At the Forefront of Energy Efficiency Technologies

For Global Warming Prevention and Stable Energy Supplies

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Renewable energy is drawing attention as a new source of energy. However, the technology for energy efficiency and conservation, though less spectacular, is a highly effective means of preventing global warming and ensuring stable supplies of energy. In the "2030 Energy Supply and Demand Outlook" [1], energy efficiency technology is expected to play a much larger role than new sources of energy (Fig.1). In addition, progress in energy efficiency is regarded as a prerequisite in some long-term energy scenarios[2] that contemplate the widespread and large-scale introduction of renewable energy.

Current energy consumption in Japan

An analysis of energy consumption in Japan in fiscal 2004[3] indicates that while industry still accounts for the largest share of energy consumption (46.3%), the share accounted for by households (27.5%) and transportation (24.7%) has increased substantially. In the household sector, substantial amounts of energy are consumed for hot water supply and heating sections in addition to power for electric appliances and lighting. The consumption in the transportation sector is dominantly for personal automobiles and freight trucks; more than 80% of the energy is consumed while the vehicles are running. Among the industrial sectors, the chemical and steel industries are still the two largest consumers of energy (Fig. 2).

Key point: Cuts in the major energy-consuming sections

There are a number of approaches to reducing energy consumption. For example, individual efforts such as turning off lights more frequently and changes in lifestyles are actually effective. Policy measures such as the so-called "top runner program" to encourage manufacturers to substantially improve the energy efficiency of their products are no less important. Developing countries have considerable room to conserve energy. It is important that Japan's advanced energy efficiency technologies are made available to developing countries through the clean development mechanism (CDM) and joint implementation (JI). CDM refers to the emissions rights that are acquired through greenhouse gas reduction projects in developing countries, and JI refers to the emissions rights acquired through projects implemented jointly with partner developed countries. Moreover, it is necessary to develop more advanced energy efficiency technologies. Of particular importance is the development of innovative energy efficiency technologies for sections that are consuming large amounts of energy.

AIST activities

In this pamphlet, we will first outline some of the latest developments at the National Institute of Advanced Industrial Science and Technology (AIST) in the field of energy efficiency through the construction of distributed energy networks. In addition to improvement of the energy performance of individual equipments, a reduction in overall energy

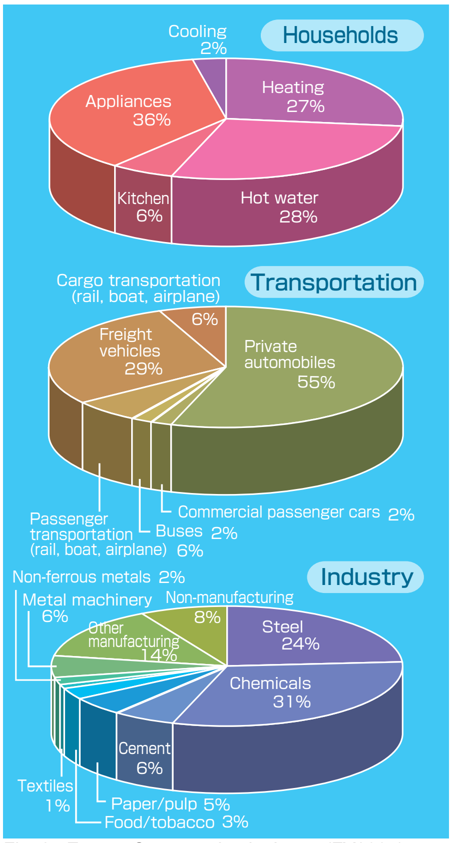

Fig. 2 : Energy Consumption in Japan (FY2004)

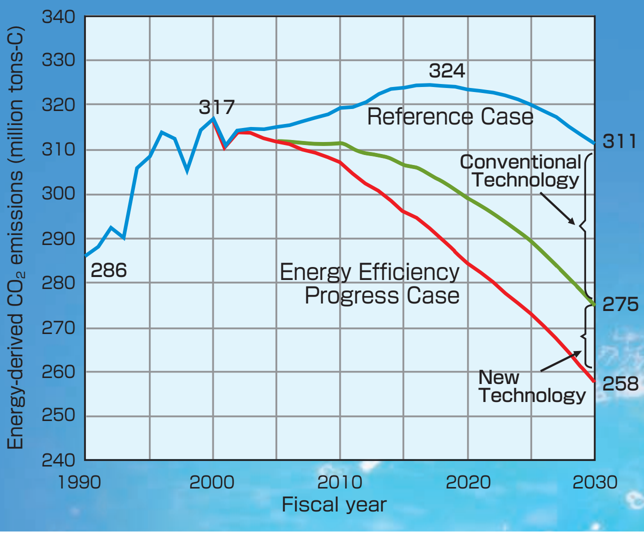

Fig. 1 : Energy Supply and Demand Subcommittee, Advisory Committee for Natural Resources and Energy, 2030 Energy Supply and Demand Outlook (Recommendations), March 2005 (in Japanese)
Conventional Technology includes heat pumps and New Technology includes fuel cells and distributed systems (except the portion as reflected in the Reference Case).

consumption is being pursued through the use of information technologies (IT) and systems technologies. Some of the energy efficiency research projects currently underway at AIST in relation to households, transportation and industrial sectors are described below.

