEVELOPMENT
OF
HYDROGEN, ALCOHOL
AND BIOMASS TECHNOLOGIES

Contents

I

Demonstration Tests for Converting Thermal Power Plant Fuel from Oil to Methanol

Methanol is expected to be an oil-alternative energy source effective in diversifying fuel for power generation. This is attributable to its following features: (1) It is in liquid form at normal temperatures (boiling point: 65°C), and it is easily transported and stored, (2) it is a clean fuel, and (3) many raw-material resources are available, such as natural gas and coal, as well as unexploited natural gas resources (small or medium-sized gas fields unsuitable for LNG).

In this research, the study of various problems related to methanol supply, implementation of verification tests regarding environmental safety, development of methanol engine systems for power generation, elemental research and total system-based verification tests of reformed-methanol power generation, and overall evaluation survey of methanol-based power-generation technologies have been implemented. The purpose is to establish methanol-based power-generation technologies as part of an effort to promote the fuel conversion of oil-fired power plants. Diversification of power sources will be thereby attained.

1. Demonstration Tests of Reformed-Methanol Gas Turbine Power Generation Total System

(1) Objectives and Work Program

This research project is operate and conduct research on a 1,000kW-class total system composed of various elements, based on results of the elemental research conducted for three years from 1985. The aim is to verify the outcome of the elemental research, to check system efficiency, the planned functions and performance of the system (such as NOx characteristics; 30 ppm or less, $O_2 = 16\%$), load response function, and start-up termination performance, and further to confirm the reliability of the system as a power generation system. Thus, the research and evaluation aims to develop technology for the practical utilization of such a system. The schedule of the research is shown in Table 1 and schematic diagram and specification are indicated in Fig. 1.

(2) Summary for FY1994

Based on operation/research results of the 1,000kW-class total system plant, completed in fiscal 1993, superiority and characteristics of a reformed-methanol gas turbine power generation system were confirmed, and extraction of its technological problems in the practical utilization of the system and the study of their countermeasures were carried out in fiscal 1994.

Table 1 Schedule of Demonstration Tests on a Reformed Methanol Gas-Turbine Power Generation Total System

Item \ Fiscal year	1988	1989	1990	1991	1992	1993	1994
• Design and manufacture							
• Basic engineering							
• Installation							
• Operational research							
• Overall evaluation							

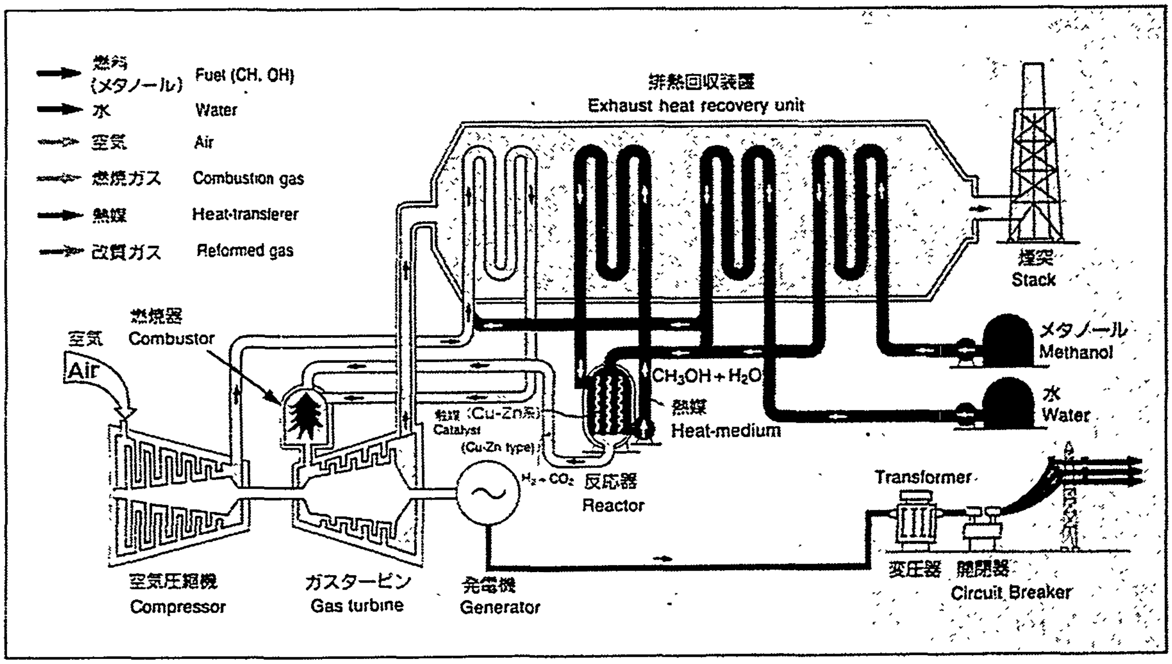


Fig. 1 Schematic Diagram and Major Specifications of Reformed-Methanol Gas Turbine Power Generation Total System

- Output: 1,000 kW class (905 kW)
- Type: Methanol-reforming, water injection and regenerative type
- Gas turbine:
  Gas temperature at inlet: 1,000°C
  Pressure ratio: 10.2
- Heat recovery rate: Approx. 70%
- Methanol reforming rate: 80% or more
- Catalysts: Cu-Zu-Al base catalyst
- Generation efficiency: 31% or more (HHV equivalent)
- NOx: 30 ppm or less (O_2=16%)

Items of research conducted in the above perspective were as follows:

(a) Research on a catalyst

(i) Production and actual utilization study of a catalyst

Based on results of property analysis of a catalyst extracted from the total system plant and of bench equipment tests, catalyst specifications (including the method of its handling and regeneration frequency) were determined on an actual-use scale to pave the way for the practical utilization of the reformed-methanol gas turbine power generation system.

Also, there appeared sufficient prospects for the industrial mass production and supply of the catalyst, as well as for automated catalyst filling.

(ii) Research on extension of the catalyst service life

Based on results of the impurity analysis of the catalyst from the total system plant and of bench equipment tests, methods of extending the service life of the catalyst were studied with an eye to realizing the practical utilization of the reformed-methanol power generation system.

As a consequence, it was concluded that the activity decline of the catalyst is attributable to poisoning due to impurities contained in methanol. As such, it became clear that, if impurities, chlorine compounds in particular, are removed, there is a strong possibility that the service life of the catalyst can be extended.

(b) Research on heat recovery/reaction systems

Based on the disassembling study of bench reactor testing equipment and the total system plant (heat recovery and reaction systems, such as a reactor and evaporator), the evaluation of the equipment in relation to methanol and reformed gas was carried out. It was ascertained that there are little effects of hydrogen embrittlement.

The concept design of a large-sized reformer/reactor was carried out for the purpose of practical utilization of the reformed methanol-type power generation system. Consequently, it became clear that the operation period of 8,000 hours and the reforming ratio of 80% or more can be achieved. The concept design of a regenerator was also implemented, which led to our conviction that the regenerator can deal with the high-temperature gas turbine if a plate-fin type is adopted.

(c) Research on combustion

Based on the disassembling study of the total system plant (the combustion system, consisting of a gas turbine, combustor, fuel lines, etc.), the evaluation of equipment materials in relation to methanol and reformed gas was carried out, and it was confirmed that there are little effects of high-temperature oxidation and hydrogen embrittlement.

For the practical utilization of the reformed-methanol gas turbine power generation, the concept design of the 1,350°C-class gas turbine, a more efficient turbine, was implemented. As a result, prospects for such a low NOx exhaust density as 12.5 ppm became apparent. This turbine will be advantageous in terms of effects on the environment, and because no denitration equipment is required, it is also advantageous in regard to cost.

(d) Study and evaluation of the system

Based on results of the operation tests

and system simulation of the total plant system, the overall evaluation of the system was carried out from the standpoint of an electric power user. As a result, the superiority and characteristics of the reformed-methanol-type power generation were ascertained.

In accordance with the practical-scale concept design of a 1,350°C (inlet gas temperature)-class gas turbine related to research on the catalyst, heat recovery/reaction systems and combustion, and concept designs of reformed methanol-type power generation systems were developed as the optimum systems for 1MW-class, 40MW-class (20MW x 2 axes), 200MW-class, and 1,000MW-class (317MW x 3 axes) power generation plants. Furthermore, their performance and economy were compared with LNG-combined power generation.

Principal results of the concept design of a 1,000MW-class power generation plant are shown in Table 2, and an overhead view is shown in Fig. 2.

The unit construction price is less than 70% that of the LNG-combined power generation system, partly because the construction cost of fuel storage facilities is lower and partly because denitration equipment and a steam turbine are unnecessary. Other characteristics are as follows:

- Because there is no separate steam turbine unit, cooling water for the condenser is unnecessary, and it is possible to establish the system at an inland location.
- In addition to no hot waste water being generated, exhaust gas contents feature a low NOx level and an absence of SOx and soot/dust; thus, the environmental characteristics of the system are excellent.

Judging from such study results, the reformed-methanol gas turbine power generation system is considered very attractive as a high-efficiency system capable of competing with LNG-combined power generation systems.

Table 2 Results of Major Conceptual Design of 1,000-kW Class Power Generation Plants

Item		Reformed-methanol power generation plant	LNG-combined power generation plant
Generation efficiency		46.7 %	48.5 %
Unit cost of construction		¥157,000 /kW	¥242,000 /kW
Unit cost of calorific value		¥3,170 /1,000 kcal	¥1,540 /1,000 kcal
Unit costs of power generation	Utilizing rate 30%	¥22.9 /kWh	¥26.8 /kWh
	Utilizing rate 70%	¥13.8 /kWh	¥13.1 /kWh

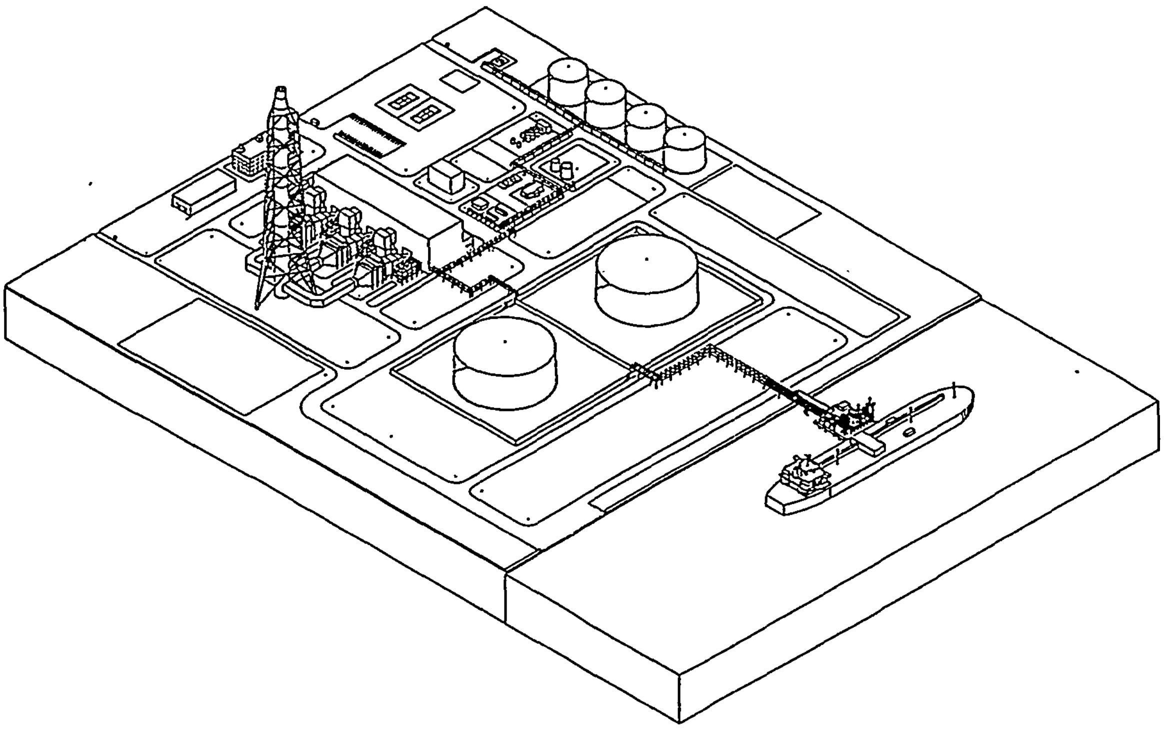


Fig. 2 Overhead View of 1,000-kW Class Reformed-Methanol Power Generation Plant

2. Overall Evaluation Research on Methanol-Based Power Generation Technology

(1) Objectives and Work Program

This R&D project is intended to study and evaluate, based on the results of research made so far and trends of various high-efficiency power generation technologies in recent years, efficiency and other characteristics, performance, economy and achieved technology level for usable power generation systems that employ methanol as fuel. For the actual utilization of such systems, furthermore, introductory types and conditions, as well as methanol distribution systems (manufacturing, storage and transport), will be studied and overall evaluation will be made regarding outlook for the introduction of methanol-based power generation technology.

(2) Summary for FY1994

During fiscal 1994, various kinds of recent high-efficiency power generation technologies were examined, and the concept design of a methanol-based power generation system was carried out.

Each research execution item is outlined below.

(a) Trends of methanol-based power generation technologies

Investigation into the current technology level was implemented with regard to the following methanol-based power generation systems:

- Reformed-methanol-type power generation
- Methanol engine systems for power generation use
- Phosphoric acid-type fuel batteries

(b) Characteristics of methanol

When methanol and LNG were compared, it was confirmed that the theoretical combustion air volume required to obtain the same quantity of heat is about 10% more in the case of LNG, that their exhaust gas is almost the same and that CO_2 in the exhaust gas of methanol is somewhat greater.

There are two methods of recovering heat based on methanol chemical reactions: using the endothermic reaction during reforming reaction, when methanol is reformed, through reaction to water, into H_2 and CO_2, and using the endothermic reaction during its decomposition reaction into H_2 and CO_2. When the higher heating value (HHV) of reforming gas (H_2) and decomposition gas (H_2, CO) were compared, it was ascertained that they were almost equal.

(c) Evaluation of methanol-based power generation technology

The concept design of the following methanol-based power generation systems was implemented to calculate their respective efficiency and construction costs and to extract technological development problems concerned.

- Methanol-stoking gas turbine cycle
- Methanol-decomposition-type gas turbine cycle
- Reformed-methanol-type gas turbine cycle
- Methanol-stoking combined cycle
- Methanol-gas-stoking combined cycle
- Methanol-decomposition-type combined cycle
- Reformed methanol-type combined cycle

As a result of such activities, it was concluded that the gas-stoking, decomposition and reformed types of combined cycles are highly attractive as high-efficiency power generation methods because they feature efficiency as high as 47-49% and because their unit construction cost is more than 20% lower than new LNG stations, although their efficiency is about the same as new LNG stations. It was also concluded that decomposition-type and reformed-type gas turbine cycles are suitable for peak power sources because, although their efficiency is about 45% lower, it is sufficiently higher than conventional steam power generation and also because their unit construction cost is lower than that of the combined cycle.

Regarding principal technological development tasks, it was learned in the case of decomposition-type or reforming-type systems that it is necessary to develop and demonstrate multi-fuel combustion equipment capable of converting fuel into methanol liquids, methanol gas, decomposed gas or reformed gas.

(3) Future Tasks

As in fiscal 1994, power generation technologies that can use methanol as fuel will be studied and evaluated. At the same time, surveys will be made on the technological development status of methanol distribution systems (manufacturing, storage and transport), and an overall evaluation will be made regarding the outlook for the introduction of the total system covering the whole range from methanol production to power generation.

II

Development of High-Efficiency Waste Power Generation Technology

1. Objectives and Work Program

With a view to seeking effective utilization of unused energy, technological development will be pursued to achieve high-efficiency power generation by generating high-temperature, high-pressure steam in a stable manner through the use of an incinerator that burns high-calorie municipal solid waste and combustible industrial waste.

To be more specific, technological development to realize high-temperature and high-pressure steam conditions (steam temperature 500°C and steam pressure about 100 kg/cm^2), which are currently 300°C and less than 30 kg/cm^2, will be implemented.

The schedule for the work is as shown in Table 1.

Table 1 Development Schedule

	1991	1992	1993	1994	1995	1996	1997	1998
1. Technological development of high-efficiency waste power generation technology								
(1) Development of high-temperature, high-efficiency incinerator								
1) Development of stoker incinerator	←	—	—	Interim evaluation →				
2) Development of internal circulation-type fluidized bed incinerator	←	—	—	Interim evaluation	—	→		
(2) Development of corrosion-resistant superheater	←	—	—	Interim evaluation	—	—	—	→
(3) Development of environmental load reduction technology	←	—	—	—	—	→		
(4) Research on optimal total system		←	→					
2. Research on evaluation technology of the environmental effects of high-efficiency waste power generation technology								
(1) Technological research by pilot plant					←	—	—	→
(2) Study of optimum total system					←	—	—	→

2. Summary for FY1994

(1) Technological Development of High-Efficiency Waste Power Generation Technology

This project was started in November 1991. During fiscal 1994, the development of a high-temperature, high-efficiency incinerator, a corrosion-resistant superheater and environmental load reduction technology and the study of an optimal total system were implemented as in fiscal 1993.

Incinerators studied were the stoker incinerator and the fluidized bed-type incinerator. Regarding the stoker incinerator, attainment of high temperature and high pressure has been pursued through development of superheater materials and design contrivances. As for a fluidized bed-type incinerator, the achievement of high temperature and high pressure has been pushed for by reducing the corrosive environment of the superheater through the use of existing carbon steel and low-alloy steel as its materials.

(a) Development of high-temperature, high-efficiency incinerators

(i) Development of a stoker incinerator

a. Single-flow type

• Optimization of the incinerator structure was pursued by analyzing programs that used analysis codes, which were demonstrated, based on actual incinerator data and test-incinerator data.

• Concerning the optimization of combustion, changes in combusting conditions resulting from the alteration of waste composition and caloric value were investigated using a test incinerator, and optimum air conditions were determined.

• As for the study of the evaporator tube structure, durability tests and evaluation of flame-coated tubes were carried out using an actual incinerator. Anti-corrosive coating materials were also evaluated and chosen.

b. Double-flow type

• The optimum combustion conditions and methods for controlling the combustor were studied.

(ii) Development of a fluidized bed-type incinerator

a. Internal circulation-type

• Durability tests of heat exchanger tubes and measurement of the corrosive environment were carried out using an actual incineration plant. Steps to mitigate the seriousness of the corrosive environment were also studied.

• Using an actual internal circulation-type incineration plant, long-term exposure tests of superheater materials were implemented, and metals suitable for the internal circulation-type incinerator were selected.

b. External circulation-type

• With regard to the automatic operation control system for a hot model (test facility), combustion conditions for simulated refuse, refuse-derived fuel (RDF) and combustible industrial waste were studied, with the optimum conditions set as a result.

• Incineration tests were implemented seven times, and various data were collected during the combustion of simulated refuse, RDF, car shredder dust and waste plastic.

(b) Development of a corrosion-resistant superheater

• Concerning new metal development,

new metals to be tested in secondary corrosion tests in the actual plant were developed, and their mechanical properties (high-temperature creep, artificial aging) were investigated.

• The secondary corrosion tests (testing hours: 700~3,000 hours; 4 actual plants; metal temperature, 450°C and 550°C) were implemented to evaluate the life of newly developed materials. Based on results of the first and second corrosion tests, metals for experiments at the pilot plant were chosen for each temperature (steam temperature 450°C and 500°C).

• In an investigation regarding superheater tube metal, effects of environmental conditions (gas temperature, tube alignment, etc.) on corrosion were examined.

(c) Development of environmental load reduction technology (development of a pulse-corona-induced plasma chemical process (PPCP) exhaust gas treatment method)

• Basic PPCP performance tests were carried out using a small-scale testing facility (exhaust gas volume: 50Nm^3/h). More than 90% of dioxin, mercury, sulfur oxides, hydrogen chloride and soot) could be removed. As for nitrogen oxides, further study is required, partly because their density in the exhaust gas was low.

• Large-sized testing facility (exhaust gas volume: 5,000Nm^3/h) was designed, with some of the related equipment manufactured.

(2) Research on Evaluation Technology of the Environmental Effects of High-Efficiency Waste Power Generation Technology

(a) Technological research at pilot plant

The location of a pilot plant was decided, and preparations to apply for authorization regarding the pilot plant were made. The conceptual design of the pilot plant was carried out, with specifications determined.

Principal specifications were as follows:

Capacity: 50t/24h x 1

Power output: 800kW

Steam conditions: 100kg/cm^2, 500°C

Incinerator type: Stoker incinerator

Boiler type: Single drum, natural circulation, water tube boiler

Turbine type: Condensing-type turbine

Construction site: Aoyama, Tsukui-machi, Tsukui-gun, Kanagawa Prefecture

(b) Study of optimum total system

In connection with high-efficiency waste power generation, the conceptual design of a large-scale plant was carried out, and its economy was calculated on a trial basis. Furthermore, the study of an optimum system and research on related technologies were carried out.

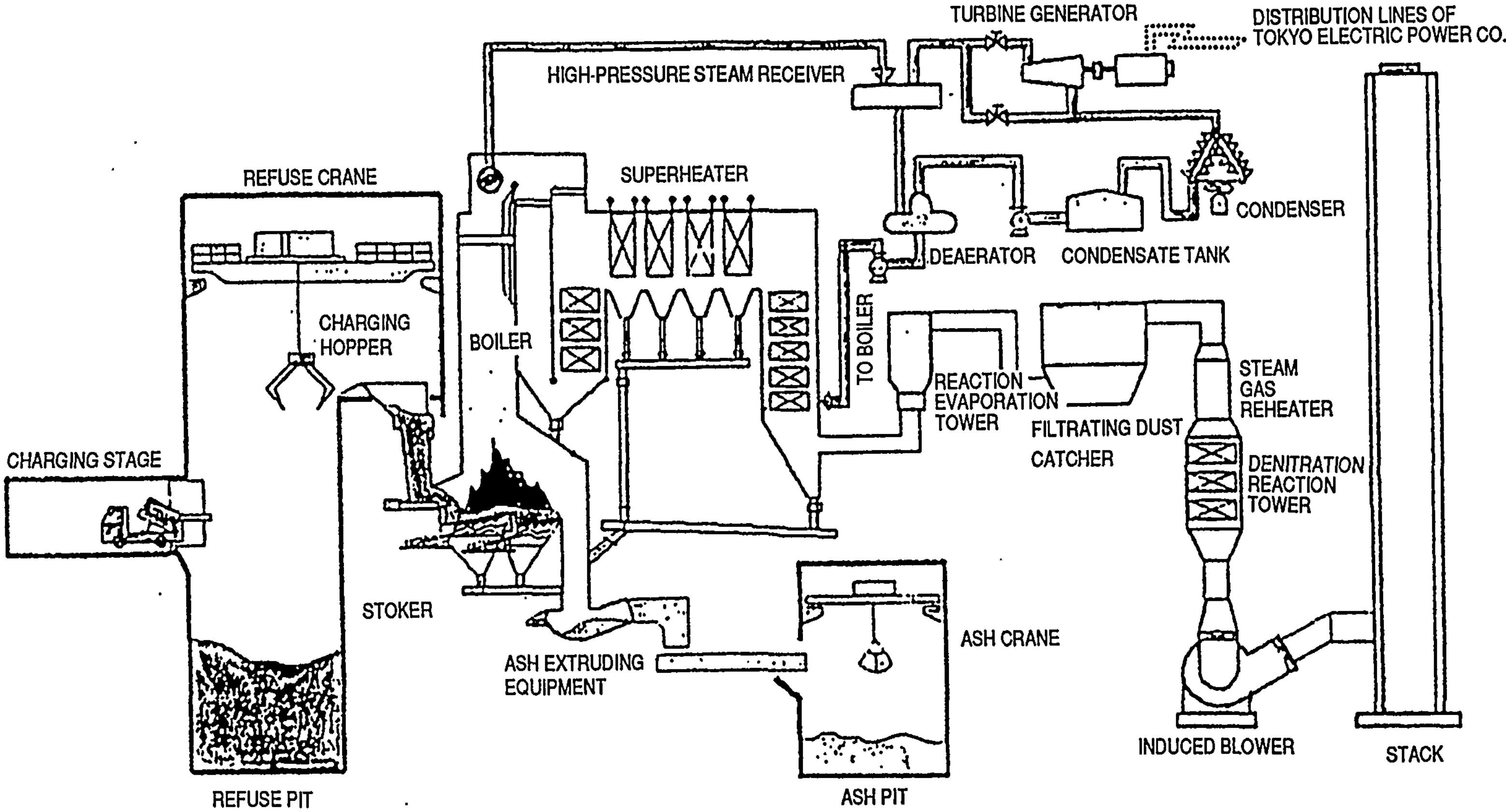
3. Future Tasks

(1) High-Efficiency Waste Power Generation Technology

(a) Development of a high-temperature, high-efficiency incinerator (development of an external circulation-type fluidized bed incinerator)

Combustion tests will be continued using a hot model, and practical utilization study will be carried out.

(b) Development of a corrosion-resistant



Basic Flow Chart

superheater

Prototype tubes will be manufactured using candidate materials (existing and newly developed materials) selected through primary and secondary corrosion tests, and tests regarding special-recognition items will be implemented with consideration given to their application to the pilot plant. Study will also be made of welding-use metal and flame-coating metal applications. Furthermore, the third set of corrosion tests at an actual plant, as well as small-scale tests, will be continued.

(c) Development of environmental load reduction technology (PPCP exhaust gas treatment method)

An large-sized testing facility will be manufactured and installed, and performance tests will be conducted.

(2) Research on Evaluation Technology of the Environmental Effects of High-Efficiency Waste Power Generation Technology

The detailed design development of the pilot plant will be continued, and civil engineering work and the manufacturing of some equipment will be undertaken.

III

Development of Methane Gas Production System from Municipal Solid Waste (MSW)

1. Objectives and Work Program

While the volume of waste being produced continues to rise, mostly because of greater domestic consumption, constructing new waste incineration plants and finding space for new landfills is becoming more and more difficult. This situation poses a serious problem.

Domestic waste consists mainly of organic substances which can actually be a valuable energy resource. Recognizing the energy potential of waste, this project aims to produce methane gas through solubilization treatment and biological fermentation. The project will also recover heat, a by-product of the solubilization treatment, as well as water, which will be purified through advanced treatment.

Thus, this project is implemented for the principal purposes of 1) developing waste solubilization technology, 2) developing element technologies for high-efficiency methane fermentation and 3) constructing a total system and researching system optimization for the purpose of eventually introducing it into residences and cities.

2. Summary for FY1994

(1) Development of Solubilization Technology for Powdered Simulated Refuse

(a) Conditions for producing solubilization solutions suitable for methane fermentation were established by dividing refuse into plastics and paper and applying physico-chemical solubilization treatment to each of them.

(b) With regard to biological solubilization, attempts were made using mixed samples of kitchen garbage and sludge, and conditions for producing solubilization solutions suitable for methane fermentation were successfully established.

(2) Development of High-Efficiency Thermophilic Methane Fermentation Technology for Powdered Simulated Refuse

Methane fermentation based on physico-chemical solubilization solutions was implemented under the membrane-type continual fermentation method or UASB (Upflow Anaerobic Sludge Blanket) type fermentation method, and also biological solubilization using the membrane-type continual fermention method. The characteristics of these fermentations were subsequently compared and investigated.

As a result of these fermentation results, it is clear that practical utilization is possible in all of the following cases: 1) membrane-type continual and UASB type fermentation using physico-chemical solubilization solutions, 2) membrane-type continual methane fermentation using biological solubilization solutions and 3) membrane-type continual methane fermentation using a mixture of physico-chemical solubilization solutions and biological solubilization solutions.

(3) Study on a Total System

Concerning the technology to treat household garbage and waste water and to recover methane gas and water at the same time, a total system was constructed based on the results of elemental research work carried out so far. With a view to realizing social and economic utilization and introduction of the technology, economic evaluation was implemented in terms of material balance, the residual ratio of solid contents, generated gas (methane, carbon dioxide, etc.) and energy balance for the purpose of constructing the conceptual design of a total system.

3. Future Tasks

In fiscal 1994, the technology for solubilization treatment of waste similar to actual refuse was established, and elemental data on thermophilic methane fermentation was obtained. In fiscal 1995, physico-chemical solubilization and biological solubilization will be applied to the actual refuse samples. The most suitable solubilization conditions, such as the reaction conditions and the density of dissolved organic substances, will then be confirmed. Problems involved in the practical utilization of the technology will also be examined. Furthermore, results of research since fiscal 1991 will be summarized, and the total system will be comprehensively evaluated.

IV

Joint Cooperation on Research and Development of Simple Purification System for Industrial Waste Water

1. Objectives and Work Programs

This research aims to develop a simple, low-cost purification system to reduce water pollutants through anaerobic treatment of water in Thailand and other developing countries.

Five-year research cooperation started in fiscal 1992 for Thailand, in fiscal 1993 for Indonesia and in fiscal 1994 for Malaysia.

2. Summary for FY1994

(1) Thailand

(a) The manufacturing and installation of a pilot plant for anaerobic treatment were completed, and operation research was started.

(b) Reactor applicability tests using bench-scale unit were conducted, and data necessary for the operation of a pilot plant were obtained.

(2) Indonesia

(a) Field survey was carried out as in the previous year, and target waste water was actually selected.

(b) Laboratory-scale testing was implemented, and it was confirmed, as a result, that the 80% COD removal ratio is attainable.

(c) The detailed design and partial manufacturing of a pilot plant were carried out.

(3) Malaysia

Local surveys were carried out to choose the kinds of waste water to be studied, and high-concentration organic waste water was selected as the research candidate.

(4) Common Achievements for the Three Countries

(a) A survey of information was conducted in Japan with regard to the possibilities of applying this system. As part of domestic support research in Japan, basic tests were conducted, using laboratory-scale testing equipment.

(b) Researchers were invited to Japan from Thailand and Indonesia. These researchers were given necessary training with regard to the projects to be launched in their own countries.

(c) A conference on industrial wastewater treatment among four countries was held in Bangkok in January 1995.

3. Future Tasks

The following research cooperation is scheduled to be conducted in fiscal 1995.

(1) Thailand

(a) The operation research of the pilot plant will be continued.

(b) Basic testing, such as granule forming tests, will be carried out.

(2) Indonesia

(a) Reactor applicability tests are scheduled to be conducted, using a bench scale testing unit.

(b) A pilot plant will be completed to start operation research.

(3) Malaysia

(a) The kinds of waste water to be investigated will be determined, and basic tests will be launched using a bench-scale testing unit.

(b) The details of a pilot plant will be designed and some equipment will be manufactured.

(4) Common for the Three Countries

(a) Supporting research will be implemented in Japan in order to assist the basic tests in the three countries.

(b) Researchers from the three countries will be trained in Japan.

(c) The second conference on industrial wastewater treatment among the four countries is scheduled to be held in Jakarta, Indonesia.

Pilot Plant in Thailand

V

Development of Integrated Recycling System for Used Household Electrical Appliances Using Cryogenic Energy

1. Objective and Work Program

(1) Objectives

Cryogenic crushing technology for waste and separation and recovery technology for plastics using cryogenic energy for LNG will be developed in order to promote the recycling of, and energy recovery from, large-scale waste, such as used household electrical appliances, which are not now sufficiently recycled. Based on these technologies, the establishment of an integrated recycling system will be achieved.

(2) Work Program

Some iron is recovered from large-scale waste, such as used household electrical appliances that are now being discarded in large quantities, but most of the other resources (especially plastics) are buried or burned, and so are not effectively recycled. When effective classification and recovery technologies and utilization know-how are established, however, such waste can be a valuable resource or energy source. In addition, this kind of recovery will be very significant from the viewpoint of global environmental protection. For this reason, a comprehensive household electrical appliance recycling system based on cryogenic crushing that effectively utilizes the cryogenic energy of LNG will be built for the four years from fiscal 1992 to fiscal 1995.

The conceptual design diagram is shown in Fig. 1. Generally, substances become brittle at a low temperature, with the point of brittleness varying according to the substance. The system is designed to achieve crushing/separation recovery, utilizing these brittleness point differences. In other words, motors and compressors of discarded refrigerators and other household electric appliances are removed, soaked in liquid nitrogen and crushed at an ultra-cryogenic temperature, with iron, copper and aluminum to be recovered through magnetic selection or eddy current separation. Regarding plastics, on the other hand, crushing is carried out in a low-temperature nitrogen gas atmosphere, and crushed plastics are divided into polyvinylchloride and polyolefine types based on the brittleness point differences. The purity of collected substances is further enhanced through specific gravity separation.

The development schedule is shown in Fig. 2.

2. Summary for FY1994

In fiscal 1994, elemental technologies were developed, and equipment necessary for the building of a pilot plant — ultra-cryogenic crushing equipment, low-tem-

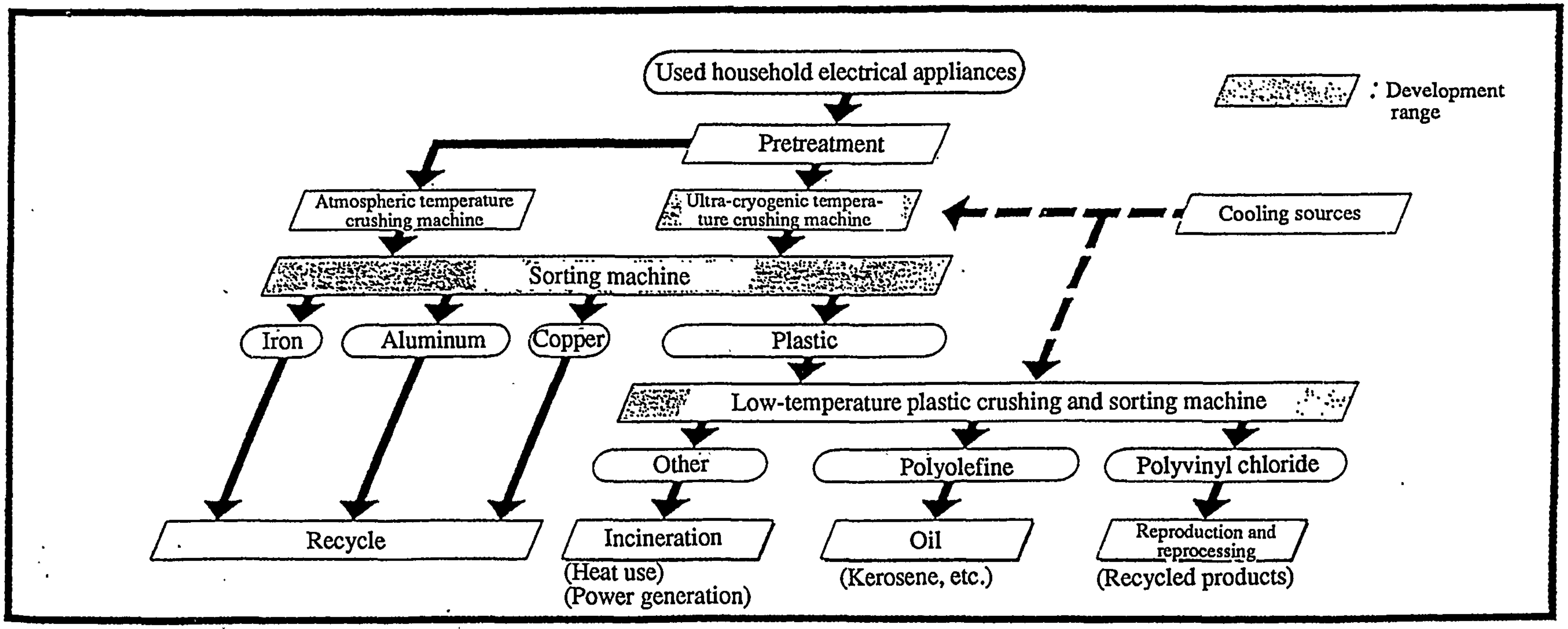


Fig. 1 Schematic Diagram of System

perature plastic crushing/classification equipment and specific gravity-based plastic separation equipment — was manufactured. Following manufacturing, installation was carried out, and a pilot plant was completed.

(1) Elemental Technology Research and Development

(a) Ultra-cryogenic temperature crushing/separation technology research

(i) Design and manufacturing of ultra-cryogenic temperature metal crushing/separation equipment

As in fiscal 1993, the design and manufacturing of elemental equipment (precooling conveyor, etc.) were carried out, and an ultra-cryogenic crushing system was completed.

(b) Low-temperature plastic crushing/classification technology research

(i) Design and manufacturing of low-temperature plastic crushing/classification systems

As in fiscal 1993, the design and manufacturing of elemental equipment (input conveyor, cooling tank, etc.) were carried out, and low-temperature plastic crushing equipment for the pilot plant use was completed.

(ii) Low-temperature plastic crushing tests

Crushing tests that used the aforementioned equipment were conducted, and relationships between such parameters as crushing temperature, blade-edge speed and blade-edge clearance, and the recovery ratio and mixture ratio were determined.

(iii) Design and manufacturing of specific gravity-based plastic separation equipment

As in fiscal 1993, the design and manufacturing of the remaining elemental equipment (feed hopper, etc.) were implemented, and a specific gravity-based plastic separation system was completed.

(iv) Specific gravity-based plastic separation testing

Specific gravity-based separation and crushing were carried out, using the aforementioned equipment, and relationships between processing capacity and efficiency were determined.

(c) Foamed urethane treatment technology research

Research was conducted on recycling and treatment technologies for foamed urethane, chlorofluorocarbons (CFCs), etc.

(d) Plastic reutilization technology research

Research was implemented on reutilization technology and oil-conversion technology for plastics.

(2) Integrated System Research and Development

(a) Manufacturing of a pilot plant

Ultra-cryogenic temperature metal crushing equipment, low-temperature crushing/classification equipment, specific gravity-based plastic separation equipment and peripheral equipment were installed at the Hitachi Plant (waterfront plant) in Hitachi. As a result, a pilot plant having a capacity of 1 ton/hour was completed.

Fig. 3 shows the external appearance of an integrated system.

(b) Carrying out of single-unit adjustment

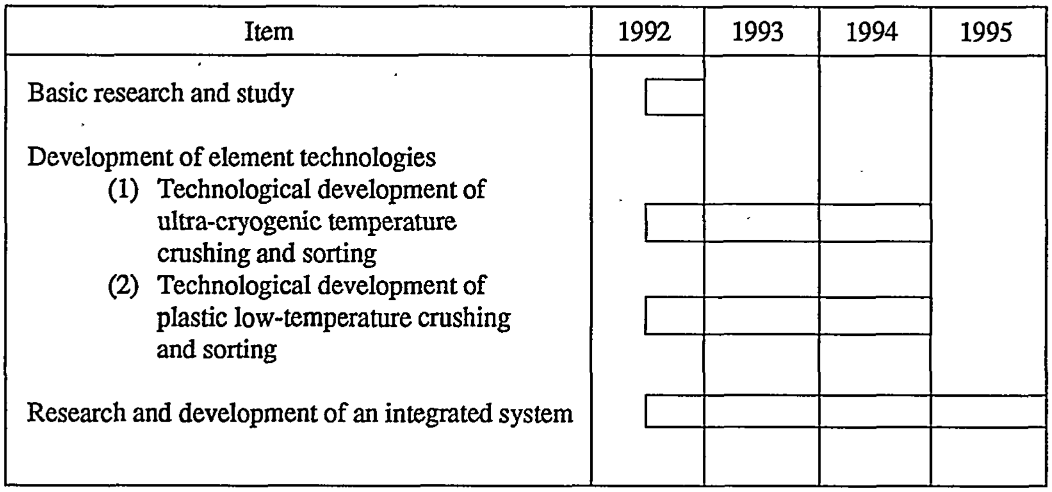


Fig. 2 Study and Development Schedule

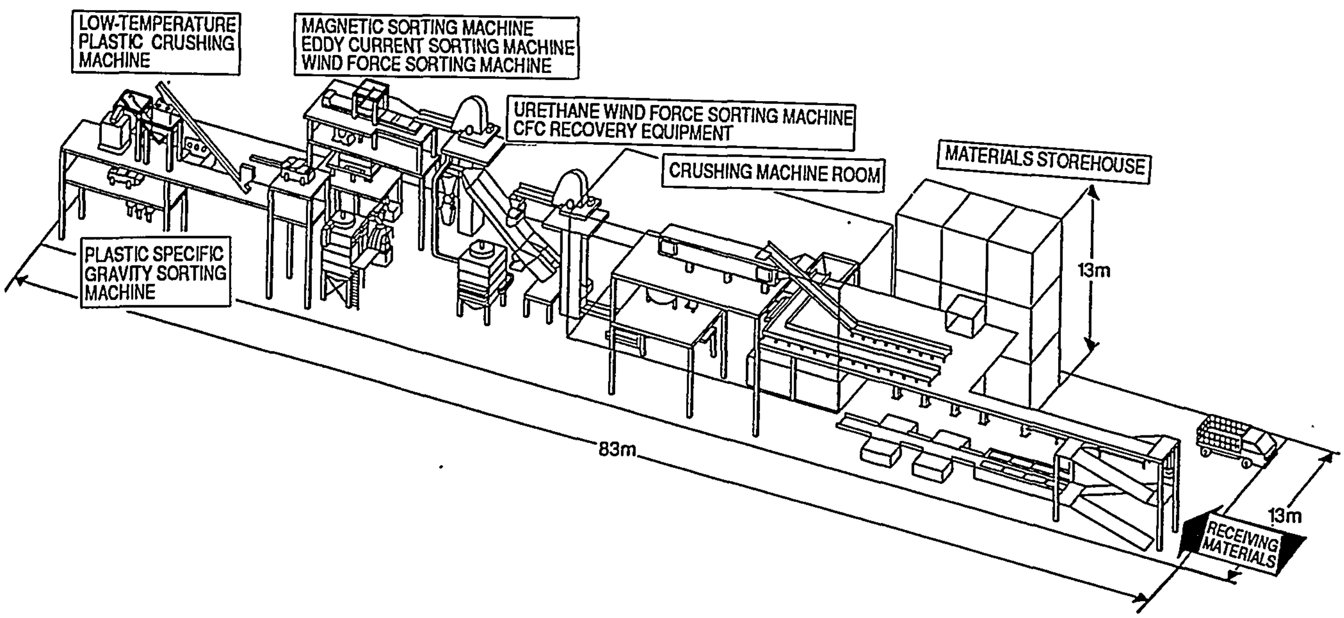


Fig. 3 Outside View of a Pilot Plant

tests

Single-unit adjustment tests were implemented for the pilot plant, and the performance of all equipment composing the pilot plant was confirmed.

(c) Study of actual-use scale

In preparation for actual use, the suitable scale of the recycle system was studied.

3. Future Tasks

The operation testing of the pilot plant will be carried out, and overall evaluation of the plant will be made. At the same time, the conceptual design of a practical utilization system will be developed, and future study themes will be extracted on that basis.

VI

Development of New Technology for Liquid Fuel Conversion (Development of Commercialization Technology for New Process)

Recently, great expectations have been placed on methanol, which is primarily being used for chemical products, as an oil-alternative fuel because it makes more effective use of natural gas resources, because of the ease of its transport and storage, and because of environmental safeguard considerations. With a view to using methanol as fuel, it is essential to reduce the costs of methanol production. The existing method of combining the steam reforming process and the quench-type methanol synthesis process is technologically established, but development of a new methanol production method, realizing further cost reduction, is necessary if methanol is to be widely introduced for fuel use.

This research aims to establish two new methods for practical utilization technology based on bench-scale plant tests:

(i) The gaseous-phase fluidized bed method achieves the benefits of scale through the combination of a composite reformer and a gaseous-phase fluidized bed methanol synthesis method, which allows the scale of the system to be increased.

(ii) Low-temperature liquid-phase method, which can reduce costs through simplification of plant facilities.

The existing method, consisting of the combination of the steam reforming process and the quench-type synthesis process, and the two aforementioned methods are compared and presented in Table 1.

1. Objectives and Work Program

The gaseous-phase fluidized bed method is designed to attain a scale of 10,000 t/d for one train, a construction cost reduction of 30% and a methanol production cost reduction of 25%.

The low-temperature liquid-phase method aims to eventually realize a scale of 5,000 t/d, one-pass conversion rate of 90% or more, a construction cost reduction of 30% and a production cost reduction of 30%.

(1) Gaseous-Phase Fluidized Bed Process

Bench-scale plant tests will be carried out by using 10 t/d equipment (Phase 1) and a 100 t/d pilot plant (Phase 2) to establish the practical utilization technology.

(a) Development and research of the heat-exchange-type multiple reforming method

Equipment material tests, combustion chamber and burner structure, investigation on operating conditions, etc.

(b) Development and research of the gaseous-phase fluidized bed methanol

Table 1 Comparison Between Existing, Gas-Phase Fluidized-Bed and Low-Temperature Liquid-Phase Processes

	Existing method	Gas-phase fluidized-bed method	Low-temperature liquid-phase method
Reforming type	Steam reforming	Heat exchange type multiple reforming	Partial oxidation method
- Major reaction	$CH_4+H_2O \longrightarrow CO+3H_2$	$CH_4+H_2O \longrightarrow CO+3H_2$	$CH_4+1/2O_2 \longrightarrow CO+2H_2$
- Operating pressure (kg/cm^2)	15 - 20	80	15
- Reaction temperature (°C)	800 - 900	650 - 1,000	700 - 1,000
- Methane decomposition rate (%)	88	92	95
Synthesis reactor type	Quenching (multi-stage)	Gas-phase fluidized-bed	Liquid-phase method
- Synthesis reaction	$CO+2H_2 \longrightarrow CH_3OH$	$CO+2H_2 \longrightarrow CH_3OH$	$CO+2H_2 \longrightarrow CH_3OH$
- Catalyst form	Fixed-bed catalyst	Pulverized catalyst; dispersing in bed	Homogenous and heterogenous suspended catalyst
- Operating pressure (kg/cm^2)	100	800 - 100	10 - 30
- Reaction temperature (°C)	220 - 280	220 - 270	120 - 150
- 1 pass flow conversion (%)	40 or less	40 - 70	90 or more
- Gas circulation ratio	5 - 6	3 - 4	Unnecessary
- Maximum scale of production	2,500 T/D	10,000 T/D	5,000 T/D
Process characteristics	Scale-size limitation	Scale enlargement	Process simplification

synthesis

The design and manufacturing of a synthesis reactor, study of the catalyst circulation method, investigation on operating conditions, etc.

(c) Development and research of synthesis catalyst production

Establishment of a production method for synthesis methanol catalysts

(d) Study on the optimization of a total system

Research on the optimization of a total system, including the heat exchanger and methanol distillation column to increase the scale of the model system

(2) Low-Temperature Liquid-Phase System

Using a small-scale continuous-flow reactor, basic data such as selection of operating variables and reaction solvent will be decided.

(a) Design and manufacturing of small-size reactors

(b) Study on the optimization of reaction conditions (temperature, pressure, gas composition, flow rate, kinds of solvent, etc.)

(c) Confirmation of the catalyst lifetime by continuous reaction testing

(d) Conceptual design of the total process system

2. Summary for FY1994

With regard to the gaseous-phase fluidized bed process, a heat exchange-type composite reformer and the fluidized bed reactor were connected, the operation test of 10 t/d equipment was started; and the performance evaluation of candidate new catalysts, the confirmation of catalyst fluidizing behavior, the study of operating conditions, and material test of the reformer for the extension of a life-time were carried out. Furthermore, the development research was conducted with regard to the methanol production for the fluidized bed catalyst. In connection with the low-temperature liquid-phase process, the performance evaluation and analysis of candidate catalysts were implemented, using small-scale reaction testing equipment.

(1) Gaseous-Phase Fluidized Bed Process

(a) Development and research on the heat-exchange-type composite reformer

For the purpose of establishing the technology design for a combustion chamber, fluid-flow analysis tests were implemented, using analogous contraction models of 20 t/d and 200 t/d combustion chambers. As a result, it was confirmed that, based on the scale-expansion factor of similarity, concentration distribution in both combustion chambers is analogous and that the time-averaged concentration within both chambers is constant and the same mixture characteristics are shown at the same times, within the operating load of 16% to 100%. Moreover, testing was carried out with the shapes (L/D) of combustion chambers, pressure and momentum factors changed; and conditions to stabilize the fluid state within the combustion chamber were found. Further, the corrosion mechanism was studied through corrosion testing, in order to select high-temperature corrosion-resistant materials.

A reformer reaction model was developed to establish a prediction method for the synthesis gas. The prediction outcome using the model turned out to be almost the same as the observed data. Further, study was implemented on the strength of the secondary-reforming catalyst-supportive bed under high-temperature conditions.

(b) Development and research on the gaseous-phase fluidized bed methanol synthesis method

For optimization study of the size and length of the cooling coil to be set up into the reactor, vibration data of the cooling coil (2.5") in the 10 t/d fluidized bed reactor was collected, and the generation limit of fluid dynamics elasticity vibrations within a 5,000 t/d reactor was investigated. Further, to optimize the catalyst particle circulation system, catalyst collection efficiency were found out with 10 t/d testing, using a cyclone. The catalyst activity deterioration rate, obtained in the reaction analysis evaluation of 10 t/d testing, showed 5 times the target value. It was turned out that a close relationship exists between the activity deterioration rate and heat-resistant evaluation results.

(c) Development and research on the synthesis catalyst production

In order to stabilize the precipitation reaction, the raw material for the catalyst was changed from zinc with a Cu/Zn ratio of 0.52, and catalyst strength improvement through spray drying based on a disk method, instead of the conventional nozzle method, was investigated. It was ascertained that, if spray drying is carried out under the conditions of high-slurry concentration, low-temperature and small supply liquid volume, the catalyst strength is increased. Also, relations between pre-treatment (baking) conditions for spray drying items and catalyst activity were investigated.

(d) Study on the optimization of the total system

After the linkage of 10 t/d testing equipment was completed, continuous operations were carried out for 320 hours. Further, a basic simulation model was developed for the whole new methanol production process.

(2) Low-Temperature Liquid-Phase Process

(a) Catalyst evaluation using a small-size continuous-flow type reaction

Continuous-flow reaction were carried out for 20 hours using one of the candidate catalysts, copper chromite-alkaline metal alkoxide catalyst in triglyme solvent. Suitable reaction conditions were decided as follows:

STY (Space Time Yield): ~50 g/l/hr

Carbon monoxide conversion: ~50%

Selectivity to methanol-based on carbon monoxide: ~95%

(b) Application evaluation of existing technologies and process simulation

Application evaluation was carried out with regard to low-temperature liquid-phase methanol production processes for existing technologies. As a consequence, it was concluded that existing technologies can be applied in a number of processes, such as pressure-up/heat recovery processes. Furthermore, simple process simulations were created and enhanced to calculate material balance and heat balance of the new model processes, including a liquid-phase synthesis process. In addition, application of the partial oxidation process based on the use of natural gas as raw material was examined, using the enhanced simple simulators. Consequently, it was learned that the conversion rate to methanol exceeds 90% if the liquid-phase synthetic process is operated at temperatures of 120°C or below and within pressure range of 30 to 70 kg/cm^2.

3. Future Tasks

(1) Gaseous-Phase Fluidized Bed Process

To solve existing problems, the following items will be investigated with particular emphasis:

(a) Comprehension of the development level of fluidized-bed catalyst and the future improvement outlook.

(b) Selection of high-temperature corrosion-resistant materials and confirmation of their lifetime extension measures and anticipated lifetimes.

(c) Identification of the critical circulation efficiency of the cyclone apparatus and decision on circulation system execution.

(d) Determination of the outlook for manufacturing a reformer and a fluidized-bed reactor.

(e) Evaluation of the economy of the new methanol production process.

(2) Low-Temperature Liquid-Phase Process

(a) Research activities will be conducted to examine catalyst performances using a continuous-flow type reactor and to calculate material-balance for the total reaction system in order to confirm the higher activity level of the catalyst performance. Also, efforts will be also made to obtain data on catalyst poisoning and to feed back the results to the catalyst development process.

(b) The low-temperature liquid-phase methanol process will be outlined and a more precise simulator will be developed.

The development schedule is shown in Table 2.

Table 2 Schedule of Liquid Fuel Conversion Technology Development

(Fiscal year)

Research item	1993	1994	1995	1996	1997	1998	1999
(1) Development of new production process							
1) Gas-phase fluidized-bed method							
(a) Phase 1				Interim evaluation			
- Study of reforming furnace material test, structure and operation	←	—	→				
- Design, production and operation of synthesis reactor	←	—	→				
- Development of catalyst production method	←	—	→				
(b) Phase 2							
- Design and production of pilot plant				←	→		
- Establishment of operating conditions						←	→
- Study of total system optimization					←	—	→
- Development of catalyst production method					←	—	→
2) Low-temperature liquid phase method							
(a) Design and production of reactor	←→						
(b) Study of optimal reacting conditions		←	—	→			
(c) Conceptual design of a total system		←	—	→			

VII

International Clean Energy Network Using Hydrogen Conversion (WE-NET)

International Clean Energy Network Using Hydrogen Conversion (WE-NET) is a technology for a world-scale clean energy system, designed to produce hydrogen from water through electrolysis, using renewable energy, such as water power, solar energy, geothermal energy and wind power; to convert hydrogen into a transportable medium; to transport it to energy consumption areas and to arrange its consumption there.

Fig. 1 shows the conceptual design of WE-NET.

(1) Objectives and Work Program

(a) Investigation and study for evaluating and reviewing R&D

This project aims to conduct the overall adjustment of individual sub-tasks and to carry out overall evaluation from the viewpoints of technological and economic aspects, as well as the purpose of the WE-NET project. By so doing, the optimization of the development projects will be studied.

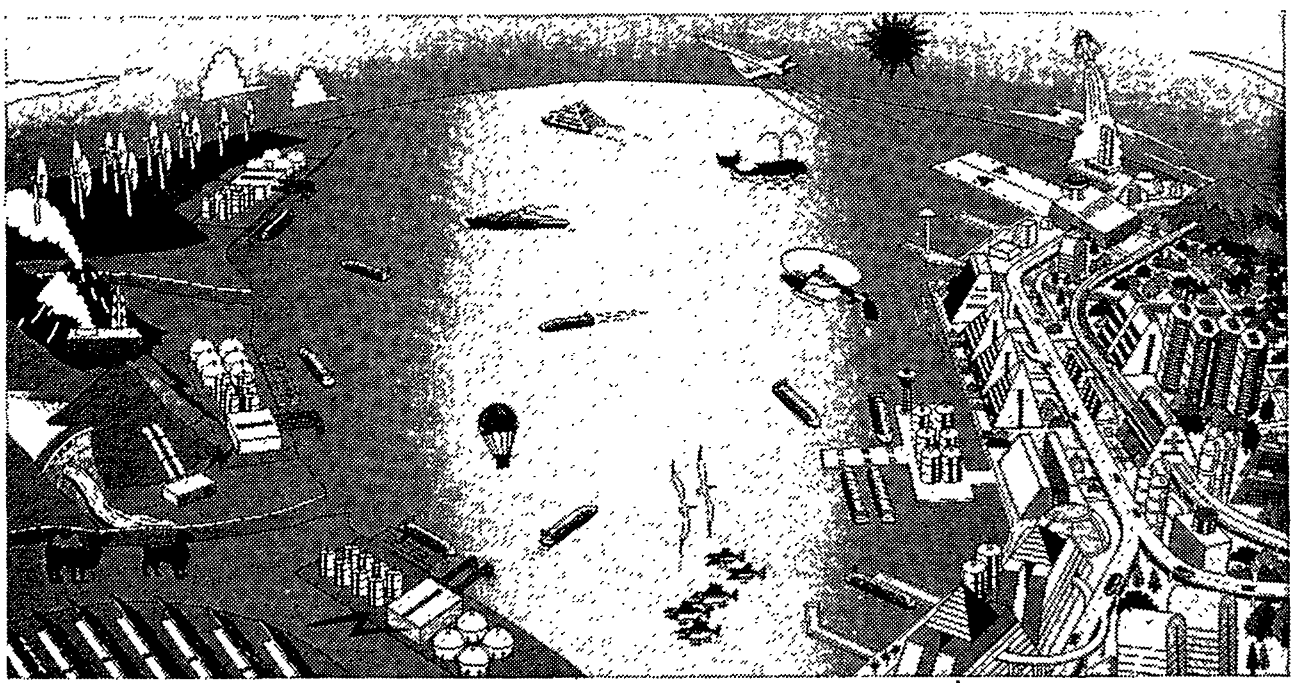


Fig. 1 Conceptual Diagram of WE-NET

(b) Review and investigation for promoting international cooperation

With an eye to building an international-scale system, regular exchanges of information will be carried out with international organizations and other countries concerned, and methods and plans for developing such efforts into international joint research will be studied.