For the household sector, it is expected to develop technologies that effectively reduce energy consumption without users' awareness. For industrial sectors, innovative and eco-friendly technologies in chemical industry need to reduce both energy consumption and the general environmental impact. Power electronics, power storage and heat technologies are crossdisciplinary and have a large ripple effect. AIST is working energetically for the further improvement of performance and cost effectiveness of these energy efficiency technologies.

References

[1] Energy Supply and Demand Subcommittee, Advisory Committee for Natural Resources and Energy, 2030 Energy Supply and Demand Outlook (Recommendations), March 2005 (in Japanese), http://www.meti.go.jp/report/data/g50328bj.html

[2] For example,

● Handout at the 13th meeting of the Research and Development Subcommittee, Industrial Science Technology Policy Committee, Industrial Structure Council, Technology Strategy Map : Ultra long-term energy vision, October 2005 (in Japanese), http://www.meti.go.jp/committee/materials/g51013aj.html

● World in Transition – Towards Sustainable Energy Systems, German Advisory Council on Global Change, March 2003, http://www.wbgu.de/wbgu_jg2003_kurz_engl.html

[3] The Energy Data and Modeling Center (EDMC), The Institute of Energy Economics, Japan, EDMC Handbook of Energy and Economic Statistics in Japan, February 2006

Energy Saving Effects from an Overhaul Project for Introducing Demonstration Plants for Distributed Energy Supply Systems

AIST Tsukuba Central and East are a research complex consisting of 134 major buildings with a total floor area of approximately 400,000 square meters in a combined land area of 1,135,412 square meters (as of January 2004). The energy for air conditioning and heating of the buildings occupying approximately 70% of the total floor area was supplied from the Energy Center that had been in operation in AIST Tsukuba Central since March 1978. As this system became antiquated, a substantial overhaul of the heat source equipment was implemented in a three-year project from fiscal 2002 through 2004.

Table 1 : Comparison of the amount of heat per area, floor area and pipe length among the selected heat supply sites

No.	Development site	Completion of construction	Heat supply per land area	Heat supply per floor space	Heat supply per pipe length
	AIST Tsukuba Central/East	Mar.1978	169.8	657.7	9.1
1	Yokohama Station West	Aug.1998	4,634.4	742.0	364.7
2	Osaki 1-chome	Jan.1999	2,613.7	402.1	85.4
3	Saitama New Urban Center West	Apr.2000	971.3	385.4	38.6
4	Shibuya Dogenzaka	Apr.2000	2,364.3	670.2	73.0
5	Harumi Island	Apr.2001	2,069.3	304.2	113.9
6	Higashi Shinagawa 4-chome	Oct.2002	778.6	466.5	177.4
7	Shiodome North	Nov.2002	4,494.0	586.7	391.9
8	Shinagawa Station East	Apr.2003	2,137.5	395.2	79.6
9	Roppongi Hills	May 2003	4,269.0	745.8	138.7
	<Average of the nine sites>		2,703.6	522.0	162.6

Data source : Computed from the Handbook of Heat Service Utilities (2004, in Japanese). Data for AIST Tsukuba are for fiscal 2001.

Table 2 : Energy saving effects from the overhaul project

	Fiscal 2001 (before)	Fiscal 2005 (after)
Electricity	1161.4	1125.3
City gas	73.7	183.0
Kerosene	322.9	0
Total	1568.0	1308.3

Primary energy base unit : TJ

Prior investigations had revealed that : (1) the installed heat source had a capacity substantially in excess of the actual supply quantity and it was also antiquated; and (2) the supply pipeline was very long and the transportation power loss was considerable (Table 1). A decision was therefore made to demolish the Energy Center, and in its stead, each of the buildings was to be served by highly energy-efficient air-cooling type heat pumps and other distributed high-efficiency energy systems. The objective was to achieve substantial reductions in energy consumption and CO_2 emissions. At the same time, the overhaul project was designed to realize a substantial reduction in costs for the maintenance of chilled and hot water pipelines and to allow for greater flexibility in the air conditioning systems in accordance with research activities in each building. As can be seen in Table 2, which compares the energy consumption between fiscal 2001 and 2005, the overhaul project that was completed at the end of fiscal 2004 achieved a 16.5% saving in energy. In addition, the project successfully cut CO_2 emissions by approximately 18,000 tons (28%) and fuel and electricity costs by more than 300 million yen (16%).