(c) Conceptual design of the total system

Studies will be made of a total system composed of renewable energy-using power generation equipment, hydrogen production equipment, transportation medium production equipment, transportation and storage equipment and a hydrogen utilization system, to be followed by evaluation of the system's conceptual design. Subsequently, studies and evaluation will be conducted to estimate the effect of introducing hydrogen energy on a world-wide level and national level. Furthermore, development of safety measures and safety evaluation technology will be conducted in consideration of the entire WE-NET system.

(d) Development of hydrogen production technologies

Regarding solid polymer electrolyte membrane water electrolysis, which can be expected to attain efficiency improvement and a higher current density, elemental technologies will be studied and evaluated with a view to achieving large-scale production and service-life extension. Also, elemental technology development will be conducted with regard to solid polymer electrolytes, catalysts for both anodes and cathodes, and materials for electrolytic cell components. Through these efforts, the technology required for the development of a pilot plant will be established.

Targets for Phase I are to attain an electrode area of about 6,000 cm^2, current density of 1 to 3 A/cm^2 and energy conversion efficiency of 80% to 90%.

(e) Development of hydrogen transportation and storage technologies

Regarding the following items related to the production, transportation and storage technology for liquid hydrogen, research and development, with emphasis placed on the former, will be carried out to obtain the findings necessary for the determination of an optimal system for long-distance overseas transportation and distributed storage and transportation:

(i) Development of large-scale hydrogen liquefaction facilities
(ii) Development of a liquid hydrogen transportation tanker
(iii) Development of a liquid hydrogen storage facility
(iv) Development of devices for common use (liquid hydrogen pump, piping, valves, etc.)
(v) Development of hydrogen-absorbing alloys for small-scale transportation and storage system

(f) Development of cryogenic materials technologies

For the purposes of studying existing or new structural materials that can be used under liquid hydrogen conditions, and suitable welding methods, basic data collection and evaluation will be implemented regarding tensile strength, fracture toughness and other mechanical characteristics in the ultra-cryogenic range and hydrogen embrittlement in ordinary and ultra-cryogenic temperature ranges for each material.

(g) Feasibility study on utilization of hydrogen energy

With regard to present and future hydrogen utilization technology and the volume of hydrogen demand, surveys and examinations will be conducted on individual utilization forms of chemical media such as hydrogen gas, liquid hydrogen and methanol in the fields of electricity generation, industry, transportation and public welfare. Utilization technology for each of these fields will be proposed, the merits and demerits of each technology will be clarified, and the development problems of hydrogen utilization technologies will be defined. In parallel with this, research on technologies related to liquid hydrogen will be conducted, to be followed by evaluation of such technologies.

(h) Development of a hydrogen-combustion turbine

Concerning hydrogen combustion turbines, necessary research and elemental technological development will be carried out with regard to the following items, and basic technologies necessary for the development of a pilot plant will be established.

- (i) Study of an optimal system for hydrogen combustion turbine
- (ii) Development of combustion control technology
- (iii) Development of turbine blades, rotors and other major components
- (iv) Development of major auxiliary components
- (v) Development of super-pyrogenic materials

(i) Study of innovative and leading technologies

Surveys, examinations and evaluation of innovative and conventional technologies for manufacturing, transportation, storage and utilization of hydrogen will be conducted.

(2) Summary for FY1994

In fiscal 1994, activities were carried out mainly to examine existing technologies for each development item, and study was undertaken regarding some elemental technologies. The outline of principal activities conducted is shown below:

(a) Investigation and study for evaluating and reviewing R&D

The study of the pilot plant in Phase II was undertaken.

(b) Review and investigation for promoting international cooperation

- (i) An international symposium was held and technologies and information were exchanged.
- (ii) Study was made of the formation of an international network and long-term visions.

(c) Conceptual design of the total system

- (i) The conceptual design of a total system was carried out for liquid hydrogen, and equipment expenses and economy were calculated on a trial basis.
- (ii) The remodeling and improvement of existing simulation models were implemented to evaluate effects of hydrogen energy introduction on the world, country and municipal scales.
- (iii) Regarding safety evaluation, selection of accidental phenomena and study of the analysis code were

undertaken.

(d) Development of hydrogen production technologies

Small laboratory cell evaluation equipment ($50 \, cm^2$) was manufactured using three methods with different electrode-junction methods — the non-electrolytic plating method, hot press method and the method for joining a catalytic electrode (porous and sintered materials), and its performance was evaluated. Furthermore, the development of hydrogen production technologies based on the zero gap method and high-temperature, high-strength solid electrolytes was undertaken.

(e) Development of hydrogen transportation and storage technology

(i) Development of large-capacity hydrogen liquefaction facilities

The helium Brayton cycle and the hydrogen Claude cycle were studied, and a schematic process was examined.

(ii) Development of a liquid hydrogen transportation tanker

Basic specifications were determined, and conceptual designs of tankers equipped with a 200,000 spherical tank and a rectangular tank having the same capacity were developed. Their external appearance is shown in Fig. 2 and Fig. 3.

(iii) Development of a liquid hydrogen storage facility

The basic system flow was studied, and schematic specifications were determined for equipment units at storage bases.

(iv) Development of devices for common use

Surveys were continued on a large-sized liquefied hydrogen pump, insulation pipes, liquefied hydrogen valves and instrumentation equipment, and technological problems were isolated.

(v) Development of hydrogen absorbing alloys for small-scale transportation and storage systems

Surveys were carried out on magnesium alloy, which is characterized by a large hydrogen absorbing capacity and light weight, and on characteristic improvement effects of nanocrystalization.

(f) Development of cryogenic materials technology

Data concerning mechanical characteristics and hydrogen embrittlement of SUS304L and SUS316L, representative stainless steel structural materials, and A5083, an aluminum alloy, in the helium temperature range were collected.

(g) Feasibility study on utilization of hydrogen technology

The current state of various kinds of hydrogen utilization technologies was surveyed, and related technological problems were studied.

(h) Development of a hydrogen-combustion turbines

(i) Study for an optimum system for hydrogen-combustion turbine

Concerning hydrogen combustion turbines, several types of systems were studied. It was ascertained, as shown in Table 1, that 60% power generation efficiency can be attained.

(ii) Development of combustion control technology

Basic tests were conducted on a small-sized burner for a hydrogen/oxygen combustor, and the stability of the flames and combustibility were evaluated.

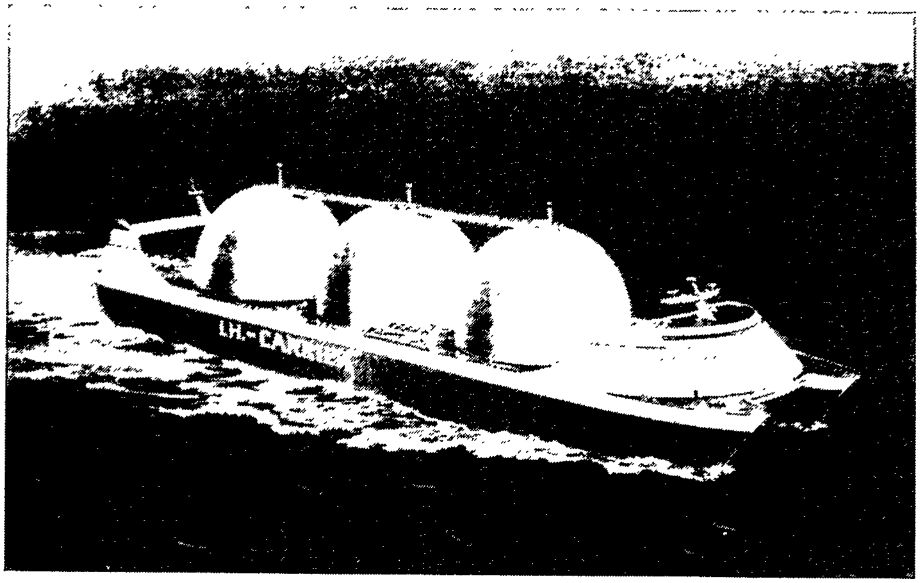


Fig. 2 Conceptual Diagram of a Liquid Hydrogen Tanker (Sphere-shaped tank)

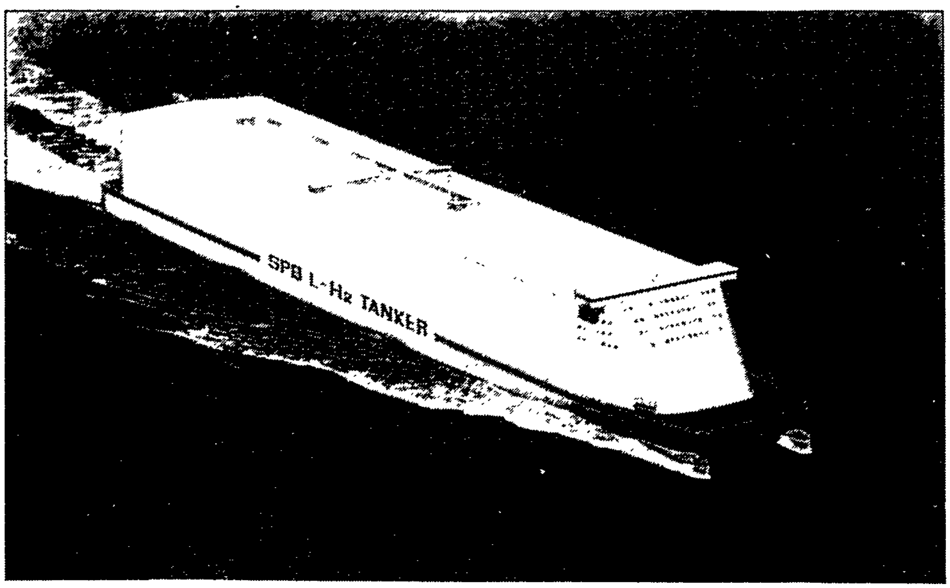


Fig. 3 Conceptual Diagram of a Liquid Hydrogen Tanker (Square-shaped tank)

(iii) Development of turbine blades, rotors and other major components

Although only based on calculations, it was confirmed that, even in the case of using existing metal materials in moving and stationary blades, the system will be able to endure a turbine inlet temperature of 1,700°C through the upgrading of blade cooling technologies.

(iv) Development of major auxiliary equipment

Surveys and study were implemented regarding heat transfer promotion technology, types/structures, materials, etc., of high-temperature heat exchangers.

Surveys and study were implemented regarding an oxygen manufacturing system utilizing cryogenic energy of liquefied hydrogen.

(v) Development of super-pyrogenic materials

Basic characteristics (physical, chemical and mechanical properties) were tested and evaluated regarding heat-resistant alloys, intermetallic compounds, ceramic composite materials and C/C (carbon fiber/ carbon matrix) composite materials which are regarded as promising materials for rotors and other super-high-temperature parts of a hydrogen-combustion turbine.

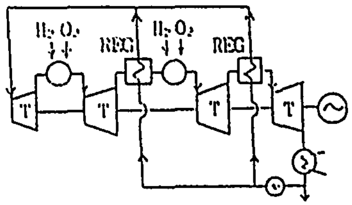
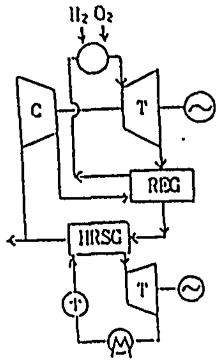
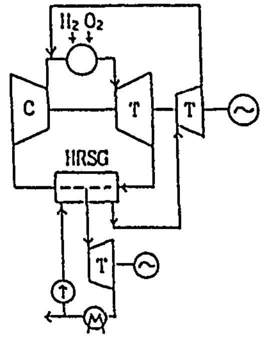
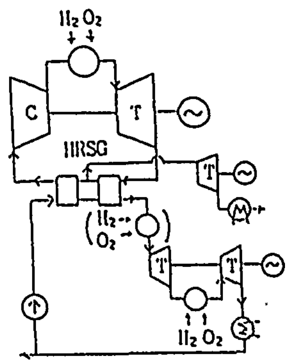
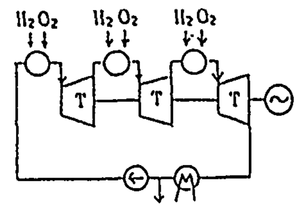
(i) Study of innovative and leading technologies

Research and study were carried out concerning the methods of finding innovative and leading technologies, and study of technology evaluation methods was implemented.

(3) Future Tasks

In fiscal 1994, research/examination, basic study and elemental technology research will be continued to obtain information necessary for the optimal design of a total system and to establish the technology required for designing and manufacturing a pilot plant.

Table 1 Outline of Various Hydrogen Combustion Turbines

Cycle	Two-stage reheating and regenerating Rankine cycle	Inert gas circulation cycle	Topping extraction cycle	Bottoming reheating cycle	Two-stage reheating Rankine cycle
System configuration					
Outline	Based on Rankine cycle. Operation medium is steam. Efficiency improved by reheating and other measures. A compressor is unnecessary.	Based on combined cycle. Operation medium for the topping cycle is inert gas plus steam, and operation medium for the bottoming cycle is steam. Same system configuration as ordinary gas turbine and steam turbine combined cycles.	Based on combined cycle. Operation medium is steam for both topping and bottoming cycles. Designed so that operation medium for both topping and bottoming cycles is the same.	Based on combined cycle. Operation medium is steam for both topping and bottoming cycles. Designed so that operation medium for both topping and bottoming cycles is the same.	Based on Rankine cycle. Operation medium is steam. Efficiency improved by reheating and other measures. A compressor is unnecessary.
Generation efficiency (Note)	60% (1700°C, 75 bar)	55% (1700°C, 50 bar)	62% (1700°C, 50 bar)	52% (1700°C, 50 bar)	62% (1700°C, 100 bar)

Note: Generation efficiencies are values at the generating end based on higher heating value (HHV). Figures in parentheses indicate maximum temperature and pressure at turbine inlets.

N96-02-0189

CHAPTER 8

DEVELOPMENT
OF
OTHER OIL-ALTERNATIVE ENERGY
TECHNOLOGIES

DEVELOPMENT
OF
OTHER OIL-ALTERNATIVE ENERGY TECHNOLOGIES

Contents

I

Technological Development for Large-Scale Wind Power Generation Systems

Wind energy is renewable energy that exists in Japan in large quantities. Since great expectations are placed on its future development, introduction, and diffusion, the intention of this project is to develop a large-scale wind power generation system with excellent reliability and economy and suitable for the current situation in Japan.

1. Development of Large-Scale Wind Power Generation System

(1) Objectives and Work Program

A 500kW-class, large-scale, three-bladed, rigid-structured wind power generation system will be developed to seek cost reduction and effective utilization of land.

After necessary conceptual design and elemental technology development are implemented, activities will proceed to detailed design and manufacturing.

(2) Summary for FY1994

(a) Development of element technology

(i) Development of variable pitch mechanism

Various kinds of test were conducted for performance evaluation and reliability confirmation of a hydraulic system mainly consisting of a variable pitch mechanism and the electro-hydraulic servo valve that controls the variable pitch mechanism. It was confirmed that the performance can satisfy under normal operating conditions. Moreover, it was confirmed by an overload test that there is no problem of strength under the normal operating conditions.

(ii) Development of blades

a. Fatigue tests on blades

Continuing the work of the previous fiscal year, blade fatigue tests with respect to the edge direction and to the flat direction were carried out on two experimental blades, respectively. The tests were conducted in the same manner as in the previous fiscal year: by increasing a load step by step in a specified number of repetitions.

As for the edge direction, cracking occurred when load step 5 (6.2×10^5 repetitions) was reached, the fatigue damage ratio at this time was 3.1, showing that the blade has strength exceeding that of a tentatively prepared fatigue diagram (a diagram of the mean values of actual blade fatigue).

As for the flat direction, there was no occurrence of cracking in the test this time and the fatigue damage ratio was greater than 12.8, indicating strength greater than that in the edge direction.

b. Crack propagation test

A notch was made artificially in

the surface of the blade skin in the flat direction, and the crack propagation state was examined.

Cracking occurred when the load step 5 (6.2 x 10^5 repetitions) was reached, enabling us to obtain important evidence for the evaluation of blade cracking.

(iii) Development of a speed increaser

A load test was conducted for the purpose of verifying the reducing effects of vibration and noise of the speed increaser by modifying gears.

The tooth profile was modified to ensure a 1.0 contact ratio between the low-speed and high-speed planetary gears. By modifying the gears, an overall acoustic energy reduction value of 2.6 was obtained.

(iv) Examination on various vibration characteristics

A confirmation test of the vibration characteristics of the nacelle cover (characteristic frequency, mode, transmission characteristic and vibration damping ratio) was implemented. The test was carried out by exciting the base of the sinusoidal wave. Moreover, a finite element method 3-dimensional vibration analysis was conducted to compare the test results.

Through the test it was clarified that the solid propagation vibration response was small at 530 Hz of high speed step engaging frequency of the speed increaser. Furthermore, it was possible to confirm that calculation of the total mode almost agrees with the test results.

(b) Fabrication

In succession to the previous fiscal year, each part was fabricated for a 500 kW large-scale wind power generation system to be constructed at the Cape of Tappi in Aomori Prefecture.

(i) Rotor head

Taking the results of strength calculation into consideration, the rotor head was designed using the finite element method. Then a rotor head having sufficient strength against external forces being applied to the three blades and their dead weight.

(ii) Variable pitch mechanism

A variable pitch mechanism was fabricated taking into consideration the results of the demonstration test and examination on the structure, strength and service life, using a system which controls the pitch angles of the three blades with one hydraulic cylinder installed in the hollow main shaft.

(iii) Speed increaser

Taking into consideration the results of a load test which was conducted for the purpose of demonstrating the effectiveness of tooth profile modification, a low-noise type speed increaser provided with tooth profile modification and the full depth tooth of high-speed step gear was fabricated.

(iv) Yawing system

Specifying the yaw driving equipment to be an electric motor type, the yawing system was fabricated based on detailed examinations of speed reducer and joint, etc. As for the yaw brake system, which consisted of six yaw brakes to fix the direction of the nacelle, a system having sufficient durability and wear resistance was fabricated.

(v) Hydraulic controller

A hydraulic controller used for variable pitch control was fabricated. This is composed of a hydraulic pump for control, a blade pitch controlling servo valve, and a hydraulic actuator for blade pitch control.

(vi) Electric controller

An electric controller was fabricated taking the following into consideration:

generated energy of wind power generation system, check of control state, remote supervisory control system for maintenance and control, connection to utility grid and site conditions including environmental temperature, lightning, etc.

(3) Future Tasks

Based on the successful results achieved in this fiscal year, surveys will be undertaken with respect to the following items:

(a) Development of element technology

Following fiscal 1994, element technology will be pursued for the development of a control system, blades, and control equipment for connecting to the utility grid.

(b) Fabrication

Blades, a system for connecting to the utility grid and a tower will be fabricated. These are the parts of an actual 500-kW wind power generation system.

2. Development of Large-Scale Wind Power Generation System (Operational Studies of Large-Scale Wind Power Generation System)

(1) Objectives and Work Program

In order to reduce power generation cost and effective utilization of land, a large-scale wind power generation system will be developed and constructed, followed by a survey on its operation, to evaluate the system. For this purpose, the present situation of wind power generation cost in Japan and other countries will be surveyed to clarify the factors of difference in price in Japan and other countries and, at the same time, measures for cost reduction will be examined.

(2) Summary for FY1994

(a) Construction costs of wind power generation system

The construction costs are broken down into the following elements:

(i) Fabrication cost of wind power generation equipment
(ii) Fabrication cost of foundation work, assembly cost of wind power generation system on the foundation, and installation cost of wind power generation equipment (work execution cost)
(iii) Cost of electric equipment to transmit generated power to utility grid and its installation cost (work execution cost)
(iv) Other expenses (design cost, test and adjusting cost, labor cost arising from application for approval)

The total construction cost differs depending on makers, machine models and construction sites. In order to compare difference in price between Japan and other countries, conditions must be adjusted as much as possible. Accordingly, the survey was done assuming the case where a domestic maker constructed the same model in Japan (Tappi Wind Park — 5 wind power generation systems), the U.S.A. (California Wind Farm — 300 wind power generation systems) and the U.K. (Wales Wind Farm — 103 windmills). The results were that the construction costs were ¥639,000/kW in Japan, ¥285,000/kW in the U.S.A., ¥189,000 in the U.K. With the Japan cost as 1, the cost is 0.45 for the U.S.A. and 0.30 for the U.K. That is to say, the same model is being constructed overseas at a cost of 1/3 to 1/2 the cost in Japan. Furthermore, the price of wind power generation equipment and construction cost (assembling cost) accounted for 70% to 88% of the entire construction cost, and it was clarified that the main factor of the difference in cost consists in these points.

(b) Operation and maintenance cost

The share of the operation and maintenance cost in the construction cost is approximately 3% in each case, with little difference apparent. A survey of the literature reports an operation and maintenance cost of 2% to 3% generally, and this is the standard value.

(c) Interest cost

In this present case, the interest is 8% in Japan, and 10% in the U.S.A. and in the U.K. although it varies greatly depending on how financing was supplied. In other countries, wind power generation systems are regarded as having a high risk yet and therefore the interest is generally high rate and short term.

(d) Service life

The service life is expected to be 20 years in general. In this present case, it is specified to be 20 years in Japan and the U.K., and 30 years in the U.S.A.

(e) Generated output

The generated output differs from site to site. It is generally assumed that profit can be ensured by an equipment utilization rate of more than 20%. The equipment utilization rate is reported to be 24% for Tappi, 39% in California and 35% in Wales. In calculating the power generation cost, it is uniformly specified to be 24% under the same wind condition.

(f) Generating cost

As a result, the generating cost is calculated to be ¥40.1/kWh in Japan, ¥18.4/kWh in the U.S.A. and ¥13.2/kWh in the U.K. The actual data report that it is ¥40.1/kWh for Japan (equipment utilization rate: 24%), ¥13.0/kWh for the U.S.A. (equipment utilization rate: 34%) and ¥9.1/kWh for the U.K. (equipment utilization rate: 35%).

(3) Future Tasks

It is impossible to dramatically decrease the cost by adjusting only one factor, and it is necessary to work on all cost-reducing factors as much as possible. The factors are explained as follows:

(a) Reduction of construction cost

It is mass production that can decrease dramatically the price of wind power generating equipment which accounts for almost all the construction costs. As the result of the same-maker, same-model survey shows it was clarified that the cause of price differences between Japan and other countries arises from the number of wind power generators fabricated. The mass production effect does not merely mean the learning effect but also material discounts through bulk purchases as well as reduced cost through the mechanization of work and improvement in efficiency brought by a dedicated production line. The problem lies in whether it is possible for the manufacturer to obtain a constant volume of orders. Accordingly, it is impossible to expect the same price as that of mass production models for a small quantity of orders to the maker even during a period when the manufacturer is not busy. If simultaneous bulk orders are not available, it would be the most realistic method to obtain products from a manufacturer (overseas, for example) having a constant volume of orders. When a 250-kW wind power generation system is transported from Denmark to Yokohama Port, the transport charge is approximately ¥700,000 to ¥1,500,000, which is equivalent to an extremely small percentage of the total construction costs. Moreover, the recent overseas trend of large-scale wind power generation systems shows a remarkable reduction in cost through upsizing. Upsizing is also a promising method for cost reduction.

(b) Site selection

If the equipment cost is fixed, the only way to decrease the generating cost is to increase energy output, and it becomes extremely important to select a site with favorable wind conditions. As far as the overseas examples are concerned, profitability can be expected only where the equipment utilization rate is more than 20%.

(c) Funds supply at a low interest rate

It is also extremely important to obtain funds at a low interest rate. In case of the Tappi Project, reduction in the interest rate by half (4%) has the same effect as a 20% reduction in the construction costs.

(d) Improvement of service life

Cost reduction is also served by improving service life. In the present situation, the appropriate service life is around 20 years, and it is necessary to examine achievements to project a longer service life.

(e) Curtailment of the distribution mechanism

In order to decrease intermediate margins, it is important to curtail the distribution mechanism. However, there was no problem with the distribution mechanism by this survey.

3. Development of Large-Scale Wind Power Generation System (Development of Control Technology for Wind Power Generation System)

(1) Objectives and Work Program

For the purpose of practical operation of a wind power generation systems designed to effectively utilize wind energy, the goal of this project is to develop design technology for several wind power generation systems and control technology for their effective operation.

(2) Summary for FY1994

(a) Survey on the optimum system configuration

In selecting models for the purchase of three wind power generation systems, a survey on the performance and delivery record of each model was conducted of manufacturers which made or were regarded as capable of making wind power generation systems. In selecting the model, each item was examined and then specifications were determined.

(b) Survey on the optimum operating technology

Continuing the work of the previous

fiscal year, systems connected to the utility grid were operated using two medium-scale wind power generation systems.

(i) Generated output

The generated output with the No. 1 unit totaled 647,780 kWh and that with the No. 2 unit totaled 673,470 kWh, and the total generated electricity with the Nos. 1 and 2 units came to 1,321,250 kWh. Comparison with the records in fiscal 1993 shows an increase of 9.7% (15.1% with the No. 1 unit and 4.9% with the No. 2 unit). Because the average wind velocity changed little, the cause is ascribed to the increase in the generated output with the No. 1 unit. The decrease in generated output in August in relation to the average wind velocity was caused by an operation halt due to periodic inspection and shutdown of the No. 1 unit on account of breakage of its wind vane and anemometer.

(ii) Equipment utilization rate

The equipment utilization rate is 30.2% on a yearly average. Comparison with the actual result of 27.5% in fiscal 1993 shows the increase in generated output with the No. 1 unit. The monthly fluctuation varied between 11.8% and 45.0%.

(iii) Operating time

The operating time was 6,090 hours (69.5% of calendar time), which is a 1.7% increase above the achievement of 5,941 hours (67.8%) in fiscal 1993.

(3) Future Tasks

Three wind power generation systems procured in fiscal 1994 were installed, commissioned and adjusted. Continuing the work of the previous year, two medium-scale wind power generation systems were operated and studied.

II

Verification Test for Establishing Centralized Load Control System

1. Verification Test for Establishing Centralized Load Control System

(1) Objectives and Work Program

In line with the diffusion of air conditioners, an increase in peak electric power demand and a widening of seasonal and daytime/nighttime demand differences have become more pronounced, and the accompanying decline in the annual load factor of power generation facilities has attracted attention as a serious problem. In particular, the peak of power demand frequently appears during summer, on weekdays and in daytime, and it has become necessary to secure new electric power supply facilities for these peak times. This, however, has caused those involved to point out problems from the viewpoints of economy and the environment. Therefore, DSM (demand-side management), which involves technologies of power suppliers to adjust and control the load equipment of users, has recently drawn strong attention as a load-leveling formula of a general type in the search for an overall solution of the issue.

Since 1986, NEDO has been conducting technological development designed to level the power load. The related verification has been concentrated on shifting the peak/bottom time zones of power demand and thereby leveling them by controlling air conditioners, water heaters and other load equipment mainly in homes and stores directly from the power supply side. As specific verification tests, a verification system was constructed in Ushuku, Kagoshima, in fiscal 1986 as Phase I. There, tests of directly controlling load equipment of actual users have been conducted since then. In fiscal 1990, a system network was constructed in Akagi, Gumma Prefecture, as Phase II. In this location, the advanced utilization method of the network and the use formula of previously laid transmission lines, such as CATV coaxial cables, have been examined toward the practical utilization of a centralized load control system.

In fiscal 1994, a demonstration site was constructed in the Shusenji and Imajuku Districts in Nishi-ku, Fukuoka City, as a part of Phase III and, for the purpose of leveling the electric power load, the indirect load control test was implemented in addition to the direct load control test by providing incentives for electricity rates. As a result, the peak-cut effect of the leveling was confirmed. Through this attempt, a project to examine the load leveling measures suitable for Japan was started by pursuing the optimum combination of direct/indirect load control.