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Toru Kato

Development of a Base Technology for the Leveling of a Distributed Energy System

– In Pursuit of Cooperation with Power Grid –

In order to meet the challenges of ensuring a stable energy supply and responding to global climate change, there is a social need to sophisticate distributed energy systems through the large-scale introduction of renewable energy and cogeneration plants.

The present technology development project focuses mainly on the three technologies shown in Fig. 1. The aim is to promote the introduction of distributed energy systems and thereby to help create new energy industries as an outcome.

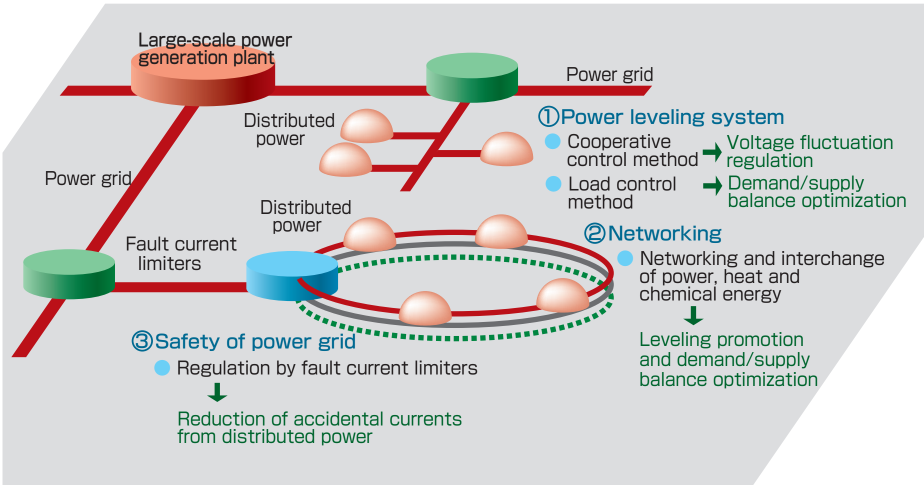


Fig. 1 : Concept of the base technology for the leveling of distributed energy systems

Power leveling system

The existing power grid depends heavily on thermal and nuclear power generation. A number of difficult problems have to be solved in order to introduce distributed powers, such as solar, wind and other natural sources of energy, and cogeneration plants into the existing grid. The problems include the control of voltage fluctuations and the maintenance of the demand/supply balance in the grid.

We have therefore proposed a new control method by introducing a system of blocks and hierarchization according to the configuration of the grid that comprises distributed powers on a large scale. The proposed method allows for cooperative control both in each block and among different blocks. With the use of an analogue power distribution simulator, the effectiveness of this method for grids actually in commercial service has been verified.

A further study is underway to develop methods of regulating the power consumption of air conditioners, electric water heaters and other heat load-type equipment in order to maintain a good demand/supply balance.

Networking in a distributed system

New networking and control technologies are being developed as illustrated in Fig. 2 that are designed to create a network of electricity, heat and hydrogen energy sources for multiple cogeneration units installed close to individual energy consumers and to optimize energy interchange and storage while meeting the energy demands of these individual consumers, thereby achieving load leveling for the overall system.

Data are being collected on the pattern and quantities of energy consumption and an analysis is also being made on the configuration, control and operation of the system. Simultaneously, year-round data for the heat and power consumption patterns of

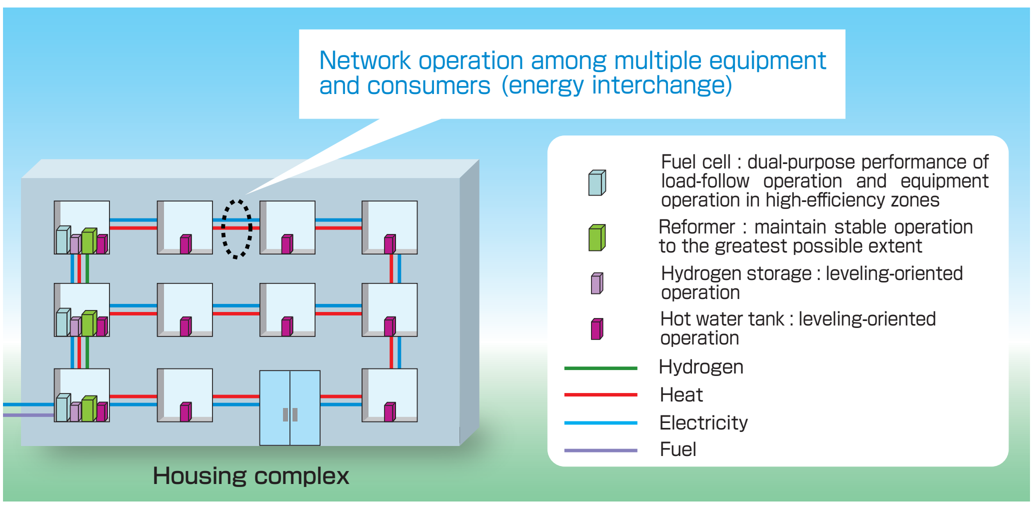
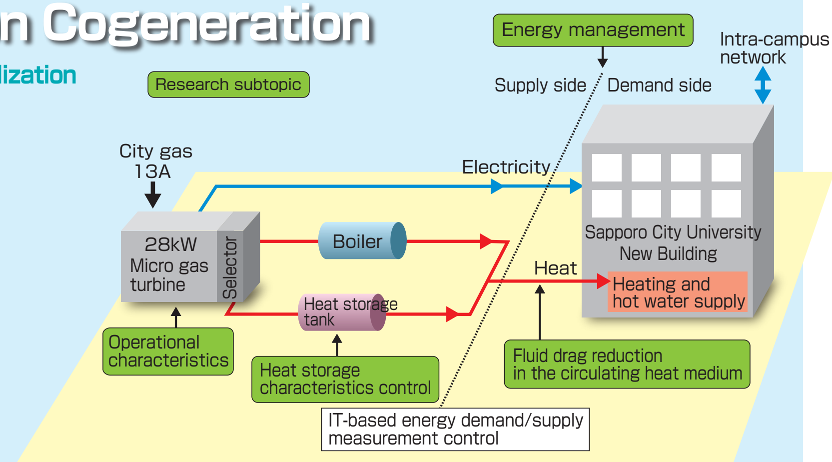


Fig. 2 : Example of a fuel cell cogeneration system with energy interchange

Demonstrative Study on Cogeneration

Establishment of Technology for Efficient Heat Utilization Required for Distributed Energy Systems



In December 2004, AIST entered into a basic agreement with the City of Sapporo for the common goal of efficient energy utilization. Under the agreement, AIST provides its technology and the city does an experiment site for a cooperative demonstration study on cogeneration with a view to creating an advanced sustainable community life.

The site of the experimental study is a new building of Sapporo City University at its Sapporo Art Park Campus, which was inaugurated in April, 2006. The system is based on a 28 kW micro gas turbine power generator installed in the new energy machine room of the building and co-generated heat of approximately 50 kW is utilized for heating and hot water supply. A new unique heat storage system is employed, utilizing a phase change material from solid to liquid due to the turbine waste heat. Another characteristic is efficient heat storage for a period of several days over weekends and holidays as well as daily heat storage. In addition, the system is operated in consideration of the energy demand/supply balance, taking advantage of data on the energy demands of the campus buildings that have been accumulated over the preceding two years. One important challenge for overall system efficiency is the reduction in pump power for the circulation of warm water in the storage tank/heating equipment loop. Fluid drag reduction technology that has been studied at AIST is being applied to the approximately 60 kW pump system.

Energy Technology Research Institute
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actual households have been incorporated into a test network of four fuel cells, and experimentation with various operational modes to evaluate leveling performance is being conducted.

Safety of power grid

One of the problems in networking distributed powers is the current surge in the event of short-circuiting. A possible solution is the introduction of a fault current limiter that regulates accidental current surges by maintaining low impedance during normal operation and increasing it at the time of short-circuiting, as shown in Fig. 3. Fault current limiter made of large-area superconducting thin-film is considered best in terms of reliability, speed, recovery performance and standby losses. Technologies for putting the devices into practical use at low cost are under development.

In the following pages, some of our latest research findings will be presented with respect to the mode of network operation that will be useful for systematization, as well as some elemental technologies for systematization, including heat transport, ice slurry and inverter devices.

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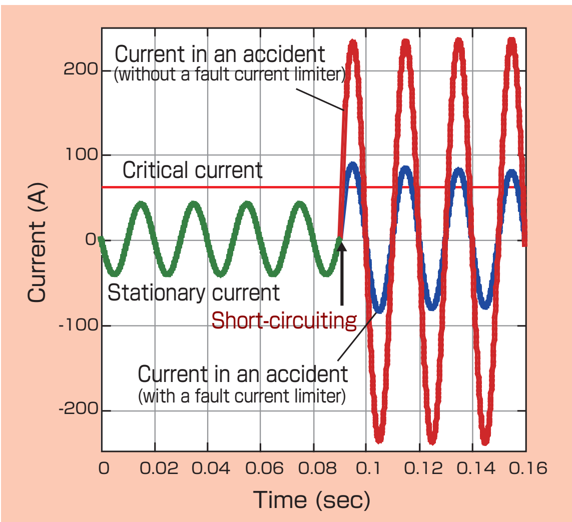

Fig. 3 : Effects of fault current limiters

Development of Heat/ Electricity Integrated Network Technology

Toward the High Efficiency Utilization of Cogeneration System

Need for cogeneration systems

In order to improve the energy efficiency of power generation, the introduction of cogeneration plants that supply heat and electric power simultaneously is increasing (Fig. 1). However, cogeneration systems do not always fully satisfy the heat and electricity demand at the same time, since the heat and electricity outputs cannot be adjusted independently.