(2) Summary for FY1994

(a) Design of demonstration test and construction

(i) Prerequisites of demonstration test and contents of test

As a result of examination on the prerequisites of indirect load control demonstration test and contents of the test, the following items were determined:

• The objective area of the demonstration test is specified to be the Shusenji and Imajuku Districts in Nishi-ku, Fukuoka City.

• The test objective users are specified to be low-voltage electric light contract (meter rates B and C) users.

• The number of users is specified to be a total of four groups of 1,600 households (400 households in each group).

• The contents of the test were categorized into technological problems, load controlling problems and load control effect problems, and test items were picked individually out of these problems.

(ii) System configuration for demonstration test

In this test area, the control center in the sales office was connected to users with communication channels. Through monitors (TVs, etc.) which were installed at users, the system was configurated to verify how electricity consumption varied by providing information on the electricity-use state at users, advice for better use of electricity, request for peak adjustment and payment of cooperative subsidy for peak adjustment. Consequently the configuration shown in Table 1 was selected:

(iii) Construction work of transmission line

In fiscal 1994, transmission line work was executed to 400 households in the Shusenji District out of the demonstration test objective Shusenji and Imajuku Districts. In constructing the transmission system, optical fiber was used for the distance from the control center to the midpoint of the Shusenji District and was connected to coaxial cables in the district.

Table 1 Configuration of Centralized Load Control System Equipment

Center unit	This nucleus of the centralized load control system monitors and controls equipment and collects and analyzes data.
Host station unit	Monitors and controls home terminal unit under instructions from the center.
Home terminal unit (HTU)	Monitors and controls equipment, such as electronic meter, home displays and air conditioner control unit, under instructions from the host station.
Electronic meter	Measures electricity based on three seasonal and five configurable time ranges, and communicates with HTU.
Household display	In addition to displaying information from the electric power company, including the status of electricity use at the consumer's home and information on charges, responds to surveys by allowing answers to be input through the display (interactive communications).

(b) Survey on DSM

The DSM technologies beginning with the load controlling technology were examined including trend surveys in and out of Japan. Fig. 1 shows the result of examination on DSM measures.

(c) Development of equipment related to demonstration test and preliminary survey

(i) Development of equipment for home automation

In order to efficiently implement the indirect load control test, the equipment for home automation that controls the load equipment in users' households automatically has been developed. In fiscal 1994, experimental equipment for home automation was installed in actual users' households followed by evaluation tests in the operability, reliability and functionality. As a result, it was clarified that it was important to provide the display and operating functions that can be understood most easily by users.

(ii) Survey on actual state of use of loaded equipment in users' households

For the purpose of examining the actual state of use of loaded equipment in users' households, based on the result of a survey implemented in fiscal 1993 with questionnaires relating to the state of electricity use (for household use and business use), the load curves of households and

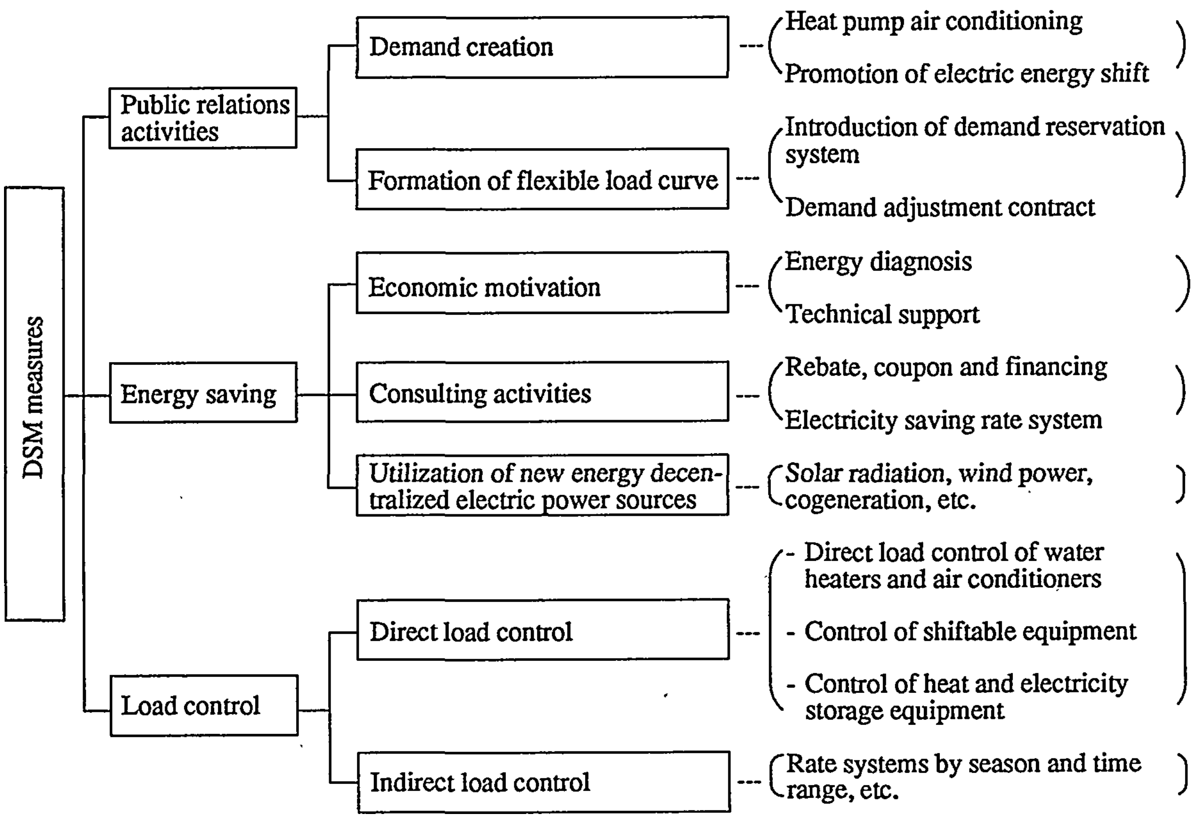


Fig. 1 Representative Concepts of Demand Side Management (DSM) Measures

small businesses were analyzed. As a result, it was clarified that the peak in the winter season in households was caused by electric power consumption for electric heating and illumination apart from air conditioners. At small businesses, in contrast, it was clarified that electric power consumption for illumination during the summer peak season was not smaller than that for air conditioners.

(3) Future Tasks

In fiscal 1995, it was scheduled to provide the transmission line with lead-in wires to 400 users' households contracted to cooperate in the test and to execute installation work of the control equipment for the demonstration test at the households. It is also scheduled to implement a load survey (survey on state of use of electricity by users) as preliminary test for the 400 households.

Because it is scheduled to start the full-scale test of indirect load concentrated test from fiscal 1996, details of test contents will be examined and determined by the end of fiscal 1995.

2. Surveys of Load Curve Improvement Technology

(1) Objectives and Work Program

Because of the recent expansion of maximum power demand, a decline in the annual load factor and a widening of demand differentials between daytime and nighttime have progressed, hampering the introduction of nuclear power and coal thermal power, which constitute the base electric power supply. To improve the load curve by shifting daytime power demand to nighttime, it is necessary to take demand-related countermeasures, including the introduction of nighttime heat/cold energy storage systems or unused energy-based heat supply systems, as well as the development and spread of nighttime power consumption equipment technologies.

In view of this situation, it is important to examine the prevailing conditions of regional heat supply, various kinds of energy saving steps and load leveling measures and to study the future development of related issues, based on expert opinions and requests.

In fiscal 1994, future demand prediction was surveyed pertaining to the cogeneration system, and the problems and measures of spreading the present cogeneration system were examined. Moreover, the indexes to judge introduction of the cogeneration system to be used in the future were examined and presented.

The effects on energy, the economy and society of the introduction of daylight saving time, a social system contributing to load curve improvement, were surveyed, and the feasibility of the introduction was surveyed and studied.

(2) Summary for FY1994

(a) Survey on promotion of high-efficiency energy utilization

According to power generating system categorization and purpose of use of cogeneration and its interconnection with electric power systems as well, the demand for power generation by 2010 was projected to total 17,160,000 kW. And, in accordance with the projection, problems of technology, laws and regulations were identified regarding the proliferation of cogeneration in the private sector. Then promotion measures were examined.

Moreover, the indexes of energy savings, environmental exhaust load and economic efficiency were examined and evaluated by comparing the cogeneration system with conventional systems. Using these indexes, the existing plants were evaluated and, as a result, it was recognized as necessary to evaluate energy savings not only by the rated values but also by the actual operation results.

Furthermore, systems utilizing unused energy were compared with the cogeneration system, then energy saving properties of respective systems were confirmed. Problems of future improvement in efficiency and effective utilization of waste heat of the cogeneration system were extracted.

(b) Survey on feasibility of daylight saving time introduction

Assuming the introduction of this daylight saving time system, energy savings and effects of load curve improvement were quantified. Reports made hitherto were researched to obtain the result that the daylight saving time has a saving effect amounting to an oil equivalence of approximately 550,000 kl. As for the improvement effect of the load curve, the effect of lowering the peak can be expected by setting the maximum temperature time (presently 14:00) to the hour when the daytime behavior pattern becomes inactive (presently 15:00). Problems of both hardware and software to be prepared in introducing the daylight saving time system were identified and measures were surveyed to create a lifestyle which can contribute to improved energy saving and load curve.

Assuming the introduction of the system, moreover, to comprehensively examine and evaluate its feasibility, influences on traffic, agriculture and commerce were surveyed including the social cost of the system.

(3) Future Tasks

Surveys will be conducted with regard to the introduction of nighttime heat/cold thermal energy storage and unused energy-utilizing heat supply systems, as well as the technological development and spread of nighttime power consumption equipment, for the ultimate purpose of improving the load curve.

III

Development of System Technology for Optimum Household Off-Peak Time Power Utilization Devices

(1) Objectives and Work Program

[Objectives]

The difference between peak time and off-peak time power demand has increased in recent years. This situation is feared to hamper the introduction of new energy sources expected to serve as oil-alternative energy sources in the future.

This increase of the difference between peak time and off-peak time power demand is considered to be largely due to the continuing increase in air conditioning demand in the household sector, which accounts for a major portion of non-industrial power demand. Accordingly, technological development of small-scale systems for residential use that can effectively utilize off-peak time electric power is a significant objective.

For this reason, peak time power demand will be restrained and off-peak time demand will be fostered for load leveling through energy storage (electric power storage and heat storage) and utilization time control of electrical equipment meeting individual needs in the cases of totally electrified homes, store/home combinations and office/home combinations, which have been gradually increasing in recent years. Further, an optimum electrical energy distribution and control system for inside the house, including direct current supply, will be developed for efficient utilization of electric power. Additionally, an electric vehicle battery replacement system effective for utilization of nighttime electricity supply will also be developed.

[Work Program]

(a) Conceptual design

Technology development trend surveys, analysis and evaluation will be implemented regarding electric and heat storage systems, home automation devices and office automation equipment. At the same time, the load leveling effect of the efficient operation of electric and heat storage systems will be evaluated. Based on this, conceptual design of a total system for upgraded power utilization will be implemented to improve the efficiency of power utilization by better control of energy, use of multiple menu electric power supplies (voltages, etc.) and improvement of supply reliability.

Also, conceptual design of an electric vehicle battery exchange system will be implemented. The system will utilize cartridge-type batteries, which may be used as electric storage facilities for residential use.

(b) Design of equipment for verification

Equipment for verification with an emphasis on its space-saving nature, compactness, maintainability and safety will be improved based on the conceptual design.

(c) Manufacturing of the equipment for verification

Equipment for detached and store/home combinations will be manufactured.

(d) Operation and evaluation of equipment for verification

Operation of equipment adapted to diverse and typical yearly and peak/off-peak power utilization patterns for homes will be carried out to evaluate this system.

(e) Study of optimal residential utilization of electric power

Survey of technological development trends will be implemented regarding power utilization systems in residences, and optimal residential use of electric power in the future will be studied.

(2) Summary for FY1994

(a) Development of verification systems

During fiscal 1994, demonstration operation of a verification system for detached houses and a system for store/home combinations manufactured in fiscal 1993 was conducted.

(i) Load-leveling effects during the peak time and off-peak time of air conditioners

A verification system composed of heat storage equipment, power storage equipment, photovoltaic generation system and multi-menu inverters was operated to verify its load-leveling effects.

(ii) Operation of storage batteries and photovoltaic generation system

The degree of the contribution of storage batteries and photovoltaic generation system to load-leveling effects was assessed and analyzed.

(b) Development of an electric vehicle battery exchange system

In fiscal 1994, verification tests of a battery exchange system and road tests of a prototype electric vehicle were carried out.

(i) Verification tests of a battery exchange system

Using a battery exchange system installed in a verification-use detached house, problems inherent in the system were determined through its actual operation, and countermeasures for the problems were devised.

(ii) Road tests of a prototype electric vehicle

In addition to verification tests of the battery exchange system, road tests of a prototype electric vehicle were carried out. Over the period of a year, battery performance including range per charge, rate of power consumption, and other factors were measured and evaluated.

(c) Research on the next-generation energy supply utilization system

Using the software produced to study the optimum use of household electrical power, based on model families/houses projected into the future, calculation and analysis were made of energy utilization volume in various combinations of energy storage equipment and photovoltaic generation system.

(i) Examination on electric utilization technology trends, development trends of load-leveling equipment and development objectives

Electric power utilization forms at futuristic model homes equipped with photovoltaic power generation equipment, heat storage equipment and power storage equipment are calculated and analyzed for each of several model homes.

(3) Future Tasks

The project under discussion ended in fiscal 1994. In the future it will be necessary to collect and analyze data and verify durability of equpiment (batteries, etc.) and the system for actual use under various weather conditions.

IV

Development of New Commercialized Housing Construction Technology and System

(1) Objectives and Work Program

Because Japanese household energy consumption is expected to grow steadily in line with lifestyle improvements, development of new energy utilization and energy conservation technologies is a long-term and crucial task for Japan, which lacks abundant energy resources. Such development is also important in attaining global environmental protection.

NEDO has been tackling technological development for household energy needs in the course of its technological development of solar energy for both lighting and heating. Under this project, NEDO will strive to promote the introduction of new energy into households and the dissemination of such energy into the market in the future. Efforts will be made to develop an overall household energy utilization system.

(2) Summary for FY1994

Work was continued on the development that had been under way since fiscal 1993.

(a) Development of an energy evaluation and optimal composition technology system
  (i) Overall research and development of an energy evaluation and optimal composition technology system

Under this theme, simulation on the following four levels was planned as a means of realizing optimal composition system:

Level 1) Evaluation of building properties — Reduction of the load itself
Level 2) Evaluation of fossil fuel energy consumption volume — Reduction of fossil fuel consumption volume
Level 3) Evaluation of life cycle costs — Economy evaluation
Level 4) Overall evaluation — Evaluation involving that of energy consumption, economy and effects on environment

Of these levels, research on the following six items was carried out in this fiscal year:

a. Preparation of meteorological data for evaluation of building performance

Meteorological data on the whole of Japan required for evaluation of performance of building and evaluation of energy consumption were prepared.

b. Preparation of data on evaluation of energy consumption quantity

Range of the capacity data on air conditioners and hot-water suppliers was expanded, and standard instrument specifications were determined.

c. Preparation of data on evaluation of life cycle cost

Data on life cycle cost of housing materials, life cycle energy and quantity of life cycle CO_2 gas generated were prepared.

d. Examination on comprehensive evaluation method

Details of the Level 4 comprehensive evaluation method were examined to prepare an evaluation program.

e. Whole integration of programs

The programs at each level which were prepared by fiscal 1993 and the programs at Level 4 which were prepared in this fiscal year were integrated into one comprehensive operable program.

f. Development of system using personal computer (Level 1)

In order to spread the program more widely, development of a personal computer version was started. The input/output part of the program of building performance evaluation at Level 1 was developed this fiscal year.

(ii) Development of energy performance simulation system

a. Development of simulation system

Using results obtained from each environmental performance subsystem, a virtual reality (VR) technology-applied audio and visual simulation system was developed continuing the work of the previous fiscal year as a means to provide information to dwellers. Specifically, the following contents were carried out:

i. Advanced VR technology and hardware were researched for the purpose of pursuing the possibility of improving the audio and visual simulation system that was developed hitherto.

ii. A thermal environment simulating system and an air quality environment simulating system were developed, with the dVS VR application development software environment of Division Corporation, of the United Kingdom, based on the function specifications prepared last fiscal year. That is to say, development was carried out with regard to the conversion of data from the CFD program output data format, which is used by the thermal environment subsystem working group (WG) and the air quality environment subsystem working group, to the VR data format, as well as the function to display results of CFD simulation on the VR.

iii. Continuing the previous fiscal year's work on the optical and visual environment simulating system, the function to display data on living space presented by the optical and visual environment subsystem WG was developed with the dVS system. Function development was carried out to upgrade the version of data conversion software from the living space data format of the optical and visual environment subsystem WG to the VR data format and to realize improvements in display resolution and graphics rendering speed.

iv. The VR-applied acoustic environment simulation system using acoustic sense was developed with dVS this fiscal year in the same manner as the aforementioned thermal environment simulating system, air quality environment simulating system and optical and visual environment simulating system. A three-dimensional sound generating system was used and it was made possible to listen to the three-dimensional state of noise insulation in a living space with headphones by means of VR by inputting the noise insulating data presented by the noise and vibration environment subsystem WG and by developing an interface system between the three-dimensional sound generating system and the dVS system.

v. A safety and functionality simulating system was also developed with the dVS system. In addition to the functionality experiencing function that was featured by the conventional system, another function was developed this fiscal year that displays data on the physical shape of a standard adult body size by means of VR and permits a visual grasp of the peripheral space.

vi. Continuing the work of the previous fiscal year, the simulation system using sensitivity technology was developed. A kitchen was tested as an objective space. Moreover, tools to expand the sensitivity database were also improved. With regard to the simulation systems categorized in each environmental element which is described in the foregoing paragraphs i) through vi), a practical test was carried out using a housing model plan to verify the effectiveness of the system.

b. Development of prediction, indication and evaluation subsystem for optical and visual environment

i. Based on a demonstration plan, a field survey was carried out to locate the building site, then a model was constructed taking its peripheral environment into consideration.

ii. The three-dimensional evaluation library was improved.

iii. A demonstration story was prepared to assist the user's evaluation procedure.

iv. In the demonstration story, data created with three optical/external/internal visual environment subsystems were integrated and displayed on the display system (real-time/walk-through).

v. Various data were connected to the simulation system via an external interface.

vi. The above-mentioned successful results were opened to the public at an exhibition and examination meeting.

vii. The brightness of an existing model house was measured to compare and verify simulated values.

viii. The demonstration images that were shown to the public at the exhibition and examination meeting were presented, then the interior simulation rendering performance was evaluated.

ix. Improvement of the image rendering performance of the system was attempted.

x. A large-screen stereoscopic display system was built.

c. Development of prediction, indication and evaluation subsystem for noise and vibration environment

i. An acoustic permeation loss predicting program was developed, which predicts the noise shielding performance of each housing module, judging from the housing structure. The program was linked with an airborne noise predicting system, and the integrated system underwent test runs and evaluation.

ii. An airborne noise predicting system was developed. The man-machine interface of the post processing component which displays calculation results was reinforced in particular, and the system underwent test runs and evaluation.

iii. A highly-accurate floor impact noise predicting system was developed by predicting the lower-room noise absorbing performance and the influence of the ceiling, and the system underwent test runs and evaluation.

iv. A floor impact noise simulating system which has a function to add the resonance of the lower room was developed, and the system underwent test runs and evaluation.

v. A simplified simulation system which permits the simulation of airborne noise only was developed. A filter was added in particular, in order to approximate the normal image position of actual noise, and the system underwent test runs and evaluation.

vi. The entire development system was opened to the public at the interim presentation and examination meeting.

d. Development of prediction, indication and evaluation subsystem for thermal environment

i. In order to make the system highly operable in developing the flow field analyzing technique, the method to prepare a composite mesh was improved for the preprocessing component, and the evaluation result display method was improved for the post-processing component. Furthermore, in order to improve the calculation effect, the optimal use method was examined for the parallel computing unit. The parallel computing unit was also connected to the non-steady thermal environment predicting method.

ii. As for the non-steady thermal environment predicting method, the following developments were implemented:

The function of automatic creation of data on the thermal circuit net from the design CAD data and the function of required data inputting component were improved, and the operability was enhanced.

As for the solver component, the humidity and latent heat calculating function was improved and the overall function was improved. As for the post-processing component, the evaluation screen concerning the exposure to the sun, thermal environment and energy savings was improved. Moreover, operation of the through system from preprocessing to post processing was confirmed.

iii. As for the database creation and support, the common database for thermal environment prediction and the database for building thermal and physical values were added and expanded so as to simplify the data inputting.

iv. Concerning the research on performance evaluation, a method to comprehensively evaluate the thermal environment was examined, and at the same time, the contents of advice on dew prevention were decided and a specific screen design was carried out.

e. Development of prediction, indication and evaluation subsystem for air quality

i. The overall control system for subsystems was developed.

ii. The data format of common data and air quality data needed for subsystems was reviewed and sample data were inputted.

iii. The preprocessor of the ventilation calculating program for macrosimulation was moved to the workstation.

iv. The effective clearance area and wind pressure coefficient were set for ventilation volume prediction.

v. The analysis code of the microanalysis software and the input file format were improved and the evaluation simulation was implemented.

vi. The dust density calculation program, micro-analysis software and pre-processing/post-processing system were interconnected.

vii. Experiments were carried out to improve accuracy of multi-room ventilation volume measurement.

viii. Ventilation efficiency was measured to examine air quality evaluation at a model house.

ix. Concentration of contamination was measured at an actual house and the measurement was compared with simulated results.

x. The performance display system to display results of simulation was improved.

f. Development of prediction, indication and evaluation subsystem for safety, durability and functionality

i. Safety

a) Prediction and display of daily safety, safety from fire and safety from trespassing and burglary were improved to provide an easily understandable display, based on results of evaluation by test runs and public exhibition.

b) Consistency with the overall system was examined.

c) Database of fire safety was prepared.

ii. Durability

a) The operation frame of durability prediction, display and evaluation subsystems for structural members of steel reinforced houses and wooden houses was evaluated and improved by exhibiting the subsystems to the public. Moreover, the database of structural members for wooden houses was examined.

b) Periods to repair and renew the interior and the exterior were indicated as a part of this subsystem, and at the same time, design of preservation program subsystem and development of the design to indicate required expenses were implemented and an experimental program was completed.

iii. Functionality

a) Improvement in display of operation space, traffic lines, housing volume, furniture and house equipment and improvement in sample data of living time were implemented, and the program was improved.

b) Interconnection with a virtual reality system was examined. A story was prepared to simulate "Coming Home from Shopping."

(iii) Development of optimal technology and system

a. Development of a system for comprehensive energy utilization and a comfortable living areas

i. In order to perform a demonstration evaluation of the successful results of the development achieved the previous fiscal year, a demonstration evaluation model combining a ceiling cooling system and a regenerative floor heating system was examined, designed and fabricated on an experimental basis.

ii. A winter demonstration evaluation test of the demonstration evaluation model was implemented, and then thermal circulation such as changes in temperatures of the room and other areas and energy balances were measured and evaluated. As a result, it was confirmed that the design targets were fully achieved.

iii. A winter demonstration evaluation test of a control system was carried out using a demonstration model integrating element technologies, and favorable results were obtained. Moreover, a demonstration evaluation on the influence of illumination and windows on the sensors was carried out to confirm the optimal position of sensors during air conditioning.

iv. An independent housing model improved in construction work execution was fabricated for the purpose of expanding the application to an detached house, then its experiment was evaluated. In order to evaluate the experiment of the independent model house, the model room fabricated in the previous fiscal year was remodeled to include an air conditioner. As a result, it was confirmed that the application of the system to independent houses is possible, and at the same time, points to be improved were detected.

v. Improvement and fabrication as well as performance evaluation of construction-panel type ANC duct were conducted to confirm that the noise absorption quantity was improved as much as 5 dB in comparison with that of the fabrication in the previous fiscal year. And, as for the traffic noise (bus noise), it was possible to reduce noise as much as 16 dB in comparison with the case of ventilation duct only, and the effectiveness of application to the living room was confirmed.

vi. A "construction panel speaker" was fabricated on an experimental basis to examine the availability of three-dimensional ANC construction module and the performance evaluation of the module. As a result, a maximum of 13 dB noise reducing effect was obtained pertaining to the low frequency noise and ultra-low frequency noise, confirming the effectiveness thereof.

b. Development of next-generation solar system for comprehensive energy utilization

i. An air-tightness test was carried out with respect to the Ayabe and Hamamatsu solar houses that were constructed in fiscal 1993, and it was confirmed that the houses had sufficient air-tightness.

ii. The living time process was set for both solar houses on weekdays and holidays in the intermediate period, and a demonstration test with centralized measurement was carried out and the obtained data were analyzed.

iii. The same demonstration test was carried out with regard to the cooling period and heating period, and the obtained data were analyzed.

iv. The solar house evaluation method was researched and studied by introducing check sheet index values, explanations and actual examples to the evaluating method for the convenience of evaluators.

v. Research was conducted through the construction of both solar houses with respect to problems in bringing the solar system into houses. Then concepts of the introduction of the solar system into houses were examined and problems to be solved prior to work execution were clarified.

c. Development of total energy evaluation and optimal configuration technology system with demonstration test houses

In order to research future life abounding in "comfort and richness" and, specifically, to determine a healthy and comfortable living environment suitable in the various environments and land circumstances of Japan anticipated in the 21st century, demonstration test houses are to be constructed, the demonstration tests in the energy utilization equipment/system including alternative energy utilization equipment at houses already being developed. The optimal configuration technology system is to be implemented at these demonstration houses.

The summary of research contents has it that demonstration houses be constructed for the intention of smoothly introducing oil alternative energy utilization equipment to houses and thereby that the total energy evaluation and optimal configuration technology evaluation be examined. Accordingly, the demonstration houses were constructed at the following three places, taking the actual characteristics of each district of Japan into consideration:

- Iwaki Experiment Site: Iwaki City, Fukushima Prefecture
- Tochigi Experiment Site: Takanezawa-cho, Shioya-gun, Tochigi Prefecture
- Hamamatsu Experiment Site: Hamamatsu City, Shizuoka Prefecture

Continuing the construction of the demonstration house in the previous fiscal year, work was executed inside the house, and equipment was installed therein. The house was completed to implement demonstration and evaluation tests.

The demonstration and evaluation tests were begun mainly for the total evaluation of the demonstration house to which the energy utilization equipment and system that had been developed hitherto were installed; then in order to evaluate and examine the total energy evaluation and optimal configuration technology system based on the basic concept of the demonstration house, the measuring instruments and equipment required for evaluation and examination were installed in the house from the viewpoints of energy saving, increased amenity, improvement for the aging society and labor savings in work execution.

(b) Development of comprehensive energy utilization control system

(i) The heat regenerative panel was integrated into the control simulation software that had been under development until the end of the previous fiscal year, making it possible to perform a comprehensive simulation using nighttime electricity, solar electricity and gas.

And the sophistication of the basic simulation algorithm permitted the simulation of aspects of energy resource effective utilization such as energy saving control by coordination and optimal control in view of meteorological forecasts.

(ii) As for an improvement and simulation test for the connection interface, a near-reality model was assumed, and a simulation test was carried out by examining a configuration combining specific instruments consisting of a personal computer and the RS-232 communication protocol for control.

(iii) Relating to the energy utilization equipment which is the object of the control system, an electric power utilization instrument controlling system was improved and examined in order to avoid the electric power peak. The system was verified to be centered around the solar electric power system and the duct air-conditioning system so as to verify methods effective in avoiding the electric power peak.

(c) Research on alternative energy comprehensive utilization system for houses

The energy utilizing state at an existing house was grasped and the possibility of introducing alternative types of energy to houses was examined.