Electric power has the advantage of its versatility (it can be used in many ways) and wide-area operability (it can be transmitted through power grids), while it is difficult to store. In contrast, heat energy can be stored with relative ease, although it lacks versatility and wide-area operability.

For these reasons, a cogeneration plant has to be installed in the vicinity of the consuming site and is operated according to the heat demand. The difference between the electricity output and actual consumption should be balanced by connecting it to a power grid.

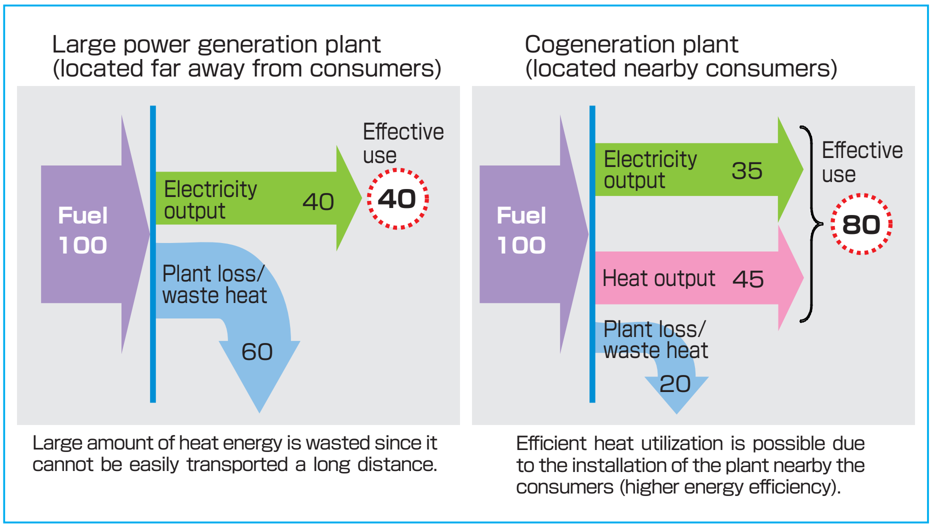

Fig. 1 : Energy efficiency improvements using cogeneration plant

Effects of the network operation

As described above, cogeneration plants have to be installed near the consuming site due to the limitation of heat transportation. The energy demand of individual users fluctuates considerably. If individual users were to install their own cogeneration plants and operate them so as to satisfy their particular pattern of demand, the operation rates would remain low and the fuel efficiency would be deteriorated due to frequent output adjustment.

It is therefore considered effective for users to share a cogeneration plant in a network in order to improve operation rate and to avoid the frequent output adjustment.

Fig. 2 shows an example of a fuel cell-based cogeneration network system for a residential district. In this case, cooperation with storage facilities enables the leveling of hydrogen production, which is normally characterized by a poor output response. Furthermore, the sharing of the plant among the networked users in a neighbourhood makes it possible to minimize the plant installation capacity (and the initial investment costs) and to maximize operation rate.

By introducing the system shown here, an improvement of approximately 15% in the primary energy utilization efficiency can be expected over conventional ones.

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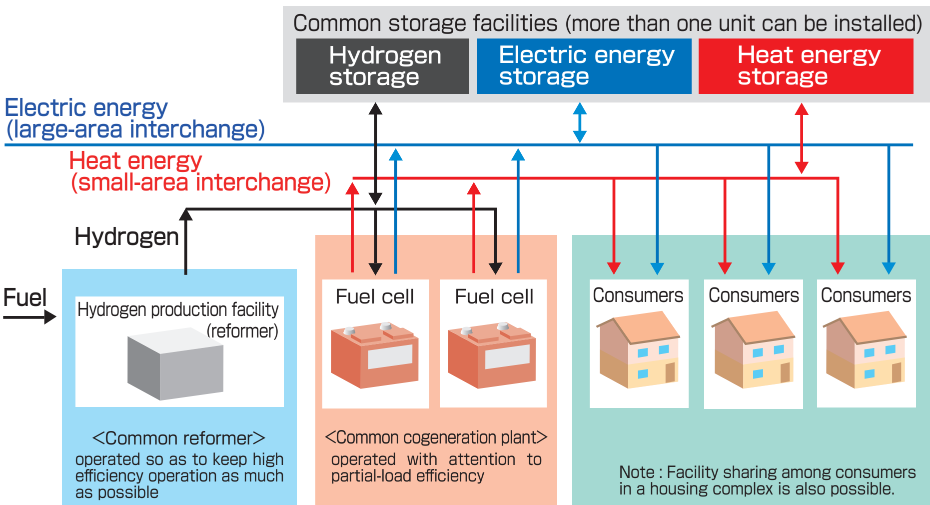