(d) Development of high-efficiency heat utilization and recycling system

(i) Development of a comprehensive system for high-efficiency utilization and recycling of exhaust heat and atmospheric heat

a. Development of a system for high-efficiency utilization and recycling of exhaust heat and atmospheric heat

i. A duct air-conditioning system fabricated experimentally to pursue improvement and a hot water utilizing system fabricated experimentally to pursue improvement were connected to the GHP outdoor unit fabricated experimentally to pursue improvement, and evaluation tests were carried out with respect to air conditioner and hot water supplier capacity, function and control.

ii. A duct air-conditioning system fabricated experimentally to pursue improvement was connected to an experimentally fabricated GHP, and evaluation tests were carried out with respect to the capacity and function of instruments related to the air conditioner.

iii. An experimentally fabricated hot water system such as a hot-water tank and a 24-hour bath fabricated experimentally to pursue improvement was connected to the experimentally fabricated GHP, and evaluation tests were carried out with respect to the capacity and function thereof.

b. Development of a ceiling system integrated with a concentrated heat recycling and air ventilating system

i. A seat-on type ceiling radiation panel to compose the ceiling system was fabricated on an experimental basis. Moreover, corrosion tests, deflection tests and radiation tests were carried out on a roll-bond type ceiling radiation panel.

ii. An air ventilation system (duct, ventilation unit and rear damper) for the supply system was fabricated.

A cold-water and hot-water piping system (piping and heat supplying unit) was fabricated and its operation confirmation test was carried out.

iii. As for the control system, ventilating airflow volume control panel (for control of airflow volume with/without people in room) and a room-temperature control panel (for control of cold water and hot water flow rates with/without people in room) were fabricated on an experimental basis and their operation confirmation tests were carried out.

iv. A ceiling ventilation system integrated with each foregoing element was fabricated experimentally, and an evaluation test for the total system in the winter season was carried out.

c. Development of high efficiency heat utilizing component assembling system

i. The basic specifications of a highly productive on-site precast concrete component manufacturing system were set, the basic design was determined, and the basic concepts of the whole system and the reinforcement assembling system were planned.

ii. As for the reinforcement assembling system in particular among the above-mentioned basic concepts, the key part of the system was fabricated and improved, then its performance was confirmed.

iii. Using each component of the

experimentally fabricated reinforcement assembling system, a simulation plant was constructed, then a demonstration test of the precast concrete member manufacturing system was carried out.

(ii) Development of a comprehensive high efficiency heat system utilizing accumulated heat and indoor heat transfer

a. Development of a high efficiency heat system utilizing accumulated heat and indoor heat transfer

i. Taking into consideration the improvement in heat collecting performance using solar heat, as well as easy installation, a heat pump was fabricated.

ii. The refrigerating circuit was improved to upgrade the air conditioning performance, and then a circuit assumed to be optimal as of today was contrived and fabricated.

In order to improve performance, examination was continued in particular with regard to the reduction of pressure loss in the circuit.

iii. Using a heat pump unit fabricated on an experimental basis, a plate type hydrothermal exchanger for heat regeneration and a heat exchanger for duct air conditioning, data on performance and other factors were collected.

iv. A control specification was examined to optimally adjust the degree of opening of an electric expansion valve for each heat exchanger with a different system.

c. Development of technology for actual use of comprehensive evaluation system to be introduced to house and house equipment in the living environment

As for the interacting inhabitant's degree of satisfaction with the VR system, the VR hardware was upgraded and integrated and the degree of the inhabitant's satisfaction with the VR software was improved based on the basic system that was developed in the previous fiscal year. Thus, attempts were made to improve the system and upgrade its functioning. In so doing, a high-performance type and a popular type were examined.

i. The contents that were implemented pursuant to the high-performance type are as follows:

- System version upgrading was intended so that two persons may experience the same virtual living space independently, each wearing a head mounted display (HMD). (The system formerly permitted only one person to experience this virtual living space at one time.)
- Version upgrading of a large-audience type VR system (a stereoscopic projection system using a large curved screen) was carried out in an attempt to improve the resolution and display speed of the projected image.
- System software was developed and improved by reviewing and adding necessary functions for editing and adding data to construct the virtual living space on the VR system examined in the previous fiscal year.
- Using the above-mentioned system and software, a virtual living space was created according to a house plan, and then test landscapes and living amenities simulations were carried out.

ii. The contents that were implemented regarding the popular-type VR system are as follows:

- With respect to the virtual living space on the VR system, functions required to perform a simplified design change were examined, and then its software was developed. Under this system, the kitchen was tested.

• Software to analyze the inhabitants' evaluation and to confirm inhabitants' satisfaction was developed and improved. Based on results of a questionnaire given to some inhabitants, this software was used to analyze the evaluation structure.

(e) Development of a comprehensive natural energy utilization system

(i) Development of a solar light and heat utilizing energy system

a. Development of a solar light and heat utilizing energy supplying system

i. In the case where the light and heat hybrid collector is introduced to houses, its mounting frame determines the waterproof performance. Paying attention mainly to the frame structure, the installation structure of the hybrid collector was examined.

ii. Based on the examined results, detailed design and experimental fabrication of the collector were carried out and frame assembling, lifting, lifting strength, work execution, and waterproofness were confirmed.

iii. Power generating performance and heat collecting performance were evaluated with a system closely approximating an actual system installed on the evaluation roof.

iv. Based on the evaluation result, control methods advantageous to energy supply were examined.

b. Development of multifunction panel

i. In order to prevent the casing from corroding from condensation inside the wall and to prevent heat insulation performance from deteriorating, a composite outer wall system combining air ventilation and humidity absorbing and discharging material was fabricated experimentally to verify the performance for practical use in a detached house.

ii. A simplified wall system of a nonstud type was fabricated experimentally to verify the performance for practical use in a multi-unit house. Moreover, the humidity control and condensation prevention performance were verified when humidity absorbing and discharging materials were used.

c. Development of a system for light control opening system

i. Based on the performance test results of the system developed the previous year for mass production type light control opening system, the method to improve the system was examined and its design was improved. Main points of improvement were that of the fixing strength of inner paper-glazed sliding door (*shoji*), prevention of reduction in heat isolating performance caused by heat convention at shoji lattices, and improvements of glass bead and frame WS.

ii. A minimum number of machining dies and part dies was fabricated to maintain the sash dimension system and assure its performance.

iii. Based on the improved design and the die fabrication mentioned above, one utility type opening system for heat isolation and one utility system for freeze area monitoring were retested.

iv. Using an experimentally refabricated utility type opening system, heat insulation performance tests and freeze area monitoring tests were carried out. Moreover, sunshine shielding performance tests and weather durability tests were also carried out.

v. In order to evaluate the indoor thermal environment with an opening system composed of multi-layer glass, simulation was carried out and the effects of this light control opening system were examined.

vi. In order to propose an opening system for diversified use environments, energy saving effects were examined using various grades of performance.

d. Development of production technology for energy-related members, etc., by variable molding

Pursuant to molds adjustable by computer control, computer-controlled free-form cutting unit and the cutting stage receiving line, system integration centered around the main control computer was carried out, and then the adjusting state, cutting state, accuracy of material dimensions, and other problematic points were determined by an extrusion test.

(ii) Development of a solar energy utilizing multifunctional roof system

a. As for the system design, two items — the multifunctional roof system and the optimal control system were developed. In the development of the multifunctional roof system, the issues and problematic points that were obtained through the design, construction and evaluation of the model house constructed the previous year were reviewed, and design details of the ridge of the roof and the eaves were improved.

In the development of the optimal system, the controllability and operability under the actual environment were confirmed. Demonstration by energy balance calculation was conducted, and as a result, it was possible to obtain performance data as expected.

b. The automatic light modulating glass panel has been measured and operated and its durability has also been verified concurrently at the experimentally fabricated model house. However, two problems, concerning slat driving and air-tightness performance arose; therefore, the design was improved.

c. As for the development of non-flammable heat-insulating roof framing materials, durability was measured using the member materials which are installed in the model house and the member materials which are exposed indoors, and no particular problem has arisen.

(f) Development of an electric power load leveling system

(i) Development of a comprehensive nighttime power utilization air-conditioning system based on accumulated/cooling thermal energy

a. Development of a radiant structural nighttime power utilization air-conditioning system based on accumulated/cooling thermal energy

i. In order to achieve the objectives of an air conditioning system of low electric power consumption and high degree of amenity by attempting to leveling the curve of electric power consumption, basic components thereof such as the heat regenerating and radiating panel, auxiliary air conditioner, heat medium unit and heat source unit were improved.

ii. Examination of the ceiling panel mounting method, performance evaluation of single heat medium unit, examination of comfort distribution and an evaluation of the heating test for an actual house were carried out.

iii. Each condition and specification was reviewed to improve the running cost and peak shift experimental calculation.

b. Development of external wall part member materials for multi-unit houses and their production technologies

i. In order to comprehensively evaluate the external wall manufacturing technology using the extrusion forming method, a sample was fabricated.

ii. In order to comprehensively evaluate the practicability of the external wall, its finished performance, water tightness and resistance against wind pressure were tested.

iii. Rationalization of the production process and the basic concept of computer-controlled production system were examined so that flexible production may be carried out. Then, a prototype system of the process capacity optimizing schedule was built and evaluated on the assumption of production by receipt of order.

c. Development of interior panel

i. Regarding the fabrication of full-scale panels, a method to adhere high-function decorative paper to a Zonotlite-based material and a method to install a fitting jig were established.

ii. In the full-scale panel installation test, a test of work execution using the fitting-in jig was carried out and the finished state was evaluated.

iii. In the functionality evaluation of the full-scale panel, the humidity adjusting property, heat insulating property, and physical performance were evaluated.

iv. Cost calculation and market research of the interior panel were carried out to examine its marketability.

d. Development of an inorganic multifunctional interior system

i. With respect to each interior material for the wall, floor and ceiling using fiber reinforced gypsum board, (1) matching and adjusting method for the wall to the floor, (2) matching and adjusting method for the wall and the ceiling, (3) work execution method for the wall and the opened part of the ceiling, (4) work execution method for wall corners and (5) the finishing method for the wall and the ceiling were examined and their visualization on screen was attempted.

ii. Various work execution techniques were established by carrying out a test to build interior member materials into a pilot room.

d. Development of slag-based noise shielding materials for houses

i. Fabrication test of large-size (8 mm in thickness and 90 cm square) noise shielding panels was carried out using magnet-selected grain iron and sieved powder of sintered iron as fillers at an actual production line, and as a result, manufacturing and material blending technologies were established for the manufacture of the noise shielding panel on a stable basis.

ii. Experimental fabrication of a thin noise shielding panel (2.4 mm in thickness) was carried out using magnet- selected grain iron as filler, and problems with manufacture were detected.

iii. Vibration and damping performance were measured using 30-mm square and 50-mm square samples which were cut out of a noise shielding panel being manufactured with an actual production machine.

The results were compared with those of small-size rectangular samples implemented the previous fiscal year. Moreover, the influence of the filler mixing ratio on the vibration and damping performance was examined.

iv. Noise permeation and loss of the thin noise shielding panel was measured using the reverberation room method.

v. 8 mm noise shielding panels were developed for a wooden noise-proof floor of the full-scale wooden test house. Measurements was taken of the floor impact noise level and noise permeation and loss in the upper and lower rooms to examine the noise-attenuating effect on sound borne through solids.

e. Development of a sanitary system

i. In order to examine the overall system (sanitary activities unit), the bathroom and the lavatory were integrated into one, and its installation work system was evaluated and examined in this unit into which a bath was integrated. Moreover, the sanitary activities unit was also examined and evaluated.

ii. As for examination on the bath unit, the comfort and convenience of a high-function and "high-amenity" bath unit was evaluated.

(g) Research and development of an air ventilating and conditioning system for highly air-tight houses

(i) Comprehensive research

In order to set up conditions for the popularization of an air ventilating and conditioning system aiming at energy savings and electric power load leveling for highly air- tight houses, various house construction methods and common specifications of developed equipment were examined and the conformity with the related construction laws and regulations was researched by the Committee.

(ii) Research and development relating to system control and configurating equipment

Various models were prepared on an experimental basis and their performances were measured and verified.

V

Work to Promote the Formation of Environmentally-Friendly Energy Community

(1) Objectives and Work Program

[Objectives]

Given the current state in which two-thirds of Japan's total primary energy supply is lost, the promotion of effective overall energy utilization measures is required.

For this reason, it is necessary to understand the entire scope of the system from energy supply to final demand, to seek to reduce environmental load and to activate the use of waste, waste heat and effectively-utilized energy currently existing here.

With an eye to promoting the formation of such an environment-friendly energy community, efforts will be made to develop and verify high-efficiency power generation technology, for the effective utilization of waste and other energy sources in the area, and related business undertakings will be promoted.

[Work Program]

With respect to a project that can be a pilot business and is effective from the viewpoint of environmental protection in its highly efficient utilization of electric power generation, dependent on each district, feasibility studies and research required to determine the technological possibilities will be implemented, and technological demonstrations required for the realization of the project will be carried out so that such a business may be established.

(2) Summary for FY1994

Because refuse solidified fuel (RDF) is comparatively uniform in shape, weight and calorific content, it is useful to recycle the energy of refuse. In fiscal 1994, the suitability of RDF as fuel was researched, and various element tests relating to strength, humidity absorbing property and septic action were implemented. As a result, it was confirmed that RDF has sufficient suitability as a solid fuel to be transported and stored.

Meanwhile, the technological demonstration project of gas turbine fired waste combined power generation was started. Demonstration facilities were scheduled to be completed in fiscal 1996. This system will have an output of 25 MW and will attempt high-efficiency power generation by using the exhaust heat from gas turbines to heat steam supplied from existing refuse incinerators.

(3) Future Tasks

Research and technological demonstrations concerning powering combined power generation with a gas turbine, etc., and RDF-utilizing power generation will be continued and developed.

VI

Environmentally-Friendly Energy Community Support Program

(1) Objectives and Work Program

[Objectives]

In the current situation in which two-thirds of Japan's total primary energy supply is thought to be lost, it is hoped that overall steps for the effective utilization of energy will be promoted. For this reason, the entire process up to the final demand stage will be positioned as an integrated system, and efforts will be made to promote the development of an effective energy utilization system, one designed to effectively use heat consistent with demand characteristics at various stages from a high-temperature to a low-temperature range, including power generation applications.

[Work Program]

NEDO subsidizes feasibility studies and installation of the following four types of systems:

(a) Large-scale cogeneration systems for district heating and cooling

(b) Cascade heat supply systems for industrial complexes

(c) Municipal solid waste (MSW) energy utilization systems

(d) Surplus energy supply systems (from power plants or factories to the community)

(Subsidy plan for projects)

(i) NEDO will invite applications by enterprises which have business plans providing for any of the four aforementioned types of effective energy utilization systems.

(ii) Suitable business plans will be selected, and subsidy recipients will be determined.

(iii) Subsidized enterprises will establish and operate facilities, and will collect data concerning items specified by NEDO. NEDO will analyze and evaluate obtained data and compile them as materials.

(iv) The subsidy rate is 15% of expenses (the upper limit of subsidy per case is ¥600 million per year).

(Subsidy plan for feasibility studies)

(i) NEDO will invite applications of enterprises planning to conduct introductory surveys on effective energy utilization systems related to the four aforementioned topics in specific areas.

(ii) Suitable business plans will be selected, and subsidy recipients will be determined.

(iii) The subsidy rate will be fixed amounts (the upper limit per case is ¥30 million).

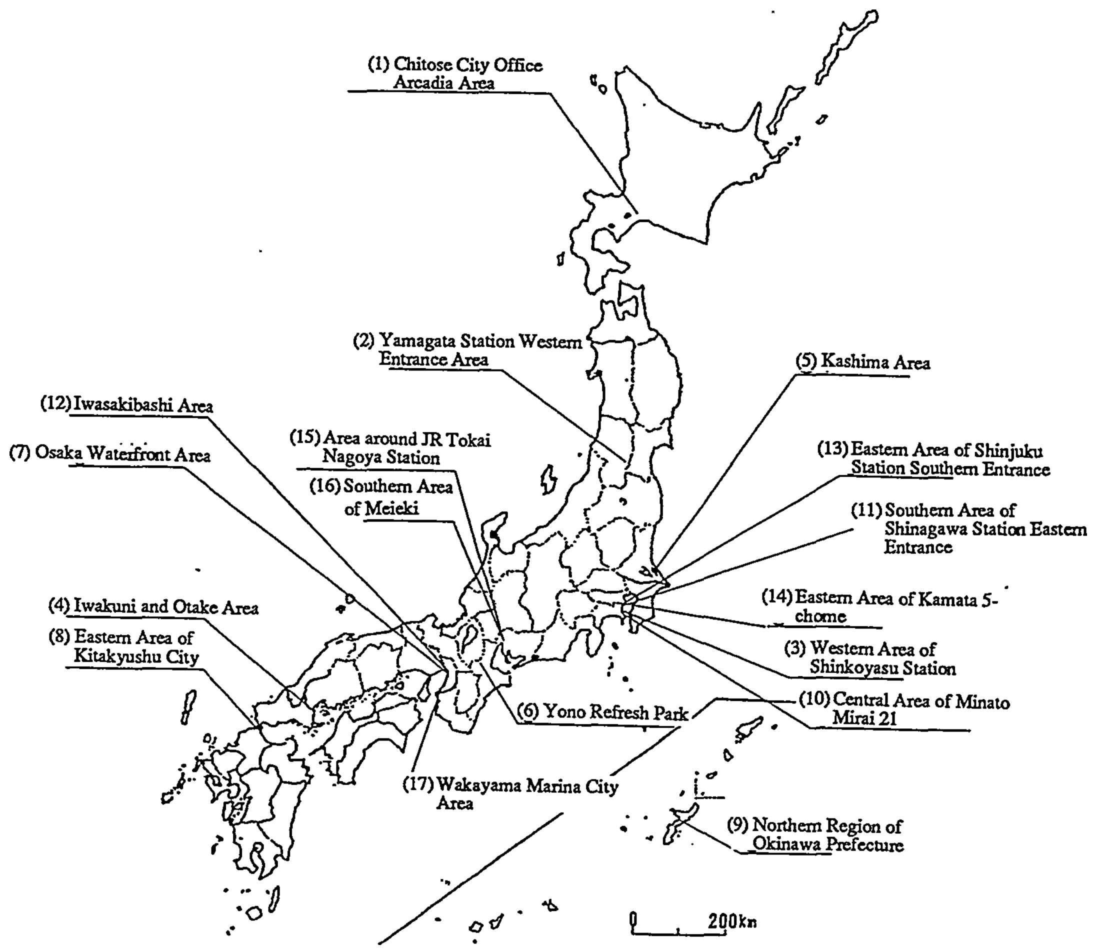
(2) Summary for FY1994

Subsidies for the project were granted to a total of eight cases — four cases of continued plans and four cases of newly adopted plans relating to installation of large-scale cogeneration systems for district heating and cooling. NEDO created software to collect and analyze data, and some data was analyzed and evaluated.

Subsidies for feasibility studies on the project were granted in nine cases for large-scale cogeneration systems for district heating and cooling and high-efficiency waste power generation (waste energy utilizing) systems.

(3) Future Tasks

In fiscal 1995, the project plans of four types of energy effective utilization system were sought and received publicly and suitable business entities were selected. Then the subsidy recipients were determined.



List of Places Where Environmentally-Friendly Energy Community Subsidized Projects Were Conducted in Fiscal 1994

	Type of project	Name of project	Organization subsidized	Remarks
Research subsidies	Large-scale cogeneration systems for district heating and cooling	(1) Chitose City Office Arcadia Area	Chitose City	
		(2) Yamagata Station Western Entrance Area	Yamagata Gas Co., Ltd.	
		(3) Western Area of Shinkoyasu Station	NKK Corp.	
		(4) Iwakuni and Otake Area	Koa Oil Co., Ltd.	
	High-efficiency waste power generation facilities	(5) Kashima Area	Mitsubishi Chemical Corp.	
		(6) Yono Refresh Park	RD Engineering Inc.	
		(7) Osaka Waterfront Area	Osaka Gas Co., Ltd.	
		(8) Eastern Area of Kitakyushu City	Kita Kyushu City	
		(9) Northern Region of Okinawa Prefecture	Ryukyu Cement Co., Ltd.	
Business project subsidies	Large-scale cogeneration systems for district heating and cooling	(10)Central Area of Minato Mirai 21	Minato Mirai 21 District Heating and Cooling Co., Ltd. and other two companies	Continued project
		(11)Southern Area of Shinagawa Station Eastern Entrance	Kowa Real Estate Investment Co., Ltd.	Continued project
		(12)Iwasakibashi Area	Osaka Gas Co., Ltd.	Continued project
		(13)Eastern Area of Shinjuku Station Southern Entrance	District Heating and Cooling Shinjuku Co., Ltd. and another company	
		(14)Eastern Area of Kamata 5-chome	Tokyo Gas Co., Ltd.	
		(15)Area around JR Tokai Nagoya Station	Nagoya District Heating and Cooling Co., Ltd. and another company	
		(16)Southern Area of Meieki	Toho Gas Co., Ltd.	
	Surplus energy supply systems from power plants to the community	(17)Wakayama Marina City Area	Wakayama Marina City Energy Service Co., Ltd.	Continued project

VII

Field Test Project for New Energy Generation

(1) Objectives and Work Programs

[Objectives]

As technological development has progressed, photovoltaic power generation and fuel cell power generation technologies are getting close to the practical utilization stage. Their mass introduction and dissemination have not materialized, however, because these technologies are not economically competitive and also because data on reliability under actual utilization conditions have not yet been adequately accumulated.

In this situation, it is hoped that long-term operation data, experience of maintenance, etc., will be collected and classified by introducing final dissemination forms of these technologies into actual use on a trial basis, and to provide the public with information on the practical use of these technologies, to contribute to their dissemination.

Accordingly, photovoltaic power generation systems and fuel cell power generation systems, will be installed on an experimental basis in various kinds of facilities, and then operation under actual load will be carried out for extended periods. Various data will be collected, analyzed and utilized for their large-scale introduction and popularization, and documents of data collection, analysis and utilization will be distributed to concerned organizations and project promoters for the purpose of forming a base for the general popularization of photovoltaic power generation and fuel cell power generation.

[Work Program]

(a) Installation of the facilities, operation and data collection

As for photovoltaic power generation systems, in consideration of solar energy density and daylight hours, systems will be installed on a trial basis in facilities (public facilities such as schools, museums and public halls [21 types of facilities]) in which power demand is relatively concentrated during the daytime and significantly improved awareness of its merits can be expected. The installation sites will be located in five typical kinds of areas in Japan — snowy, cold, standard, well-sunlit areas and windy/salt damaged areas. These systems will be operated under actual load, and a variety of operational data will be collected.

As for fuel cells, systems will be installed in hospitals, hotels, business offices, plants and other facilities [33 types] on a trial basis, with the point of view that these facilities will constitute a promising market for on-site cogeneration systems for commercial and industrial applications in the near future. They will be operated under actual load, and a variety of operational data will be gathered.

These activities will be conducted as joint research work of NEDO and cooperating enterprises.

(b) Data analysis, evaluation and compilation

Operational data collected will be analyzed and evaluated; it will be compiled as useful material for full-fledged introduction and distributed to the appropriate organizations and companies.

(2) Summary for FY1994

This project was started in fiscal 1992. After examining joint research project proposals, which were accepted following a general invitation announcement, in terms of the specific nature of joint research projects, the reasonableness of project promotion setups and the dissemination-promoting effects from an overall viewpoint, joint research organizations were selected and target facilities installed power generation equipment on a trial basis. In fiscal 1994, this joint research was implemented as in fiscal 1992 and 1993. There were 11 research locations (11 in 1992 and 19 in 1993) throughout the country for photovoltaic power generation, and four (15 in 1992 and 4 in 1993) for fuel cell power generation.

(3) Future Tasks

As for the photovoltaic power generation field test project, installation of systems in candidate objective facilities (21 types in five districts) has already been completed. From fiscal 1995 and on, taking the past experience into consideration, the contents of project will be changed to reduce the cost of the systems. At the same time, field test of wind power generation systems will be started.

List of Field Tests of PV Systems Installed in Fiscal 1992 - 1994

	No.	Cooperating research organization	Place where test was conducted	Application	PV system installation place	System capacity (kW)
FY 1992	(1)	Nakagawa Town, Nakagawa-gun, Hokkaido	Nakagawa Town Pompira Aqua R^2 ing	Bath filtration and lighting	Adjoining slope	30
	(2)	Noto Town, Fugeshi-gun, Ishikawa Prefecture	Mawaki Ruins Park (Noto-machi, Ishikawa Prefecture)	Lighting of public hotspring baths	Adjoining slope	20
	(3)	Ishikawa Prefecture	Ishikawa Prefectural Central Children's Center (Kanazawa)	Lighting	Roof of existing building	20
	(4)	Kumamoto Prefecture	Oguni Town Oguni Gakuen School (Oguni -machi, Kumamoto Prefecture)	Lighting	On the ground	20
	(5)	East Japan Railway Company	Tokyo Station, Tohoku and Joetsu Shinkansen platforms	Lighting and air conditioning	Roof of platform	30
	(6)	Global Environment Centre Foundation	Osaka City Tsurumi Ryokuchi Park (Osaka)	Lighting and air conditioning	Rooftop of new building	20
	(7)	The Chugoku Electric Power Co., Ltd.	Hiroshima Regional Park (Hiroshima)	Pumping of fountains and wall fountains	Adjoining slope	30
	(8)	Shizuoka Prefecture Industrial Environment Research Center	Miyakoda Research Institute (Hamamatsu-shi)	Lighting and air conditioning	Rooftop of new building	10
	(9)	International Center for Environmental Technology Transfer (Foundation)	ICETT training building (Yokkaichi-shi)	Lighting and air conditioning	Rooftop of new building	10
	(10)	Hyogo Prefecture	Awaji Agricultural Research Center (Mihara-cho, Hyogo Prefecture)	Air conditioning in green houses	On the ground	25
	(11)	Amakusa Town, Amakusa-gun, Kumamoto Prefecture	Guest-house "Amakusa-so"	Lighting and air conditioning	Rooftop of existing building	20
	—	——	——	——	——	Total 235
FY 1993	(12)	Ichinoseki City	Ichinoseki City I-DOME (Iwate Prefecture)	Lighting and air conditioning	Adjoining slope	20
	(13)	Corporation Bureau, Yamanashi Prefecture	Okano Park (Kiyosato, Yamanashi Prefecture)	Lighting and air conditioning of the Park office	Slope	95
	(14)	Koganei City	Kuriyama Park Health and Athletic Center (Koganei-shi, Tokyo)	Lighting and power source	Rooftop of new building	10

List of Field Tests of PV Systems Installed in Fiscal 1992 - 1994 (Continued)

	No.	Cooperating research organization	Place where test was conducted	Application	PV system installation place	System capacity (kW)
FY 1993	(15)	Mejiro Gakuen School	Mejiro University (Iwatsuki-shi, Saitama Prefecture)	Lighting and air conditioning	Rooftop of new building	30
	(16)	Maeda Construction Co., Ltd.	Tokyo Hikarigaoka sport facilities (Nerima-ku, Tokyo)	Lighting and air conditioning of sport building	Rooftop of new building	20
	(17)	Ebina City	Regional Community Center (Ebina-shi, Kanagawa Prefecture)	Air conditioning of the Center and lighting of rooms	Rooftop of new building	20
	(18)	Co-op Kanagawa	Eastern Yokohama Cooperative Buying Center (Tsurumi-ku, Kanagawa Prefecture)	Lighting	Roof of existing building	10
	(19)	Tajima Fukushien	Home for aged "Myoken-so" (Youka-cho, Hyogo Prefecture)	Lighting and air conditioning	Rooftop of existing building	30
	(20)	Okayama City	Jouto School Lunch Center (Okayama-shi, Okayama Prefecture)	Lighting	Roof of new building	10
	(21)	Corporation Bureau, Okayama Prefecture	Okayama Prefectural Office (Okayama-shi, Okayama Prefecture)	Lighting and air conditioning	Rooftop of existing building	20
	(22)	Oita Prefecture	Oita Prefecture Agricultural Technology Center (Usa-shi, Oita Prefecture)	Machine operation	On the ground	20
	(23)	Kanagawa Prefecture	Kanagawa Prefecture Industrial Technology Research Institute (Kanagawa Prefecture)	Lighting	Rooftop of new building	25
	(24)	Co-op Shiga	Silvi Co-op Hikone (Hikone-shi, Shiga Prefecture)	Lighting	Rooftop of new building	15
	(25)	Shiga Prefecture	Shiga Prefectural University (Hikone City, Shiga Prefecture)	Power source for engineering department building	Rooftop of new building	15
	(26)	Hijikawa Town	Hijikawa Town "Museum of Wind" (Ehime Prefecture)	Lighting and air conditioning	Rooftop of new building	20
	(27)	Oita Prefecture	Oita Prefecture Industrial Science and Technology Center (Oita-shi, Oita Prefecture)	Lighting and machine operation	Rooftop of new building	50
	(28)	Suntory Ltd.	Suntory Museum (Osaka)	Lighting and air conditioning	Rooftop of new building	13
	(29)	Yanagi Gakuen	Yanagi Gakuen School (Awaji Island, Hyogo Prefecture)	Lighting of class room building	Rooftop of new building	13
	(30)	Phoenix Resort	Phoenix Resort "Sea Gaia" (Miyazaki-shi, Miyazaki Prefecture)	Lighting and air conditioning of "Paradise Garden"	Rooftop of new building	40
	—	—	—	—	—	Total 476