Fig. 2 : Example of network operation

Intermittent Heat Transport Technology

Low-Grade Waste Heat Recovery and Storage

Transport without motive energy

For the purposes of energy efficiency and alleviating urban warming, it is important to recover and utilize waste heat of less than 150 degC, which is discharged from micro gas turbines, polymer electrolyte fuel cells (PEFC) and other distributed power sources. An intermittent heat transport technology (Fig. 1) to recover waste heat or solar heat and transfer it over a distance of several to tens of meters without motive energy is presented here.

When an evaporator is heated by waste heat with an electromagnetic valve in the closed position, the heat medium liquid in the evaporator is evaporated and the vapor builds up inside. When the vapor pressure reaches the prescribed value, the solenoid valve opens and the vapor flows out to the low-pressure line into the condenser. The condenser is equipped with a latent heat storage medium, which takes heat out of the vapor, thus partially condensing it. The condensate is carried to the return line by the force of the remaining vapor, becoming a two-phase gas-liquid flow. It goes through a gas-liquid separator and returns to the evaporator (low pressure). By repeating this process, it is possible to transport waste heat to a heat storage tank intermittently with only a small amount of power to operate the solenoid valve. The heat transport performance expressed in terms of thermal conductivity is 20-60 kW/mK, over 50 times more conductive than copper, which is known as a highly conductive material (thermal conductivity of 0.38 kW/mK). This technology is more advantageous than a heat pipe, a similar heat transport device, since the heat can be transported over a longer distance and the transport is less susceptible to gravitational forces.

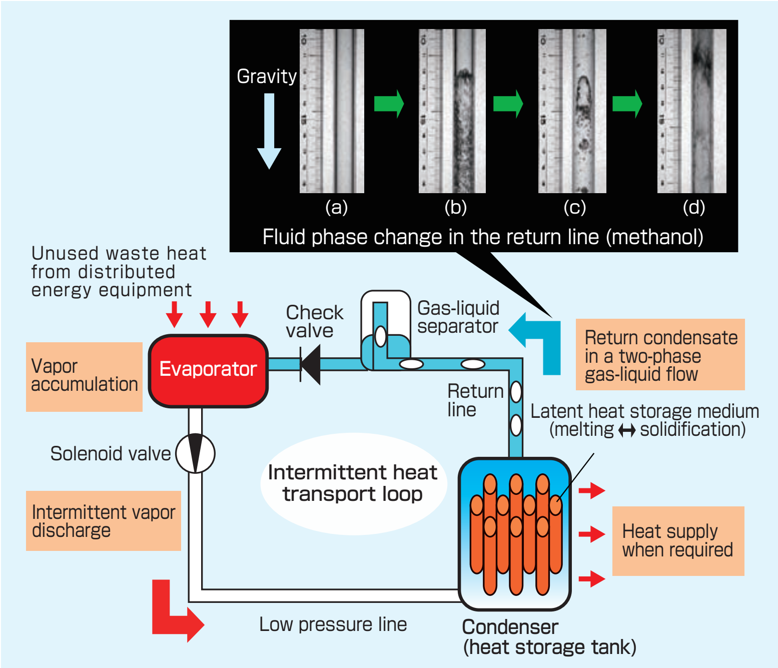

Fig. 1 : Outline of a intermittent heat transport loop and aspects of the heat medium returning flow