List of Field Tests of PV Systems Installed in Fiscal 1992 - 1994 (Continued)

	No.	Cooperating research organization	Place where test was conducted	Application	PV system installation place	System capacity (kW)
FY1994	(31)	Kanai Gakuen	Fukui Institute of Technology (Fukui City, Fukui Prefecture)	Lighting, air conditioning and experimental facilities	Rooftop of existing building	30
	(32)	Shimane Prefectural Police Headquarters	Saigo Police Station (Saigo-cho, Oki-gun)	Lighting and air conditioning	Roof of new garage	15
	(33)	Tokyo Metropolis	Tokyo Metropolis Waterworks Bureau Higashi Murayama Filtration Plant (Higashi Murayama City)	Waterworks plant facilities	On the ground	70
	(34)	Kanagawa Prefecture	Kanagawa Prefecture Disaster Prevention Center (Atsugi City)	Lighting, air conditioning and machine operation	Rooftop of new building	35
	(35)	Toyosato Town, Inukami-gun, Shiga Prefecture	Toyosato Town Health Center (Toyosato-cho, Inukami-gun)	Lighting, air conditioning and health and medical treatment facilities	Roof of new building	20
	(36)	Kyodo Gakusha	Kyodo Gakusha (Machida City, Tokyo)	Lighting and air conditioning	On the ground	30
	(37)	Chuo Koseikai	Sakuragi Nursery School (Kakegawa City, Shizuoka Prefecture)	Lighting and air conditioning	On the ground	10
	(38)	Yagi Town, Funai-gun, Kyoto Prefecture	Yagi Town Yagi Junior High School (Yagi-cho, Funai-gun)	Lighting and air conditioning	Rooftop of new building	50
	(39)	Shizuoka Prefecture	Shizuoka Prefecture Environment Radiation Monitor Center (Hamaoka-cho, Ogasa-gun)	Lighting, air conditioning and information processing equipment	Rooftop of existing building	20
	(40)	Tanabe City, Wakayama Prefecture	Tanabe Citizen Center (Tanabe City)	Lighting, air conditioning and health and medical treatment facilities	On the ground	20
	(41)	Kochi Prefecture	Kochi Prefecture Noichi Animal Park (Noichi-cho, Kami-gun)	Sewage disposal	Outdoor new parking lot	70
	—	——	——	——	——	Total 370

List of Field Tests of Fuel Cell Systems Installed in Fiscal 1992 - 1994

	No.	Cooperating research organization	Place where test was conducted	Application	Fuel cell system installation place	System capacity (kW)
FY 1992	(1)	Tokyo Gas Co., Ltd.	Tokyo Kogakuin College (Koganei-shi)	[Electric power] System interconnected to the utility grid [Waste heat] Hot water supply and heating of pool water, etc.	Machine room (above the ground)	50
	(2)	Tokyo Gas Co., Ltd.	Meguro Gajoen (Meguro-ku, Tokyo)	[Electric power] System interconnected to the utility grid [Waste heat] Hot water supply	Machine room (2nd basement)	50
	(3)	Tokyo Gas Co., Ltd.	Nippon Telephone and Telegram Co., Ltd. Yokohama Branch (Yokohama)	[Electric power] System interconnected to the utility grid [Waste heat] Air conditioning	Machine room (1st basement)	100
	(4)	Tokyo Gas Co., Ltd.	East Japan Railway Company Ohi Works (Shinagawa-ku, Tokyo)	[Electric power] System interconnected to the utility grid [Waste heat] Heat source of rolling stock washing water	Outdoor installation	100
	(5)	Tokyo Gas Co., Ltd.	Tokyo East 21 (Koto-ku, Tokyo)	[Electric power] System interconnected to the utility grid [Waste heat] Hot water supply	4th floor rooftop	200
	(6)	Osaka Gas Co., Ltd.	Koshien Miyako Hotel (Nishinomiya-shi)	[Electric power] Power source for cooling pump [Waste heat] Hot water supply	3rd floor rooftop	50
	(7)	Osaka Gas Co., Ltd.	Koshien Toyo Building (Nishinomiya-shi)	[Electric power] Power source for cooling pump [Waste heat] Hot water supply	3rd floor rooftop	50
	(8)	Osaka Gas Co., Ltd.	Hankyu Corporation Headquarters (Osaka)	[Electric power] System interconnected to the utility grid [Waste heat] Hot water supply	Machine room (2nd basement)	100
	(9)	Osaka Gas Co., Ltd.	Mitsui Garden Hotel Osaka (Osaka)	[Electric power] System interconnected to the utility grid [Waste heat] Hot water supply	1st floor rooftop	100
	(10)	Osaka Gas Co., Ltd.	Esteem Life Gakuenmae (Nara)	[Electric power] System interconnected to the utility grid [Waste heat] Air conditioning and hot water supply	Outdoor separate building	100
	(11)	Osaka Gas Co., Ltd.	Sumitomo Chemicals Co., Ltd. Osaka Plant (Osaka)	[Electric power] System interconnected to the utility grid [Waste heat] Preheating of boiler feed water	Outdoor installation	200
	(12)	Osaka Gas Co., Ltd.	Asia and Pacific Trade Center (Osaka)	[Electric power] System interconnected to the utility grid [Waste heat] Air conditioning and hot water supply	Machine room (1st basement)	1,000
	(13)	Toho Gas Co., Ltd.	Port of Nagoya Public Aquarium (Nagoya)	[Electric power] System interconnected to the utility grid [Waste heat] Preheating of boiler feed water	Outdoor installation	100

List of Field Tests of Fuel Cell Systems Installed in Fiscal 1992 - 1994 (Continued)

	No.	Cooperating research organization	Place where test was conducted	Application	Fuel cell system installation place	System capacity (kW)
FY 1992	(14)	Chubu Electric Power Co., Ltd.	Toenec Corporation Education and Training Center (Nagoya)	[Electric power] System interconnected to the utility grid [Waste heat] Air conditioning and hot water supply	Machine room (above the ground)	50
	(15)	Global Environment Centre Foundation	UNEP International Environmental Technology Centre Building (Osaka)	[Electric power] System interconnected to the utility grid [Waste heat] Air conditioning and hot water supply	Outdoor installation	50
	—	—	—	—	—	Total 2,300
FY 1993	(16)	Tokyo Gas Co., Ltd.	Tachikawa City Center (Tokyo)	[Electir power] System interconnected to the utility grid [Waste heat] Air conditioning	8th floor roof	400
	(17)	Tokyo Gas Co., Ltd.	Riverside Sumida (Tokyo)	[Electric power] System interconnected to the utility grid [Waste heat] Air conditioning and hot water supply	On the southern ground of tower building	100
	(18)	Osaka Gas Co., Ltd.	Matsushita Electric Works, Ltd. (Kadoma-shi, Osaka)	[Electric power] System interconnected to the utility grid [Waste heat] Preheating of boiler feedwater	On the southern ground of plant No. 1	200
	(19)	Osaka Gas Co., Ltd.	Osaka Red Cross Hospital (Osaka)	[Electric power] System interconnected to the utility grid [Waste heat] Preheating of boiler feedwater	Outdoor installation	200
	—	—	—	—	—	Total 900
FY 1994	(20)	Tokyo Gas Co., Ltd.	Tokyo Environmental Science Laboratory (Koto-ku)	[Electric power] System interconneced to the utility grid [Waste heat] Air conditioning	On the outdoor ground	200
	(21)	Tokyo Gas Co., Ltd.	Itabashi-ku Ecopolis Center (Itabashi-ku)	[Electric power] System interconneced to the utility grid [Waste heat] Air conditioning	2nd basement	50
	(22)	Osaka Gas Co., Ltd.	Kirin Brewery Co., Ltd. Kyoto Factory (Kyoto City)	[Electric power] System interconneced to the utility grid[Waste heat] Hot water supply and steam utilization	Outdoor installation	400
	(23)	Osaka Gas Co., Ltd.	Nisshin Steel Co., Ltd. Sakai Works (Sakai City, Osaka Prefecture)	[Electric power] System interconneced to the utility grid [Waste heat] Hot water for cleaning	Outdoor installation	200
	—	—	—	—	—	Total 850

1. Types of Candidate Facilities for Installing PV Systems

Candidate facilities for installing PV systems corresponding to types of facilities listed below in every region which has following area characteristics (5 area characteristics and 21 types of facilities).

<Regional characteristics>
(1) Snowy (2) Cold (3) Standard (4) Well-sunlit (5) Windy/salt-damaged

<Types of facilities>

(1) Kindergartens, day-care centers
(2) Elementary, junior, senior high schools
(3) Universities
(4) Libraries, museums
(5) Public halls, prefectural halls
(6) Homes for the aged
(7) Health centers, clinics
(8) Hospitals
(9) Human waste and sewage treatment plants
(10) Public lodges, sanatoriums
(11) Gymnasiums, sports facilities
(12) Public research labs
(13) Police stations, fire stations
(14) Police boxes
(15) Post offices
(16) Prefectural offices, city, town, village halls
(17) Parks
(18) Agricultural cooperatives, fishermen's cooperatives
(19) Railway stations
(20) Expressway sound barriers, banks of river levees

2. Types of Candidate Facilities for Installing Fuel Cell Systems

Candidate facilities for installing fuel cell systems corresponding to types of facilities listed below.

<Types of facilities>

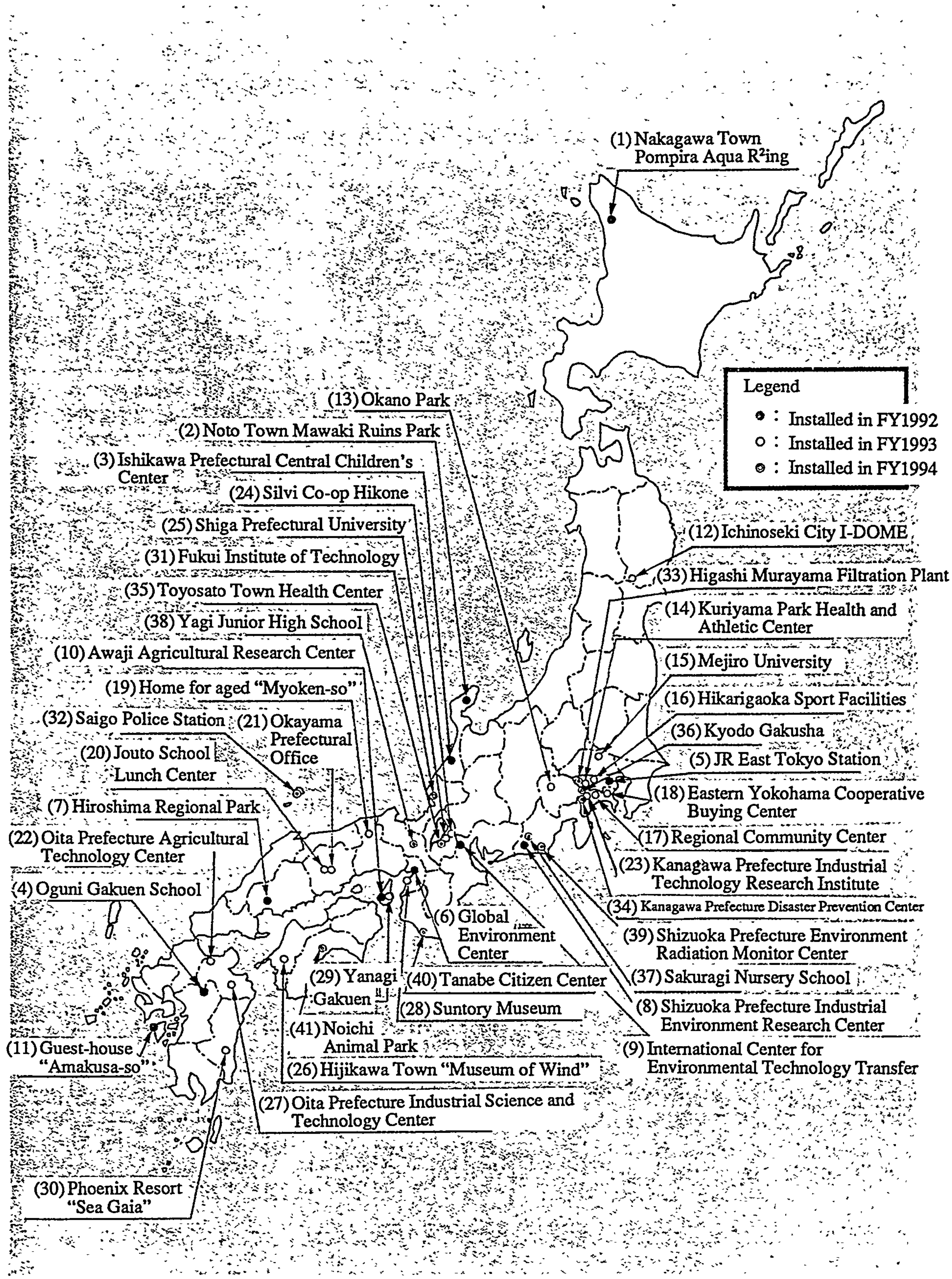
Private facilities

(1) Business hotels
(2) City hotels
(3) Resort hotels
(4) Small-scale office buildings
(5) Large-scale office buildings
(6) Intelligent buildings
(7) Universities
(8) Science and engineering universities, research laboratories
(9) Elementary and junior high schools
(10) Training facilities
(11) General hospitals
(12) Welfare facilities
(13) Sports facilities
(14) Large-scale retail stores
(15) Underground shopping malls
(16) Food service (restaurants, etc.)
(17) Residential communities
(18) Commercial buildings
(19) Multi-purpose buildings
(20) Wedding and banquet halls
(21) Broadcasting stations
(22) Warehouses

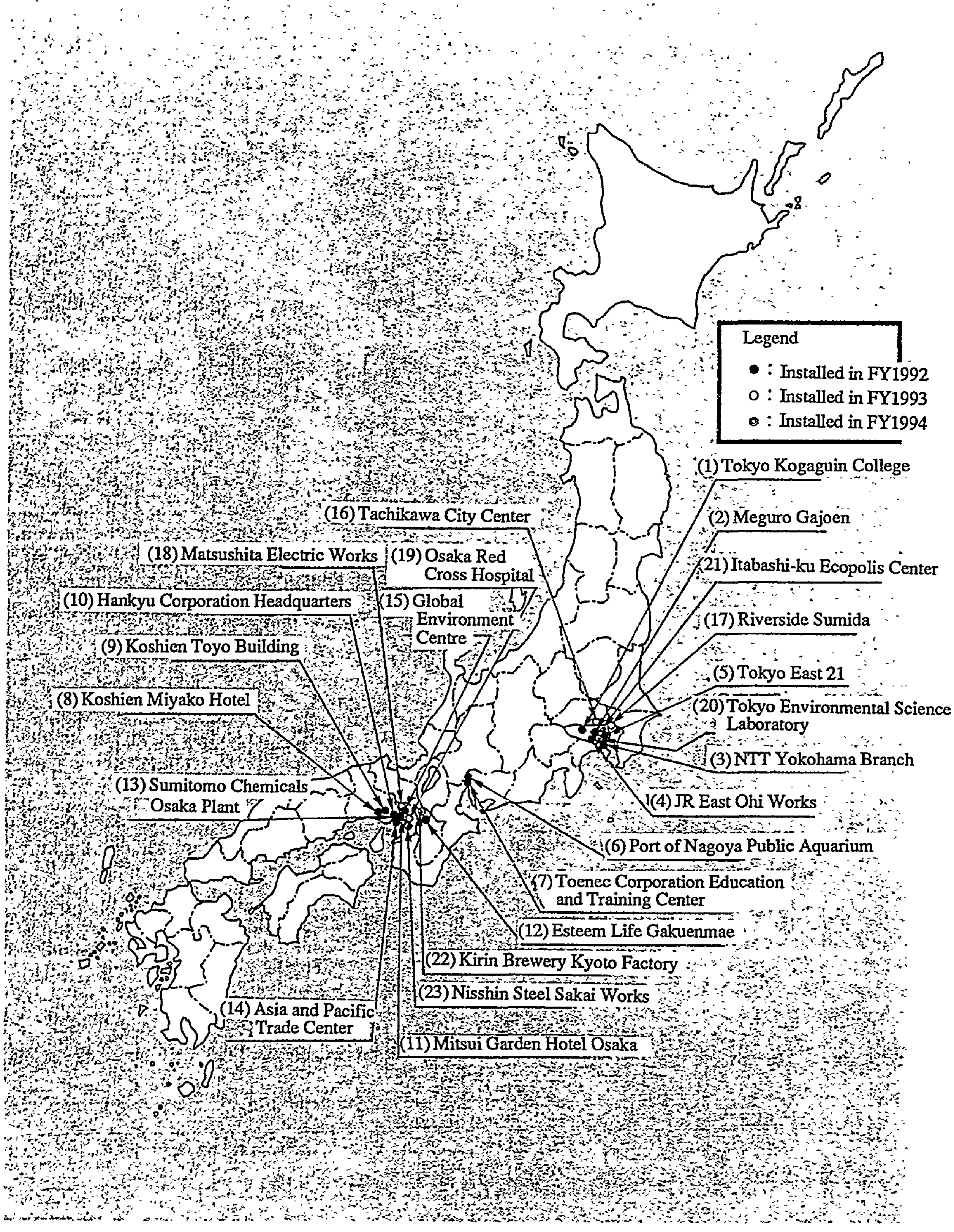
Industrial facilities

(24) Users of high- and low-temperature waste heat (chemical companies)
(25) Users of high-temperature waste heat (food companies)
(26) Users of byproduct gases (petrochemical companies)
(27) Salt electrolysis, electrorefining
(28) Railroads
(29) Telecommunications
(30) Users of low-temperature waste heat (semiconductors, electronics parts)
(31) Plant air conditioning (electric, machinery, assembly)
(32) Base operation
(33) Pharmaceutical companies

Field Tests of Installed PV Systems



Field Tests of Installed Fuel Cell Systems



VIII

Demonstration Test for Establishing Technology for Peakload Shaving with Dispersed Small Residential PV Systems

(1) Objectives and Work Program

(a) Objectives

The planned introduction of photovoltaic power generation is expected to produce the effect of leveling daytime and nighttime loads (peakload shaving effect) in summer, etc. As for its method of introduction, dissemination by installing related equipment within structures, such as houses, is considered to be promising, particularly in Japan. But for its full-fledged introduction into houses and so on, it is necessary to establish an evaluation technology for the peakload shaving effect of a residential photovoltaic power generation system (PVS) and at the same time to optimize the PVS.

For this reason, a PVS will be established in actual houses, demonstration tests will be conducted based on interconnection with the utility power grid, and the evaluation technology for the peakload shaving effect of PVS will be established through introduction of the system into homes. Furthermore, through acquisition of data for optimization of the residential PVS, efforts will be made to lay the technological foundation for the full-scale introduction and dissemination of photovoltaic power generation.

(b) Work program

(i) System construction and operation

Residential PVSs will be established in a number of new detached houses and data collecting equipment will be installed in the residential areas of urban districts or their peripheries. By conducting demonstration tests based on interconnection with the utility power grid, various demonstration data will be obtained.

(ii) Analysis and evaluation

Establishment of evaluation technology for load leveling effects and optimization of residential photovoltaic power generation system will be attempted by collecting and sorting such information as demonstration operation data and durability data on some instruments and by analyzing and evaluating these data.

(2) Summary for FY1994

(a) System construction and operation

System construction was terminated in fiscal 1993, and the residential photovoltaic power generation system was installed on the roofs of 25 newly-build houses.

- Four houses in Sendai
- Six houses in Shiga
- Ten houses in two areas in Akita
- Five houses in Shizuoka

The operation of the system was demonstrated by interconnecting it to the utility grid, and then demonstration operation data on weather conditions such as quantity of solar radiation, quantity of power generation, quantity of load demands of residents, and state of system operation were obtained and, at the same time, the system was maintained and inspected to ensure normal operation.

(b) Analysis and evaluation

Demonstration operation data obtained from the residential photovoltaic power generation system were analyzed and evaluated, and at the same time, technological information such as durability data on some instruments was collected and analyzed to prepare a database of various kinds of technological information relating thereto.

(i) Collection of demonstration operation data
(ii) Construction of database for load leveling
(iii) Examination of method to analyze load leveling effects
(iv) Examination of optimal system configuration
(v) Preparation of related data (collection of technological information and construction of data base of systems relating to residential photovoltaic power generation system)
(vi) Evaluation of equipment durability
- Interconnection equipment with inverter
- Residential photovoltaic power generation system equipment

(3) Future Tasks

Continuing the work done in fiscal 1994, demonstration operation of the residential photovoltaic power generation system connected with the utility power grid, maintenance and control of the system, and collection, sorting, analysis and evaluation of demonstration operation data and related information will be implemented in fiscal 1995.

General View of Tomen Nakayamadai (4 houses), Sendai Area

IX

Demonstration Test of Advanced Power Supply System Utilizing Dispersed Generation

(1) Objectives and Work Program

(a) Objectives

Dispersed power generation, such as photovoltaic power generation and fuel cell power generation equipment, are expected to be actively introduced as new energy/ power sources located close to the areas of demand.

To help achieve this purpose, it is necessary to build up a new interconnected power grid that incorporates more advanced control technologies, designed to utilize functions of dispersed power generation to the utmost degree. It is required in this connection to establish system control and other technologies essential for the buildup of the system.

(b) Work program

To establish an advanced power supply system that utilizes dispersed power generation, research and development will be carried out regarding the following items.

(i) Development of autonomous dispersed system control technology

It is desired to establish a local power supply network using electric power system and power supply from dispersed power generation power at the same time based on the interconnection with the utility power grids and introduction of dispersed power generation. The operation and control of dispersed power generation system groups, necessary for the organization of the network, will be studied, and cooperative operation with utility power grids and system optimization steps will be examined. Along with this, necessary verification tests will be implemented to establish said technologies.

(ii) Development of high-efficiency power supply systems

In order to organize highly efficient power supply/ consumption systems while utilizing characteristics of dispersed power generation, research will be conducted on optimal systems for high-efficiency power supply, using direct current which can be introduced into tight places, such as office buildings, depending on the preferences of the user. Necessary verification tests will also be conducted.

(iii) International cooperative work

NEDO will participate in Task V of IEA's implementing agreement for a cooperative program on photovoltaic power systems. As the national operation agency of Task V, it will also establish a research promotion setup necessary for the international joint research and will prepare operational plans. Furthermore, NEDO will jointly carry out the collection, analysis and evaluation of technological data of various countries related to interconnecting with the grid, as well as the modification of facilities and the verification necessary for testing interconnection with the grid of related countries.

(2) Summary for FY1994

(a) Development of autonomous dispersed system control technology

(i) Research and analysis

Typical loading patterns in residential area, commercial area, etc., were collected, and the optimal system configuration under a district electric power supply network which utilizes dispersed power generation was examined by combining operation patterns of dispersed power generation such as photovoltaic power generation and fuel cell power generation.

(ii) Design, fabrication and installation of demonstration test equipment

The following main instruments that make up the district electric power supply network utilizing discrete dispersed power generation were designed, fabricated and installed:

- The central controller that controls each dispersed power generation
- Interconnected units
- Battery storage system

(iii) Development of a demonstration test plan

A demonstration test plan which uses the equipment installed in fiscal 1994 was devised in order to examine the stability of the district electric power supply network and the coordination between that network and the utility power grid.

(b) Development of high efficiency electric power supply network

(i) Research and analysis

Continuing the work of the fiscal 1993, the merit of utilizing direct current distribution was evaluated, and the effect of direct current on reducing electrical loss was clarified; at the same time, the configuration of a direct current supply system was examined at a model office building.

(ii) Development of technology

Aiming at improving the efficiency of electric power use, the detail designs of the interconnected inverter and the DC-DC converter that are the main instruments in configuring a high efficiency electric power supply system using direct current power distribution were carried out; moreover, characteristic evaluation of a direct current breaker was made.

(c) International cooperative work

(i) Operation of Task V

As the operating agents of Task V (grid interconnection of building-integrated and other dispersed PV systems), the task progressing state was controlled and operation of project plans was implemented.

(ii) Collection of technological data in each country

The guidelines and technological data on distribution system in each country relating to the interconnection of photovoltaic power generation systems were collected, and the configuration of a database system required for accumulation and utilization of technological data was examined.

(iii) Examination on demonstration items and improvement of demonstration facility

With regard to the items of concern in each country relating to the system interconnection demonstration test, the necessity of the demonstration test was examined, and at the same time, the equipment of the Rokko Test Center was improved so as to make possible the interconnection test on inverters of each country.

(3) Future Tasks

Continuing the work done in fiscal 1994, development of the autonomous dispersed power generation control technology and development of the high efficiency electric power supply system will be examined and researched for optimization of the systems. Furthermore, required test equipment will be improved and demonstration operation of some equipment will be implemented. As for international joint research cooperation, participation in the Task V for cooperation in the IEA implementing agreement for a cooperative program on photovoltaic power systems will be continued for Task V operation in relation to interconnected photovoltaic power generation.

X

Development of Heating and Cooling Technologies for Electric Load Leveling and Advanced Utilization of Unused Energy

(1) Objectives and Work Program

To establish practical technologies for a high efficiency district heating and cooling system (including heat reserves) utilizing unused energy from sea water and river water and exhaust heat from waste treatment, to meet the increasing heating and cooling demand related to air conditioning in urban areas and to pursue the leveling of electric power load, technologies will be developed for heat generation, transport and retaining of heat with highly efficient heat exchangers and heat pumps, as will the technology for system optimization.

(2) Summary for FY1994

Based on the results of applications which were categorized into each development theme relating to the locations of demonstration tests carried out in fiscal 1993, four candidate locations (Tokyo waterfront area, Osaka area, Kobe area and Fukuoka area) were selected, taking into consideration the energy saving effects at the demonstration locations, types of unused energy and physical conditions such as space.

The contents of demonstration tests scheduled to be implemented from fiscal 1995 were examined, then the demonstration test equipment and the system were examined at each demonstration site. Design and work execution of some demonstration equipment was started.

Fiscal 1994 falls in the final year of element test research and in this year an interim evaluation was carried out for the demonstration test to be conducted in fiscal 1995.

(a) Development of unused energy utilizing thermal plant

(i) Technology development for low-temperature unused energy utilizing thermal plant

a. Heat exchanger improved for unused heat sources

i. Heat exchanger improved for natural heat sources

Confirmation test of measures to prevent the plate type heat exchanger from becoming fouled by sea water was carried out in actual sea water using a commercially available plate type heat exchanger. The heat transfer element of the heat exchanger that was improved for natural heat sources to be provided for the demonstration plant was designed and fabricated, and then the basic design of dust-preventive and fouling-preventive equipment was made.

ii. Heat exchanger improved for city waste heat

Soldered plate-fin type heat exchanger materials, fin shape and structure most suitable for the air and water heat sources were examined. Moreover, optimization of the crude sewage water heat exchanger and air heat source heat exchanger was attempted, based on data obtained in fiscal 1993, and then demonstration heat exchangers were designed. Moreover, specifications of heat exchangers and the system for the demonstration plant were examined.

b. High density heat transport system

Composite durability by phase change and fluidity of the PCM capsule that was obtained by the research carried out in fiscal 1993 was tested. The fluidity and heat transfer test equipment fabricated in fiscal 1992 was modified to carry out the fluidity and heat transfer test of the PCM capsule slurry. Results obtained by the basic test were evaluated and examined for the subsequent demonstration test.