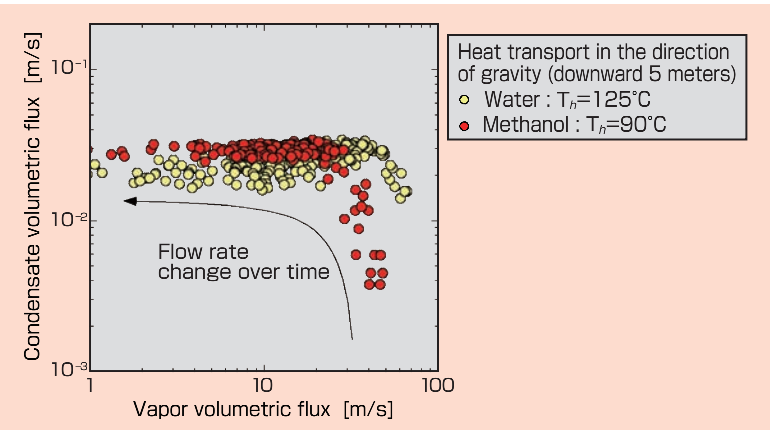

Fig. 2 : Flow rate change of the vapor-condensate two-phase returning flow

Challenges and prospects

The most difficult technological aspect is to return the condensate back to the evaporator. Fig. 2 shows the change in velocity of the vapor and condensate in the return line over time (T_h representing heating temperature). Here, the volumetric flux represents the velocity when the liquid or vapor is assumed to run through the line alone. Inside the return line, the liquid flows in the form of a thin film adhering to the inner surface of the pipe. The volumetric flux of the vapor is therefore almost equal to the actual velocity. As the graph shows, the vapor velocity reaches 40-70 m/s at some points, indicating that a high-velocity vapor stream can be obtained from low-temperature heat of approximately 100 degC. Based on these findings, the application of this technology is under consideration for heat recovery or the cooling of various types of machinery and equipment generating a large amount of waste heat.

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Storage and Transport of Cold Energy Using Flowing Ice

Toward the Practical Application of Large-scale Ice Slurry Transport

Storage and transport of cold energy using ice

In the introduction of distributed energy systems, a major challenge is to increase the efficiency of cold energy utilization for air conditioning, etc. In particular, heat transfer media suitable for the storage and transport of cold energy are being sought in order to reduce the mismatch of demand and supply both in time and in space. The use of ice has become popular as a means of cold energy storage from the viewpoints of safety, economics and heat storage density. Recently, increasing attention is being paid to “flowing ice” (ice slurry), which is a mixture of fine ice particles with water and hence has improved flowability. However, ice particles tend to aggregate in water and the problem is that such aggregated ice particles hinder the smooth storage or transport of the ice slurry.

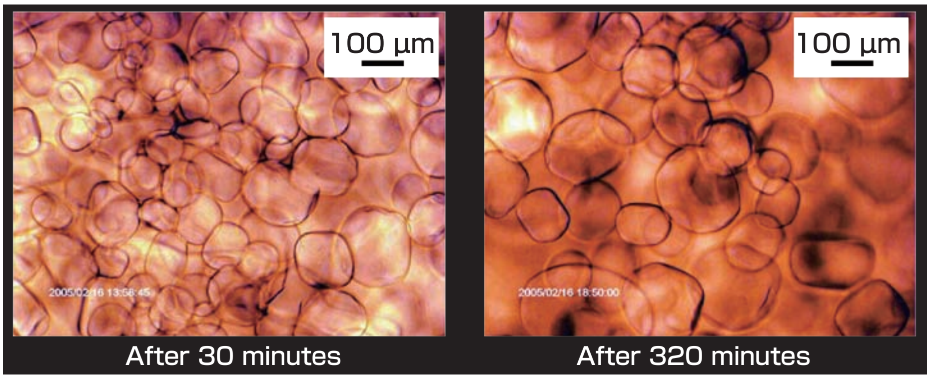

Fig. 1 : State of ice slurry kept at 0 degC with the addition of PVA (4.4 mg/ml)

Making flowing ice – application of biological mechanisms –

In order to prevent ice slurry aggregation, the addition of antifreeze proteins (AFPs), which are unique to organisms living in cold climates, is proposed. Water containing AFPs has a temperature zone in which ice does not develop further even below the melting point. The difference between the temperature at which ice begins to grow and the melting point is called thermal hysteresis. When a small amount of AFP is added to ice slurry, the thermal hysteresis process operates to inhibit the aggregation of ice particles and permits their transport. However, AFPs are still expensive; it will therefore be some time before ice slurry is used for practical applications on a large scale.

A new method of preventing ice particle aggregation – a polymer that acts on ice –

A search was therefore undertaken for synthetic polymers that would have similar functions to those of AFPs. It has been confirmed that polyvinyl alcohol (PVA), which is widely used for industrial purposes, exhibits thermal hysteresis. When a small quantity of PVA is added to ice slurry, the shape of the ice particles is kept almost stable for an extended period (Fig. 1). An ice slurry storage test (at 0 degC for 10 hours) showed that the addition of PVA keeps the ice particle size almost unchanged (Fig. 2). Further study is underway in search of yet higher performance substances to realize the practical application of flowing ice technology.