The conveying units from the ice slurry/water and ice slurry/air heat exchanger and ice heat reserve tanks, the IPF (ice packing factor: ice charging rate per capacity) adjusting system and large-capacity calorie measuring method were researched and developed, and the results obtained by the instrument development test were evaluated and examined for the subsequent demonstration test.

The basic plan for three-ward supply simulation test units was examined for the plant test equipment. Moreover, trade-offs were examined with respect to the case in which the heat reserve tank of the high density heat transport medium was installed in the heat source equipment, the case in which the heat reserve tank was installed directly at the users' location and the case in which the tanks were installed in both the heat source equipment and at the users' location.

c. Heat pump system improved for low-temperature unused heat source

i. Heat pump system improved for heat source load

The bench plant that was partially fabricated in fiscal 1993 was completed and its system performance was determined through study of its operation. Each element unit was also operated for support research on the bench plant. Field research was carried out in order to install the demonstration system at candidate demonstration test sites, and their specifications were determined and confirmed.

ii. Heat pump system improved for low-temperature heat source

Based on the successful results of research and development carried out until the end of fiscal 1993, the reliability of collecting low-temperature heat and extracting high-temperature hot water was improved, the freezing prevention method was established, and technology to maintain high efficiency despite changes in sea water temperature was verified.

Combined use with a heat pump was optimized, the configurating instruments were optimized for the improvement in efficiency and reliability, and reactant (oxydant) removing technology was established. Further, combined use with the bench test heat pump unit was carried out to verify the basic performance of the organism adhesion preventive system.

The demonstration test machines scheduled to be installed at the demonstration test sites in fiscal 1995 were designed and drawings were produced.

(ii) Element technology development for thermal plants utilizing unused high-temperature energy

a. Turbine-driven turbo-type heat pump

i. Simultaneous chilled- and hot-water extraction heat pump system improved regarding heat source load

The piping and instrumentation equipment of the plant were installed, and then performance test operation was carried out to verify the basic instrument and equipment specifications followed by test operation regarding utilization of unused energy.

The plant test machines were used as demonstration machines at the site, then the design of the driving system was modified and the related systems were designed. Further, equipment installation at demonstration test site was planned and designed.

ii. High efficiency heat pump system improved regarding heat source load

Parameter values required for optimal control of the bench plant were examined, and the automatic control unit was designed, fabricated and installed. The piping was remodeled and pipes were added as required in order to carry out the varying water flow rate control test.

The system's dynamic characteristics were tested and analyzed with an operation test for a two-stage tandem type heat pump at the bench plant, and then the dynamic characteristic parameters required for the optimal control were determined and their optimal values were confirmed. An operation test was also carried out under the anticipated operating conditions of the two-stage tandem cycle to confirm the reliability of each machine element.

The basic design was examined for the demonstration test and the demonstration plant was studied in detail and designed and the design of instruments of the demonstration test machine was completed.

b. High efficiency absorption type heat pump

i. Absorption type heat pump system improved for natural heat sources

In order to evaluate the performance of the operating medium and the absorption cycle selected for the present research development, the experimental equipment for the dual-loop, double-effect cycle was designed, fabricated and its operation was prepared, based on the plan of the experimental equipment that was successfully implemented the previous fiscal year. A control system to stably and efficiently operate the dual-loop, double-effect cycle experimental equipment was developed.

In order to improve the efficiency of the fraction operation that significantly affects the COP, a detailed simulation relating to the fraction of operating medium and absorption liquid (TFE-NMP) was carried out.

Design of system, piping and wiring was carried out for the demonstration test.

ii. Absorption type heat pump improved for urban waste heat

A two-stage absorption, triple-effect-cycle-type heat pump on a scale of 20 tons of refrigeration was fabricated in accordance with its application structure standard. Automation of operation start/stop was evaluated for the whole system. Furthermore, automatic operation in normal operation mode and the system response to change in load were confirmed. Performances of the whole system and each element instrument were confirmed. A deaeration performance test unit using nitrate solution was fabricated and its deaeration performance data were collected. A demonstration equipment with a capacity of 30 tons of refrigeration was designed and its fabrication was prepared. A confirmation test started in the previous fiscal year with regard to the system for removing scale caused by sewage water treatment from the heat transfer tube of heat exchanger. This confirmation test was continued this fiscal year together with the material corrosion test, and an evaluation of the tests was completed.

iii. Waste-heat-driven absorption-type refrigerator

Each element part was designed again and parts were laid out based on the test results previously obtained, and then experimental equipment with a controlling mechanism was fabricated. The refrigerator capacity and COP fluctuation were tested and evaluated with regard to the driving heat medium temperature, cooling water temperature, chilled water outlet temperature, load, etc. The start-up characteristics and problems with actual operation of the refrigerator were researched.

Operation check and control check were implemented, assuming situations which do not fall within the rated condition when the solution density goes up, when the cooling water temperature is low, when the thermal medium flow rate changes, and when the load fluctuates. Moreover, confirmation of the safety unit in an abnormal mode was also carried out.

iv. Urban-type underground heat storage tanks

Demonstration test items, test methods and specifications of test equipment were examined to clarify their contents. Based on the specifications of test equipment and geological survey at the test site, the main body of the heat storage tank was designed. A heat storage tank construction plan was made based on the design result and the test result of mud water properties. In addition, water supply and draining equipment, measuring equipment and ancillary equipment were also designed. The test site was surveyed and its peripheral area was researched to establish conditions for temporary construction equipment, water supplying/draining equipment, test equipment and access. Moreover, research boring locations were determined, geological research was conducted, and boring was carried out.

Soil layer checks and standard penetration tests were carried out in the boring holes. Using the collected samples, laboratory tests (physical test, dynamic test and water permeation test) and the mud water property test were carried out to clarify geological and mud water property details. In order to examine the applicability of simultaneous low- and high-temperature heat storage, the existing indoor test equipment was modified. Then the heat storage and supply test was carried out for the purpose of examining applicability, paying attention to the thermal behavior on the boundary surface between the hot water layer (upper part) and the chilled water layer (lower part).

(iii) Development of high efficiency heat supply system

a. Low flow rate high efficiency heat supply system

The successful results of "development of the low flow rate heat exchanger system," "development of the low flow rate DHC optimal control system" and "development of the high density heat storage system" obtained by the end of fiscal 1993 were fed back to the program of this total system, then specifications of the low flow rate high efficiency heat supply system were determined. Continuing the work of the previous year, the low flow rate DHC optimal control system was tested in compliance with various load patterns which differ depending on seasonal fluctuation, and then the operability of heat source machine and heat reserve tank, the stable supply with a low flow rate, and the energy saving properties of the total system were confirmed, and moreover, improvement in the operation controlling method was intended.

A fan coil unit for low flow rate air conditioning which was fabricated in the previous year was installed in the model load room of this control system, and its control was studied by actually operating the low flow rate air conditioner.

b. Discrete type unused energy utilizing system

As for the chilled and hot water transferring system, the COP was evaluated in each operation mode, the unused water high utilization refrigerant cycle equipment was fabricated, the refrigerant control and operation controlling techniques were established, the unused water high-efficiency utilization refrigerant cycle (hetero-thermal condensation and hetero-humidity evaporation) effects were evaluated, and the technology of alternative refrigerant HFC134a was established.

As regards the refrigerant transferring system for houses, a bench test machine was designed and fabricated, the COP in each operation mode was evaluated with the bench test machine, the unused water high utilization refrigerant cycle equipment was fabricated, its refrigerant control and operation control were established, and then the main specification and control specification of the demonstration test machine were determined.

(iv) Development of plant optimization plan and operation system

a. Research of plant optimization plan and operation technology

The element technologies and the basic system to be installed at the demonstration test site were researched, and then research was carried out on the equipment plant and test contents/methods for implementation of the demonstration test. Various plants and facilities utilizing unused energies or planning to utilize them, and their utilizing methods, were studied to reinforce the infrastructure for development of this technology. Because sea water occupies an important position among sources of unused energy, the present situation of the sea water utilizing facilities was studied with attention paid to obtaining permission for sea water utilization and to the maintenance of such facilities.

Subsequent to the research in fiscal 1993 on the utilization of unused energy and new energy in Europe, documents of actual utilization of unused energy were collected from North America, Canada, Southeast Asia and Oceania.

b. Plant optimization planning system

Simulation was implemented using the developed plant optimization planning system by assuming a model area and by examining the heat source system of aerial heat supply facilities planned there, and then sensitivity analysis was carried out. The calculation function of the thermal unit price was added to the profitability calculation menu of the plant optimization planning system.

c. Plant optimization operating system

The actual function of the program was reinforced. The predicting control system of the heat source instruments was examined so as to maintain efficiency even if there arise gaps in demand prediction.

Simulation models of unused energy utilizing plant equipment were created, as were models of the heat exchanger improved for unused energy, the dynamic simulator for hot water boilers, and the demonstration plant configurating instruments. Using these plant simulators, an operation plan which was calculated under the optimal operating system for the demonstration plant was simulated dynamically, and then the responses of heat source instruments were simulated. Based on the examination results of the creation method of the demand model hitherto employed, a new demand generation model was created and improved for the examination of the interconnection with the optimal operating system. Sea water was picked as the objective unused energy, the annual temperature fluctuation of sea water was analyzed, and its prediction method was examined. Improvement in the algorithm was examined to sequentially correct abnormality prediction and to present more realistic abnormality treating measures. Furthermore, in order to evaluate operation of the heat source instruments, methods to assume and verify economic loss by deterioration of the instruments and their deterioration characteristics were planned.

(3) Future Tasks

Demonstration test research will start at the actual heat load site from fiscal 1995.

XI

Research on Technology to Introduce Waste-fired Power Generation

(1) Objectives and Work Program

[Objectives]

This project is a part of an advisory project to introduce new energy sources and it aims at supporting the introduction of waste-fired power generation to autonomous bodies by preparing manuals concerning power generation with wastes.

The manuals should reflect implementation results of specific studies, experiences and positive achievements by advanced autonomous bodies so that they can be of actual use to autonomous bodies and others in their introduction of power generation with wastes. Moreover, the future technological trend should be taken into consideration.

[Work Program]

(a) Preparation of introductory manual for waste-fired power generation

To comprehend the trend of technology of waste-fired power generation and related technologies, and the needs of autonomous bodies, introductory manuals required for specific examination of its introduction will be prepared.

(b) Implementation of case study

Support and advice will be made to autonomous bodies examining the introduction of waste-fired power generation, and a case study will be carried out with specific conditions set.

(2) Summary for FY1994

Preparations were begun for the basic manual and technological references for the introduction of power generation with wastes.

(3) Future Tasks

(a) Selection of autonomous bodies for case study

(b) Detailed introduction manuals will be prepared by incorporating the results of the case study into the basic manual in order to introduce and enrich its contents.

XII

Advisory Project to Introduce and Support New Energy

(1) Objectives and Work Program

[Objectives]

With the development and progress of new energy technologies, a variety of energy supply systems and new energy supply methods have appeared. These include new power generating technologies and instruments, cogeneration systems for urban areas, district heating and cooling systems using solar power generation and wind power generation and power generation from waste. It is desirable to promote the introduction of these technologies.

Because public and private organizations are showing a growing interest in new energy, the need for specific facilities and support for various kinds of related technologies have been increasing.

Therefore, support and advice for the introduction and dissemination of new energy to autonomous bodies were given. The current project was started in fiscal 1994 for the purpose of promoting an efficient introduction.

[Work Program]

(a) Research on needs

Specific needs of autonomous bodies will be grasped by administering questionnaire surveys on the introduction of new energy technologies.

(b) Holding explanatory meetings

Explanatory meetings will be held at nine regions of the Regional Bureau of International Trade and Industry with respect to the present situation of new energy technological development, case studies of their introduction, promotion measures, and so on.

(c) Itinerant support for introduction

Itinerant support for technology introduction will be carried out through research on the needs and explanatory meetings to individual consultation from applicants for support of introduction and schemes to which the introduction of new energies is anticipated to be effective.

(2) Summary for FY1994

(a) Research on needs

With regard to projects concerning new energy, questionnaire surveys were carried out involving 409 local autonomous bodies at the point of "already having implemented these technologies," at the step of "planning to implement" or at the step of "conducting research." Replies from 170 autonomous bodies were obtained.

(Result of research)

(i) As for the visions concerning the new energy, 23 such visions were described by 19 autonomous bodies, and 14 visions were under consideration or were to be considered by 13 autonomous bodies.

(ii) As for the projects concerning new energy already implemented or now being implemented, 115 projects were implemented or were being implemented by 70 autonomous bodies.

(iii) As for the projects undergoing planning or at the blueprint stage, 76 projects were being promoted by 54 autonomous bodies.

(b) Holding explanatory meetings

Explanatory meetings were held at 19 places in the nine regions of the Regional Bureau of International Trade and Industry for the main promising local autonomous bodies.

(c) Itinerant support for introduction

Itinerant support for the technology introduction was carried out at 25 places for individual consultation from local autonomous bodies.

(3) Future Tasks

Continuing the work done in fiscal 1994, research on needs, explanation meetings and itinerant support for introduction will be carried out in fiscal 1995. In addition to these, feasibility research will be supported.

(a) Research on needs

(i) Based on the successful results of research in fiscal 1994, detailed information will be determined through individual visits to autonomous bodies.

(ii) Research on needs of the civic sector will be carried out.

(b) Explanatory meetings

Explanatory meetings will be held in response to the needs of local autonomous bodies so as to provide information on case studies of the introduction of new energy technologies.

(c) Itinerant support for introduction

Implementation of itinerant support for the introduction of the technologies will be continued by carrying out needs research and explanatory meetings for individual consultation.

(d) Support of feasibility research

(i) Promotion to prepare introductory manuals for new energy, etc.

(ii) Feasibility research on introduction will be promoted through cooperation with autonomous bodies while making use of various research plans.

XIII

Research and Development of High-Performance Industrial Furnaces and Other Equipment

(1) Outline of Research

For the purpose of contributing to the conservation of the global environment, research and development will be conducted regarding high-performance industrial furnaces that can reduce energy consumption and meet the requirement for environmental protection. This will be attained through analytical evaluation of flame control parameters utilizing the microgravity environment, other basic research concerning the determinant factors of flame shapes and research on combustion systems.

The target value of thermal efficiency improvement is 30% for industrial furnaces. Regarding boilers, the goal is an improvement of about 5% over the thermal efficiency level of 90% during rated load operation.

With regard to development of basic technologies to control combustion utilizing the microgravity environment, NEDO will cooperate with the German Space Agency (DARA) and the French Science Research Agency (CNRS) in mutual utilization of microgravity testing facilities and promote information exchanges through personal exchanges of researchers in order to raise research and development efficiency.

(2) Summary for FY1994

(a) Development of basic technology for combustion control

To improve the performance of industrial furnaces, put to use the research on the basic technology for combustion control and make use of a microgravity environment, test data on combustion limit characteristics and flame control parameters were obtained, evaluated and analyzed, and then the combustion mechanism was clarified.

(i) Research on basic technology for combustion control

A coordinating conference concerning joint research with France and Germany was held to create the implementing institution and to specify themes.

(ii) Fabrication of study and test equipment

A high-speed digital image processor and a counterflow combustion test unit were fabricated and mounted on the microgravity test equipment.

(iii) Study on flame shape controlling technology

In order to evaluate combustion limit characteristics and to analyze and evaluate the flame control parameters, the following subthemes were studied, and the test data on the governing factors such as the combustion limit, flame shape and flame stability of various fuels were obtained:

a. Study on the blowoff limit of diffusing flame

b. Study on the instability of jetting and diffusing flame

c. Study on the stability of jetting and diffusing flame under microgravity

d. Study on the shape of jetting and diffusing flame through laser visualization.

(iv) Study on characteristics of flame heat radiation

For the purpose of analyzing and evaluating the flame controlling parameters, the following subthemes were studied and test data on the combustion mechanism for generating a high-heat radiation flame with various fuels were obtained:

a. Control of heat radiation characteristics of diffusing flame

b. Generation of high brilliance flame by two-step combustion (rich combustion and lean combustion)

c. Observation of soot particle generating behavior in the diffusing flame in a microgravity environment

d. Flame propagating behavior of fuel-air mixture of gaseous fuel and fine fuel particles

e Study to clarify turbulent combustion mechanism by microflame

f. Observation of diffusing flame using high-temperature preheated air.

(v) Study on low-pollution combustion technology

In order to develop low-pollution combustion technology, preliminary studies on the following subthemes were started. It became possible to establish a test method centered around the measuring technology of flame reaction intermediates concerning the characteristics and analysis of exhaust gas:

a. Measuring technology of reaction intermediates in flame

b. Control of the generation of combustion products in a microgravity environment

c. Low-pollution combustion of methanol

d. Study on NOx exhaustion characteristics in two-step diffusion combustion.

(b) Development of a high performance industrial furnace

(i) Research and study of common technological items

Research was carried out on patents related to "regenerative combustion technology," and the trend of patents and the technological contents of patents applied for up to March 1993 were charted.

The survey on the thermal efficiency of industrial furnaces in Japan was carried out.

Meanwhile, in order to clarify the direction of the present research, the basic concept of development was examined, then it was determined that a high-efficiency and low-pollution industrial furnace will be realized by developing the technology to raise the furnace temperature, the furnace temperature averaging technology and heating control technology, utilizing the high-temperature preheated air combustion method or oxygen combustion method. Moreover, calculation expressions to obtain the high performance ratio were examined for fair evaluation of successful results.

(ii) Research and study on basic technology for high performance

In order to develop a high-performance industrial furnace, the following themes were researched and studied:

a. Highly efficient heat recycling

technology

Materials of heat transfer elements and seal plates were examined as the basic material and structure to match the high temperature of the heat exchanger, and then element tests were carried out to confirm their heat resistance.

A small experimental heat exchanger was designed and its performance was predicted.

b. Highly efficient exhaust heat utilizing system

A testing and analyzing unit was installed to carry out the basic test. This unit consisted of an anoxia heat chamber adopting a regenerative combustion system which performed combustion at an air ratio of 0.6 or less and a heating chamber which performed the secondary combustion using this combustion product gas as the fuel.

c. Technology to improve degree of soaking in heating steel

A quantitative evaluation of dry skid was carried out by developing a heat resistant metallic material for dry skid and a candidate material of heat insulating material and by performing heat transfer analysis so as to confirm their effects.

d. Highly efficient heat transfer technology by high- temperature flame jet heating

In order to research the basic fluid characteristics of jet flame heating, a fluid analysis test was carried out using a water model.

e. Self-completion type high radiation heating technology

i. Research on the emissivity of radiative gas in its high density range and high-temperature range and confirmation test for steam blowing-in effect on the oxygen burner and regenerative burner

Steam blowing-in to a small oxygen burner with a combustion volume of 250,000 Kcal/h was tested. As a result, it became possible to realize for practical use a NOx oxygen burner as a heating furnace excellent in soaking property and high radiation property.

ii. Basic research on the prevention of partial heating and on the furnace pressure control in a small-volume, high- temperature and high-radiative gas environment

The stabilizing conditions for the burner blowoff jet were researched by means of a water model test and a three-dimensional nonstationary state numerical analytical simulation.

iii. Planning, design and partial fabrication of common-use test furnace #1

Common-use test furnace #1, to be used for the seed technology development and performance verification, was designed and partially fabricated.

f. Research and development of high-performance atmosphere furnace

The introduction of analytic tools was completed. The atmospheric flow was analyzed in a simulation furnace to establish a technology to promote the forced convection effect. The heat flow was analyzed at the typical furnace. Then, analytical software was improved for development of the technology to predict comprehensive numerical value of heat transfer.

g. Measurement controlling system

Specification of stereoscopic temperature gauge and the processing control technology were examined.

h. Furnace shape optimizing technology for the heating furnace

The heat transfer simulation technique was examined, and the test method for measurement and evaluation of flame heat transfer was created.

i. Circulative combustion system in pure oxygen combustion

The basic concept of a pure oxygen burner and its combustion system was designed.

j. High-speed jet and flame impact heating technology

Research was carried out with respect to the analysis of heat transfer characteristics of rapid heating by flame. Then, heat fluid was analyzed, assuming a heat transfer simulation model by oxygen combustion flame.

k. Laser measuring method inside an industrial furnace

A measurement test was carried out using a model furnace, and data on the OH distribution plane inside the furnace were obtained.

l. Heat transfer optimizing technology in nonstationary state of steel heating

i. In-furnace heat transfer analyzing technology

Development of a stationary basic model was started using the zone method. A three-dimensional in-furnace stationary heat transfer analytical model was created, and thereby it became possible to assume the optimal furnace shape, taking the arrangement and capacity of the burner as well as the supply quantity of fuel and air into consideration.

ii. Detailed design of common-use test furnace #2

The contents and scale were examined, and the detailed design was completed.

Research was carried out with respect to the averaging of the furnace temperature under the in-furnace circulating system of the regenerative burner to be mounted on the common-use test furnace #2 as well as the basic characteristics of low NOx by the two-step fuel combustion system.

m. High-efficiency heat transfer technology

In order to examine the heat transfer characteristics and the proper control in a high temperature field, a small combustion unit for a basic heat transfer model and a combustion test unit for high-temperature flame control preliminary research were fabricated to perform the combustion test. Moreover, in order to examine the flame temperature measuring method in the high-temperature field, a combustion test unit for flame measurement method preliminary research was designed and fabricated. A non-combustion fluid test was carried out so as to examine the complicated three-dimensional fluid characteristics being formed by the in-furnace gas in the high-temperature field.

n. Rapid temperature raising and combustion controlling system by high temperature and high radiation

The control system of common-use test furnace #1 was examined and the unit selection was completed. As for the flame detector, the filter effect to eliminate the influence from the high-temperature furnace walls was confirmed using a blackbody furnace.

o. Optimal combustion controlling technology for regenerative burner furnace

The nonstationary combustion control and the gas flow controlling method conforming to the specification of common-use test furnace #2 were examined. A multivariable model prediction control was adopted for the controlling system.

A basic configuration plan was prepared by adopting the multivariable model prediction control for the on-line, schedule-free heating control system of the regenerative burner furnace.

p. Development of a highly efficient melting furnace

An aluminum melting furnace user in the U.S.A. was visited to research and collect information on the use conditions of refractories for the melting furnace.

Remodeling of the test furnace for burner combustion was examined so as to improve the high momentum of the regenerative burner.

(c) Research and study on high-performance boiler technologies

In order to improve the performance of the boiler, detailed research was carried out with respect to the state of development of technologies in and out of Japan concerning the main technology elements of the boiler, i.e., the combustion technology, high-temperature and low-temperature corrosion resistant materials, boiler operation enhancement and systemizing technology, and boiler auxiliary controlling technology as well as the present situation of demonstration plants. As a result, concrete plans for each element technology were laid out.

(3) Future Tasks

Development of basic technologies to control combustion will be continued through experiments at microgravity testing facilities and analysis and evaluation of testing data. Development of high-performance industrial furnaces will also be carried out based on research and development of performance improvement foundation technology. Development of high-performance boiler technology will be continued, while a pilot plant for high performance industrial furnaces and other equipment will be built, and overall evaluation of research results will be implemented.

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CHAPTER 9

PROMOTION
OF
DEVELOPMENT AND INTRODUCTION

PROMOTION
OF
DEVELOPMENT AND INTRODUCTION

Contents

Promotion of Development and Introduction

1. Energy Supply and Demand Structure Improvement Research Project

(1) Objectives and Work Program

Oil-alternative energy-related technologies that the New Energy and Industrial Technology Development Organization (NEDO) is now developing include coal energy utilization technology, solar energy utilization technology, geothermal energy utilization technology, fuel conservation and storage technology and hydrogen, alcohol and biomass energy technology. NEDO is also striving to develop coal resources and geothermal resources.

In order to effectively and smoothly promote the development and introduction of these oil-alternative energy forms, NEDO will conduct comprehensive research on energy supply and demand structure enhancement, research on the development foundation for energy supply and demand structure enhancement, studies on improvement and promotion of overseas coal importation infrastructure, research on development and utilization of overseas supply and demand structure enhancement, research for formulation of the vision for energy supply and demand structure enhancement, basic research for promoting the introduction of energy supply and demand structure improvement technology, and guidance program for promoting the introduction of energy supply and demand structure improvement.

(2) Summary for FY1994

(a) Comprehensive research on energy supply and demand structure enhancement
- (i) Study of trends regarding technological development of new energy in Australia and New Zealand
- (ii) Study of the energy and infrastructure situation in China
- (iii) Study of actual effects of energy and environment problems on the transport sector in China
- (iv) Preparations for holding the 2nd Japan-U.S. Workshop
- (v) Study of research evaluation methods adopted by energy-related research organizations
- (vi) Subcontracted work regarding translation of IEA-related documents into English and Japanese
- (vii) Surveys for collecting special overseas information
- (viii) Surveys on the real state of new energy in principal overseas countries
- (ix) Study of the heat island phenomenon
- (x) Study of problems related to the technological development for

LNG automobile introduction

(xi) Study of technological development and introduction regarding new geothermal energy exploration methods

(xii) Study of activation technologies regarding heat supply through the utilization of unused energy

(xiii) Technology succession status study

(xiv) Study of the status of energy consumption in the private-use sector

(xv) Research on the measurement and analysis of oil-alternative energy

(xvi) Study of the real status of medium- and small-scale power generation due to easier control in the U.S.

(xvii) Study of the preparation of manuals concerning detailed wind-situation surveys

(xviii) Study of geothermal power development and environment (scenery)

(xix) Study of the form of introduction regarding waste-utilized power generation systems (policy concerning power generation methods)

(xx) Study of the form of introduction regarding waste-utilized power generation systems (diversification of waste shapes)

(xxi) Feasibility study of the application of NEDO-owned industrial properties to other fields

(xxii) Study of promoting the spread of waste-utilized energy systems in cold areas

(xxiii) Surveys regarding the preparation of model files related to oil-alternative energy systems

(xxiv) Preparation of databook II regarding new energy-related technological development (other new energy and crossover themes)

(xxv) Surveys on local power supply systems of the distributed power source-utilization type

(xxvi) Study of small-sized fuel battery application possibilities

(xxvii) Interview surveys on specialists concerned with new energy-related projects

(xxviii) Surveys 1 - 5 on international energy-saving standards

(xxix) Study of the effect of energy supply and demand structure improvement on the global environment

(xxx) Feasibility study III on technological development for combined use of energy resources

(b) Research on the development foundation for energy demand and supply structure enhancement

(i) Study of power generation systems using shape-memory alloys

(ii) Research on the cell deterioration factors of phosphoric acid-type fuel batteries

(c) Studies on improvement and promotion of overseas coal importation infrastructure

(i) Study of coal status of coal-producing countries

(ii) Study of overall status of Indian coal

(iii) Study of coal supply and demand in Latin American countries

(iv) Feasibility study of the business for providing improved coal based on simultaneous upgrading of low-grade coal and heavy oil

(v) Study of the quality improvement of sub-bituminous coal based on the low-temperature drying method

(d) Research on development and utilization of overseas energy supply and demand structure enhancement

(i) Feasibility study of the merchandising of co-processing technology

(ii) Feasibility study of new energy development including photovoltaic power generation in developing countries

(iii) Study of the present conditions and problems of energy-related projects in Asian countries

(iv) Feasibility study of international cooperation in certification research regarding geothermal exploration technologies

(v) Feasibility foundation study II of technological development for the prevention of silica scale

(vi) Feasibility study of international joint research in the Asian region

(vii) Feasibility study of demonstration tests related to hybrid-type mini-hydraulic power generation technologies

(viii) Surveys on U.S. assistance projects regarding energy

(ix) Feasibility foundation study of energy-related cooperation in Vietnam

(x) Feasibility study of overseas energy supply and demand structure enhancement

(e) Research for formulation of the vision for energy supply and demand structure improvement

(i) Feasibility study of field tests regarding wind-force power generation

(ii) Survey for the preparation of a databook regarding technological development of new energy (solar light data)

(iii) Survey for the preparation of a databook regarding technological development of new energy (collection of solar light utilization cases)

(iv) Survey for the preparation of a databook regarding technological development of new energy (fuel batteries, waste power generation, cogeneration and unused data)

(v) Study of the application of photovoltaic power generation systems to the hazards of earthquakes and other natural disasters

(vi) Study of analysis and evaluation methods for the development of new energy or energy-saving technology

(vii) Study of enlightenment and diffusion activities related to regional new energy

(viii) Study of the best mix of CO_2 reduction measures for the introduction of new energy

(f) Foundation research for promoting the introduction of energy supply and demand structure enhancement technologies

(i) Study of diffusion promotion and guidance regarding new energy introduction

(g) Guidance for promoting the introduction of energy supply and demand structure enhancement
   (i) Compiling the results of questionnaire survey regarding new energy introduction

(3) Future Tasks

Leading and basic studies will be made to promote the development and introduction of oil-alternative energy as in fiscal 1993.

2. PR Activities for Energy Supply and Demand Structure Improvement (ESDSI)

(1) Objectives and Work Program

Activities will be conducted to provide oil-alternative energy information, diffuse ESDSI technologies, promote ESDSI education, and hold NEDO's annual general meeting — all to promote the public's understanding and awareness of oil-alternative energy.

(2) Summary for FY1994

(a) Activities to provide ESDSI information
Periodicals, such as *BEST MIX*, *NEDO NEWS* and *New Energy Overseas Information*, were published, and brochures explaining NEDO's projects were distributed.

(b) Activities to diffuse ESDSI technologies
In order to further spread knowledge about oil-alternative energy, exhibitions were participated inside and outside Japan, such as "The 19th Exhibition on Effective Utilization of Energy," "Earth Environment Technology Exhibition" and "Pollutec '94." At these exhibitions, the state of NEDO's activities and the development and introduction status of oil-alternative energy were introduced.

(c) Activities to promote ESDSI education
In order to systematically promote the public's understanding of energy issues, "Cases of Actual Implementation of Energy Education" (for high schools) was compiled and distributed, and energy education materials such as video tapes were produced and distributed. Furthermore, competitions for hand-made projects utilizing solar cells were held for elementary and junior high school students and their family members.

(d) Holding of NEDO's general meeting
The 14th annual general meeting of NEDO was held at the Hotel Grand Palace on September 28, 1994. The meeting was composed of the general assembly, a social gathering and the sessions of the 11 subcommittees (coal technology, solar technology, geothermal technology, energy conversion and storage technology, alcohol and biomass technology, alcohol business, domestic coal mining structural adjustment, coal resources, industrial technology, global environment technology, and new energy promotion activities). Some 4,000 people representing companies and technological research bodies entrusted by NEDO, government agencies, and so on attended the meeting.

(3) Future Tasks

Following the achievements in fiscal

1994, public relations activities will be carried out to promote the public's understanding and awareness of oil-alternative energy.

3. International Information and Personnel Exchange Activities

(1) Objectives and Work Program

In order to promote international exchanges related to oil-alternative energy, activities will be carried out to promote exchanges of energy supply and demand structure improvement information, exchanges of international information on energy supply and demand structure improvement, international cooperation for coal utilization technology, international cooperation regarding alcohol utilization technology, support for the 16th meeting of the World Energy Conference in Tokyo, the Asia-Pacific Coal Supply and Demand Seminar and training of coal engineers.

(2) Summary for FY1994

(a) Promotion of information exchanges about energy supply and demand structure improvement

NEDO participated as the Japanese signatory in the IEA Implementing Agreement for the Establishment of the IEA Energy Technology Data Exchange and the IEA Implementing Agreement for the Establishment of the IEA Center for the Analysis and Dissemination of Demonstrated Energy Technologies. Furthermore, it took part in the Greenhouse Effect Gas Technology Information Exchange as the Japanese representative. Thus, NEDO conducted information exchanges and promoted such exchanges based on the principle of mutual cooperation. It also implemented bilateral information exchanges with representative research organizations in the United States, France and Sweden.

(b) Activities to promote international information exchanges about energy supply and demand structure improvement

NEDO participated in the Symposium on Pacific Energy Cooperation (SPEC) which it also promoted with the support of the Ministry of International Trade and Industry (MITI) and the Ministry of Foreign Affairs. At this meeting, NEDO specialists conducted exchanges of information with experts from the Pacific region regarding new energy development and introduction and future international cooperation. NEDO also invited new energy technology specialists from EU countries to promote the exchanges of opinions and information with related research and development organizations in Japan.

Furthermore, NEDO collected energy information in the Pacific region and held an international symposium as part of an APEC project.

(c) Overall research on coal supply and demand in the Pacific Rim

To establish an information exchange system regarding coal supply and demand trends and coal development utilization in countries in the Pacific Rim, NEDO launched the Pacific Rim coal information network activities by publishing "Coal in Asia Pacific" and conducted a survey on the policy trend of the Clinton Administration in energy and environmental fields in East Asia.

(d) International cooperation regarding coal utilization technology

NEDO took part in various meetings about the IEA Implementing Agreement for Cooperation in the Field of Fluidized Bed Combustion (FBC) and the IEA Implementing Agreement for a Program of Research, Development and Demonstration on Coal/Liquid Mixtures (CLM) and conducted international cooperation in such areas as information exchanges concerning coal utilization technology.

(e) International cooperation regarding alcohol utilization technology

NEDO participated in the IEA/CERT Implementing Agreement for a Program of Research, Development and Demonstration on Alcohol and Alcohol Blends as Motor Fuels and the IEA Implementing Agreement for a Program of Research, Development and Demonstration on Bio-Energy. NEDO representatives attended regular executive committee and specialized committee meetings of both agreements and conducted information collection and exchanges.

(f) Holding of the Asia-Pacific Coal Supply and Demand Seminar

The first coal supply and demand seminar for coal specialists was held in Japan based under the joint sponsorship of Japan and Australia within the framework of APEC. For the purpose of exchanging coal-related information in the Pacific Rim, non-regular publications were produced and distributed.

(g) Coal engineer training activities

To train specialists engaging in the development of overseas coal for the ultimate purpose of facilitating smooth development and importation of overseas coal, would-be trainees were invited from among persons in coal-related industries, and instruction in English conversation and coal-related knowledge was conducted.

(3) Future Tasks

Just as in fiscal 1994, NEDO will promote international information and personnel exchanges, especially regarding oil-alternative energy.

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CHAPTER 10

ACTIVITIES
OF
THE NEDO INFORMATION CENTER

ACTIVITIES
OF
THE NEDO INFORMATION CENTER

Contents

Activities
of
the NEDO Information Center

1. Objectives and Work Program

Amid the diversification and internationalization of energy and industrial technologies (including environmental technology), the NEDO Information Center makes its library/data room available to the public, provides database services, exchanges information with foreign countries and publishes information journals.

2. Summary for FY1994

(1) Opening the Library/Data Room to the Public

The NEDO Information Center manages publications of past achievements in research and development activities (2,200 reports) and renders services for their perusal.

It also holds specialized energy-related documents (1,500 books), reference books and general publications (2,300 books) and periodicals (190 kinds), centering on Japanese and foreign books/data about new energy. The Center makes these books and data available for visitors to use.

(2) Distribution of Map Showing Results of Comprehensive Survey of Nationwide Geothermal Resources

Based on the results of the first comprehensive survey of nationwide geothermal resources carried out by NEDO, the NEDO Information Center provides copies of geothermal maps to the general public at cost.

(3) NEDO-EDBS Services

(a) The Center engages in database services by storing the technological literature information (in English) obtained based on two multinational information exchange agreements carried out under the IEA and providing such information under NEDO-EDBS (NEDO Energy Database System).

NEDO-EDBS is an overall energy database system, with the scope of its technological information covering fossil fuel energy and renewable energy, as well as such secondary themes as environmental science and energy policy. It even carries information on some non-IEA member countries.

Contents of these database services include on-line retrieval and such unique services as off-line output, SDI (Selective Dissemination of Information) service and a copying service for non-commercially available literature.

In fiscal 1994, a new system was built, and service improvement was pursued through the reduction of retrieval time and the improvement of retrieval displays on monitor screens.

(b) Name of agreement: Energy
Technology Data Exchange (ETDE)
Signatory agencies: NEDO, Japan Atomic

Energy Research Institute

Participating countries: Japan, United Kingdom, United States, Italy, the Netherlands, Canada, Switzerland, Sweden, Spain, Denmark, Germany, Norway, Finland, France, Republic of Korea, Poland, Australia and Brazil (18 countries; Republic of Korea, Poland and Brazil participated as associate members).

Administrative agency: United States Department of Energy, Office of Scientific and Technical Information (DOE/OSTI)

Activities: Collection and processing of energy technology literature and data from signatory nations and building a common database.

(c) Name of agreement: IEA Coal Research (IEA-CR)

Signatory agency: NEDO

Participating countries: Japan, United Kingdom, United States, Italy, Australia, Austria, the Netherlands, Canada, Sweden, Spain, Denmark, Finland, Belgium and the European Union (13 countries and one organization)

Administrative agency: British Coal Research Public Corporation (Coal Research)

Activities: Collection and processing of coal-related technological literature and information from signatory nations and building a common database.

(4) Optical Disk Database Operation

NEDO constructed an optical disk database system (in English and Japanese) designed to process information on new energy-related trends obtained from various specialized overseas periodicals, to store that information and to provide it graphically. It has already been made available for use by Japanese and foreign users. The number of energy-related trend data items input totaled about 120,000. As for retrieval, access is also possible in Japanese, with searches based on the kind of energy, keyword, title, or author.

(5) Supply of CADDET Technological Information

(a) NEDO, as Japan's signatory organization, participated in the CADDET Agreement, a multinational information exchange agreement concluded and executed under the IEA. This agreement is to introduce and provide technological information on effective energy utilization by participating countries and technological information about renewable energy sources obtained through this agreement to domestic organizations concerned and to end users.

With regard to the details of the CADDET Agreement, information exchanges about efficient utilization of conventional energy technologies were carried out under ANNEX I, as shown below. In addition, exchanges of information about renewable energy technologies were started as Annex II in April 1993. NEDO is participating in both of these arrangements.

(b) Name of agreement: IEA Information Centers for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET)

[Annex I]

Signatory agency: NEDO

Participating countries: Japan, United Kingdom, United States, Italy, Australia, the Netherlands, Canada, Switzerland, Sweden, Denmark, New Zealand, Norway, Finland, Belgium and the Republic of Korea (15 countries; Republic of Korea participated as an associate member.)

Administrative agency: The Netherlands Agency for Energy and Environment (NOVEM)

Activities: Collection, evaluation and analysis of demonstrated new energy and energy-saving technologies (high-efficiency energy utilization technologies on the user side) of signatory nations for the purpose of promoting effective utilization of such technologies, and providing them to end users in these nations.

Results:

(a) Registered information: A database on floppy disk containing demonstrated energy technology information, collected from signatory nations (1,685 items)

(b) Brochure information: Pamphlets containing recommendable technology information selected from registered information (232 items)

(c) Newsletter: Annex I organ issued four times a year

(d) Analysis report: Reports containing technological and economic analysis of specific technologies (13 volumes)

[Annex II]

Signatory agency: NEDO

Participating countries: Japan, United Kingdom, United States, Australia, the Netherlands, Switzerland, Sweden, Denmark, New Zealand, Norway, Finland and the Republic of Korea (12 countries; Republic of Korea participated as an associate member.)

Administrative agency: United Kingdom's Energy Technology Support Unit (ETSU)

Activities: Collection, evaluation and analysis of demonstrated renewable energy technologies (renewable energy technologies on the supplier side) of signatory nations for the purpose of promoting effective use of such technologies, and providing them to end users in these countries.

Results:

(a) Registered information: A database on floppy disk containing demonstrated energy technology information collected from signatory nations (107 items)

(b) Brochure information: Pamphlets containing recommendable technology information selected from registered information (9 items)

(c) Newsletter: Annex II organ issued four times a year

(d) Mini Review: A report summarizing trends and current states of specific technologies in individual countries (Reports on three areas were issued during fiscal 1994.)

(6) Participation in GREENTIE Activities

(a) NEDO participated in the following IEA-sponsored multinational information exchanges as Japan's representative agency and engaged in the build-up of a comprehensive database (directory) of information sources concerning technologies pertaining to the reduction and control of greenhouse gas emissions and related services, as well as in the preparation of an environment facilitating future technology transfers.

(b) Name of activity: Greenhouse Gas Technology Information Exchange (GREENTIE)
Signatory agency: NEDO
Participating countries: Japan, United Kingdom, United States, Italy, Australia, the Netherlands, Sweden, Denmark, Germany, Norway, France, and the Republic of Korea (12 countries; Republic of Korea participated as an associate member.)
Administrative agency: The Netherlands Agency for Energy and the Environment (NOVEM)

(7) New Energy-Related Fact-Finding Surveys in Principal Countries

NEDO is collecting information about and conducting surveys of the latest trends in new energy-related policies, research and development projects and other matters in principal overseas countries (12 countries and one region — United Kingdom, China, Italy, Indonesia, Canada, Sweden, Germany, Brazil, Philippines, Belgium, Malaysia, South Africa and the former Soviet Union). Collection and survey results are available for perusal in the Library/Data Room and also reported in *Shin Enerugii Kaigai Joho* ("Alternative Energy Overseas Information"), a NEDO monthly periodical.

(8) Publication of Overseas Information Periodical

NEDO obtains the latest information about new energy-related trends from overseas newspapers, magazines and various reports, and it processes, analyzes and evaluates the information. It publishes this information in *Overseas Information about New Energy*, and distributes it to related government organizations and private bodies.

(9) Buildup of NEDO R&D Database

From a viewpoint of effectively utilizing past research results of NEDO for efficient promotion of future research and development/introduction and diffusion projects, we have been systematically and continually sorting out and collecting all research reports and related technological documents to build a database, which will be easily used through the Internet.

In fiscal 1994, the following activities were conducted in this regard.

(a) Collection of photovoltaic power generation-related technological information

(b) Collection of residential photovoltaic battery introduction/diffusion information

(c) Fundamental research for the buildup of the NEDO R&D database

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CHAPTER 11

INTERNATIONAL ENERGY-PROMOTION ACTIVITIES

INTERNATIONAL ENERGY-PROMOTION ACTIVITIES

Contents

International Energy-Promotion Activities

The overall promotion of energy and environmental protection measures is necessary to respond to the upgrading of energy supply and demand structures in developing countries, where a sharp expansion of energy demand is anticipated. For this reason, since fiscal 1993 NEDO has been conducting international energy use promotion activities, namely technology transfers pertaining to energy-saving and clean coal technologies in countries such as China and Indonesia.

With regard to energy-saving technology, model projects aimed to improve energy consumption efficiency in steelmaking, power generation, oil refining and other energy-consuming industries were launched, along with efforts to create a comprehensive database and cooperation in the preparation of energy-saving master plans. As for clean coal technology activities, NEDO has been conducting model projects which aim to reduce the environmental load factors in the fields of coal utilization, in addition to the master plans related to coal utilization.

1. International Coal Utilization Project

Demand for coal is expected to grow hereafter as a main oil-alternative energy source. However, sulfur oxides, nitrogen oxides and coal ash that are generated in coal combustion have become major inhibitors of the expansion of coal utilization.

To contribute to the further stabilization of energy supply and demand in Japan by reducing these environmental load factors and promoting the use of highly efficient coal, NEDO has been conducting demonstrations of clean coal technology (CCT), improving the basis for its diffusion and preparing overall master plans related to coal utilization, jointly with other Asian and Pacific nations.

1.1 Research Program for Environmentally-Friendly Coal Utilization Systems

(1) Objectives and Work Program

Based on the level of coal utilization technology in developing countries and their economic conditions, coal utilization systems, such as environmental measures related to coal utilization and the improvement of coal utilization efficiency, are being researched and evaluated. Subsequently, a program to assess the overall possibility of introducing such systems will be worked out.

(2) Summary for FY1994

(a) Investigation in China

(i) In connection with the investigation of the coal industry, implemented jointly with the Ministry of Coal Industry in China, a master plan was formulated with regard to the introduction of an environmentally-friendly coal utilization system. The system was designed to improve the efficiency of environmental measures appropriate for the Chinese situation.

(ii) Concerning surveys carried out in non-coal industry fields jointly with the State Planning Commission as the NEDO counterpart, study was made of the introduction of an environmentally-friendly coal utilization system in the model area.

(b) Regarding investigation in Indonesia, detailed study was made of coal energy utilization.

(c) With regard to study in the Philippines, an investigation was implemented on the overall state of energy utilization.

(3) Future Tasks

Concerning the investigation in non-coal industry fields in China and the investigation in Indonesia, environmentally-friendly coal utilization systems that can be actually introduced in these countries will be investigated and studied, and introduction/master plans for such systems will be prepared.

With regard to the investigation in the Philippines, a detailed study will be launched on coal utilization technology for each industry, and environmentally-friendly coal utilization systems that can be actually introduced will be examined and studied.

Concerning new target countries, study will be made of the overall state of energy utilization in such countries.

1.2 Demonstration Projects for Environmentally-Friendly Coal Utilization Systems

(1) Objectives and Work Program

To improve the basis in Asian and Pacific nations for the dissemination of coal utilization technologies that are characterized by a small load on the environment, demonstration projects are being carried out jointly with these countries, including China and Indonesia, regarding simple desulfurization equipment, fluidizing bed boilers and briquetting equipment. At the same time, joint demonstration activities are being implemented with regard to water-saving coal preparation systems produced by adding Japanese know-how to the technologies current in target countries.

(2) Summary for FY1994

(a) Introduction-supporting activities

In accordance with the basic agreements concluded in fiscal 1993, the following activities were implemented in fiscal 1994.

(i) In accordance with the basic plans and basic design enforced in fiscal 1993, detailed design was carried out.

(ii) Basic specifications were finalized through consultation with target countries, and various kinds of basic design documents were prepared.

(iii) While equipment and tubes were manufactured, purchase equipment was procured and transported to the target countries.

(iv) Supervisors were dispatched to locations of local construction work under the control of the target countries, and guidance for the work was undertaken.

(v) The persons concerned with supporting projects were invited from the target companies, while the examination and study of related equipment were carried out, and observation of equipment inspection was implemented.

(b) Joint demonstration activities

During fiscal 1994, the following activities were implemented.

(i) In the execution of cooperative work, consultations were made to determine the counterpart organizations of target companies, to select implementation sites and to decide on shares of the division of work.

(ii) Basic agreements were concluded to implement joint demonstration work.

(iii) Investigations necessary for the design and manufacturing of equipment, consultation with execution sites, equipment design and part of equipment manufacturing were carried out during fiscal 1994.

(3) Future Tasks

(a) Introduction-supporting project

After the installation of machinery and equipment jointly with counterpart organizations of the target countries, demonstration operation will be implemented following trial operation and performance tests. After confirmation of required functions, technological guidance will be rendered for the stepped-up diffusion of technologies in the countries.

(b) Joint demonstration project

Manufacturing and procurement of part of equipment, inspection and maritime transport of equipment, part of local construction work and training of operators will be implemented jointly with counterpart organizations of target companies.

1.3 Promotion Program for International Cooperation

(1) Objectives and Work Program

In order to stabilize coal supply and demand while responding to anticipated increases in coal demand, particularly in Asian and Pacific countries, and to global environment issues, NEDO participates in clean coal technology-related projects through APEC (Asia-Pacific Economic Cooperation forum), thereby contributing to the creation overseas of a basis for the development of clean coal technology.

(2) Summary for FY1994

NEDO cooperated in planning and running a clean coal seminars and a coal clean training course, held by the APEC Energy Working Group, and also actively cooperated in other multinational efforts related to the introduction and dissemination of CCT.

(3) Future Tasks

Utilizing APEC as the channel for multinational cooperation, NEDO will actively participate by holding seminars, conducting training activities and carrying out surveys for future activities.

2. Project for Rationalization of International Energy Use

In the past several years, Asian and Pacific countries have attained high economic growth, and efforts have been made for industrial progress, improvement of people's living standards and stabilization of their livelihood. This region is predicted to experience continuing development.

Reflecting this rapid economic growth, energy demand has continued to rise dramatically. This, however, has added to apprehension and concern regarding the stabilization of energy supply and demand within the region in the future. Furthermore, the Asia-Pacific region faces such serious environmental problems as acid rain and global warming.

For well-balanced sustainable development in the years to come, it is necessary to ensure energy security while at the same time considering the global environment. In particular, it is important to improve the efficiency of energy utilization, particularly in the countries of the Asia-Pacific region.

Under these circumstances, an urgent task has become to effectively transfer energy conservation technologies to China and other Asia-Pacific countries and to promote their diffusion there.

To contribute to completing these tasks, the Basic Survey for Improving Energy Efficiency in Developing Countries, and Model Projects of Energy Consumption Efficiency Improvement in Developing Countries are being carried out.

2.1 Basic Survey for Improving Energy Consumption Efficiency Improvement in Developing Countries

2.1.1 Database Development

(1) Objectives and Work Program

The purpose of this project is to promote efficient energy utilization with a focus on countries in the Asia-Pacific region from the standpoint of stabilizing the energy demand-supply balance. For this purpose, NEDO will create a comprehensive database containing existing energy-related information and industry-by-industry energy usage data, which will be necessary for the introduction of energy-related measures by Japan and other countries concerned.

(2) Summary for FY1994

Information for development of energy databases in Japan and target countries was collected and provided, and studies were conducted regarding database systematization and its utilization methods.

- Principal items of collected data
  - (a) Industrial sector-related data
  - (b) Policy-related data
  - (c) Energy supply and demand data
  - (d) Energy source-based classification data

2.1.2 Energy Rationalization Planning

(1) Objectives and Work Program

NEDO will support China, Indonesia and other selected countries preparing energy-saving master plans for effective energy utilization.

(2) Summary for FY1994

In connection with effective energy utilization in target countries, studies were made in preparation for the collection, analysis and evaluation of information from industry-based research. Furthermore, a feasibility study related to the Energy Conservation Model Project was conducted.

- Target business fields

China: Synthetic ammonia-manufacturing, cement manufacturing
Indonesia: Steelmaking, cement manufacturing

2.1.3 Green Helmet Project

(1) Objectives and Work Programs

Examination and research will be conducted on methods of dispatching personnel, and based on results of such examination/research, specialists will be sent to provide energy-saving technological know-how and to render support for the diffusion of said energy-saving technologies.

(2) Summary for FY1994

Work manuals related to "energy-saving specialist-dispatching cooperation" with developing countries were prepared, and studies were made of proposals concerning technological transfer, entrenchment and spread of energy-saving technologies, based on the dispatch of personnel.

2.1.4 Holding Regular Consultations on Promotion of Energy-Saving Measures in Developing Countries

(1) Objectives and Work Program

An international conference is held to discuss technological developments related to energy-saving, future methods of its promotion and how to promote international cooperation for that purpose.

(2) Summary for FY1994

NEDO held a two-day international meeting on November 27 and 28, 1994, on the theme of "fostering personnel for the promotion of energy saving." At this meeting, discussions were undertaken by energy-related working-level persons from 10 other countries regarding analyses of the current states of individual countries, diffusion methods and actual international cooperative steps, all concerned with the fostering of energy-saving-related personnel.

2.2 Model Projects for Energy Consumption Efficiency Improvement in Developing Countries

(1) Objectives and Work Program

The projects call for installing facilities based on energy-saving technologies already established and in actual use in industrially advanced nations, on the grounds of existing plants in developing countries that have not yet introduced such technologies, and they call for demonstrating the efficiency and practical value of these technologies. Furthermore, the projects aim to promote the diffusion of these technologies jointly with the developing countries concerned.

(2) Summary of Project Implementation in FY1994

(a) Model project for coal moisture control
Country involved: The People's Republic of China (Chongqing Iron and Steel (Group) Company, Sichuan)

Outline: The aim of this model project is to demonstrate technology for coal moisture controlling equipment, designed to reduce the amount of energy needed to produce coke at the steelworks by decreasing the water content of coking coal using waste heat from coke ovens.

Results: Detailed design of principal facilities, including drying equipment and flue gas exhaust-use heat exchangers, was completed, and manufacturing of equipment was undertaken.

(b) Model project for blast furnace hot stove waste heat recovery

Country involved: The People's Republic of China (Laiwu Iron and Steel Company, Shandong)

Outline: The aim of this model project is to demonstrate technology for recovering waste heat from blast-furnace hot stoves. This technology is designed to reduce the amount of fuel gas used during heat accumulation by recovering waste heat generated during heat accumulation at the blast-furnace hot stoves and by raising the temperatures of combustion air and fuel gas used during the heat accumulation period.

Results: Principal equipment, such as heat exchangers, was manufactured, and ship-loading was completed. Further, operational training of Chinese engineers was carried out in Japan.

(c) Model project for soot blower

Country involved: The People's Republic of China (Tianjin Jun Liang Cheng Power Plant, Tianjin)

Outline: The aim is to demonstrate soot blower technology designed to ensure surface heat transfer performance and improve boiler efficiency by injecting high-pressure steam, thus regularly removing ash and soot adhering to the heat transfer surface area of the power generation boiler in a power plant.

Results: The manufacturing and onsite installation of soot blowers were completed, and trial operation of the blowers was implemented. As a result, operational data were obtained indicating that the annual coal saving volume (on a standard coal basis) in the case of full-load operation would be 1,638 tons.

(d) Model project for variable-speed clutch for Induced Draft Fan (IDF) and Forced Draft Fan (FDF)

Country involved: The People's Republic of China (Tianjin Jun Liang Cheng Power Plant, Tianjin)

Outline: The aim of this model project is to demonstrate variable-speed clutches for IDF and FDF technology designed to reduce the electricity consumed by the IDF and FDF during partial-load operation. This will be done by installing variable-speed clutches between the FDF/IDF and the drive motor of the power generation boiler of a thermal power plant, and then controlling the rotation speed in accordance with power generation output.

Results: The manufacturing and onsite installation of wet-type multi-panel clutches were completed, and trial operation of the equipment was implemented. As a result, operational data were obtained indicating that the annual coal reduction (on a standard coal basis) in the case of a partial load (80%) would be 1,275 tons.

(e) Model project for oil refinery power recovery

Country involved: The People's Republic of China (SINOPEC, Qilu Petrochemical Corporation, Shengli Refinery, Zibo Shandong)

Outline: The aim of the project is to demonstrate oil refinery power recovery equipment technology designed to reduce power consumption of oil refineries by generating electric power through recovering high-temperature and high-pressure exhaust gas from the refinery's fluid catalytic cracking (FCC) facility and expanding it through a turbine. Results: Basic design was completed, and part of the detailed design was undertaken. Manufacturing of some principal oil refinery power recovery equipment, such as a gas expander, was implemented. Further, a plan for training the Chinese engineers was worked out.

(f) Model project for application of pregrinder

Country involved: The Republic of Indonesia (P.T. SEMEN PADAN, West Sumatra)

Outline: The aim of this model project is to demonstrate pregrinder technology designed to reduce the amount of energy required for clinker crushing in a cement plant by carrying out preliminary grinding of clinkers using a vertical-type grinding device installed at the stage prior to existing clinker crushing equipment.

Results: The equipment manufacturing and procurement of pregrinder facilities were completed, and a ship operation schedule for loading was prepared. Further, installation work and trial-operation training of Indonesian engineers were carried out in Japan.

(g)Model project for blast furnace top pressure recovery power generation

Country involved: The People's Republic of China (Panzhihua Iron and Steel (Group) Company, Sichuan)

Outline: This project is designed to demonstrate the technology to generate power through a turbine, utilizing the pressure of blast furnace gas discharged from the top of a blast furnace.

Results: The counterpart organization on the other country was determined, and a basic agreement was concluded with the counterpart to confirm the project site, equipment specifications and work sharing between the two parties. Further, preparations were made to conclude the basic agreement implementation documents to confirm details of the project.

(h) Model project for waste heat recovery from an ammonia plant primary reformer

Country involved: The People's Republic of China (Sichuan Chemical Works (Group), Sichuan)

Outline: This project is to demonstrate the technology to reduce fuel for heating a steam reforming furnace, designed to produce hydrogen out of natural gas in an ammonia plant, by recovering waste heat from combustion exhaust gas discharged from the furnace and preheating combustion-use air with the waste heat.

Results: The counterpart organization of the other country was determined, and the basic agreement was concluded with the counterpart to confirm the project implementation site, equipment specifications and division of work between the two parties. Further, preparations were made to conclude the basic agreement implementation document to confirm details of the project.