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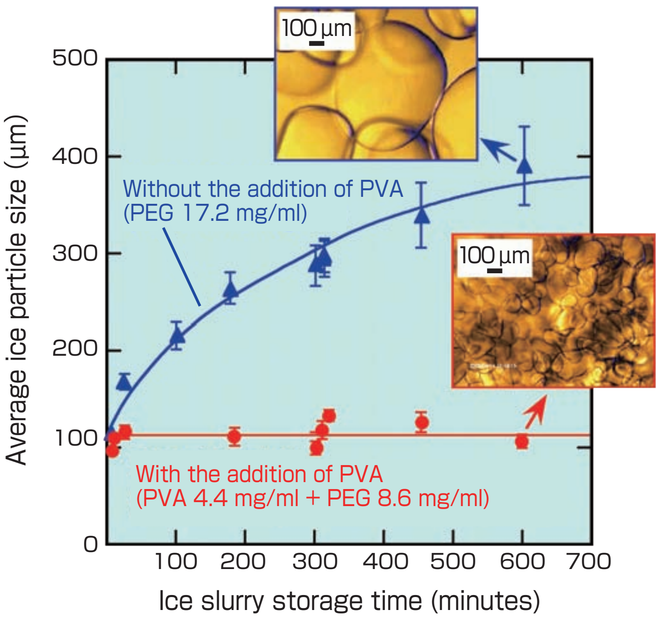

Fig. 2 : Effect of additives on time-course change in ice particle size (PEG stands for polyethylene glycol)

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Low-energy SiC Power Device for Inverters

For the Future of Energy Networks

Low-energy consuming device that underpins energy networks

Increasingly active research is being carried out to develop power devices based on SiC semiconductors. An SiC power device is a promising candidate for a low-loss switching device, which is a key component in an energy network. At AIST, intensive R&D is being promoted on SiC single crystal growth, device development and inverter application technologies. Some of our recent accomplishments in the development of an SiC switching device are presented here.

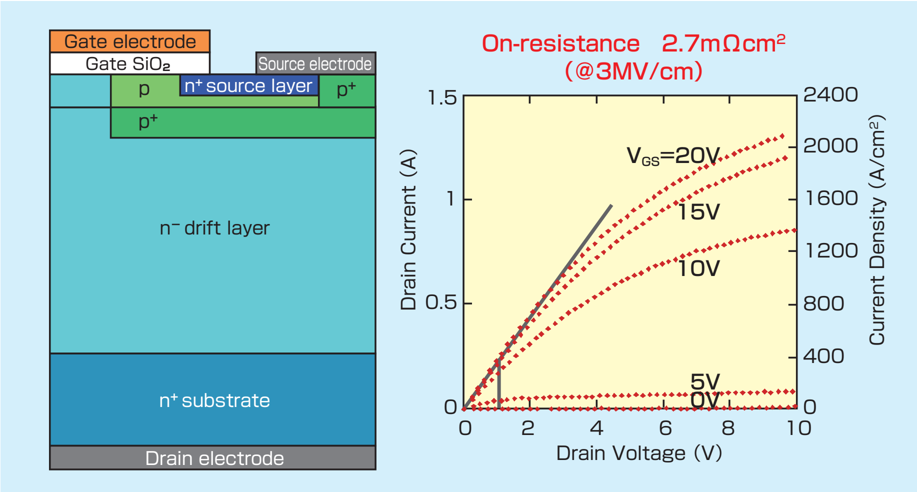

Fig. 1 : Device structure (left) and output characteristics (right) of an SiC-IEMOSFET prototype

Development of a low-energy consuming SiC switching device

A MOS gate device is easily driven as it requires voltage, not current. Such Si-based devices are already used widely in commercial applications in the form of IGBT or MOSFET, but they still have certain shortcomings. One major problem of SiC-MOSFET is that the MOS interface has a large interface state density and the channel mobility is small. An original IEMOSFET (Fig. 1) with a new structure has therefore been developed and optimization of the structural parameters has been sought. In addition, AIST's proprietary technologies have been incorporated for the reduction of the interface state (utilization of a carbon face consisting of two different wafer crystal faces and unique gate oxidation and post-treatment technologies). As a result, an on-resistance of 2.7 m Ω cm^2 and a channel mobility of 72 cm^2/Vs at a 700 V withstand voltage have been achieved. This on-resistance is approximately one fifth of that of conventional Si-IGBTs and is the smallest as far as SiC-MOSFETs are concerned. It has been confirmed that this device in a 0.8-by-0.8 mm chip is capable of switching a current of several amperes at high speed.

Another major problem of SiC-MOSFETs is that the reliability of the gate oxidized film has not been established. A static induction transistor (SIT), in contrast, is an FET with a pn-junction type gate structure and hence is free from the problem of oxidized film reliability. In addition, low on-resistance can be expected since the channel mobility is equal to the intrinsically high electron mobility of SiC crystal.

Fig. 2 illustrates the original buried gate SiC-SIT prototype that our Research Center has manufactured. Microfabrication technology to make the ultrafine buried gate was the key. Though normally kept on, an on-resistance of 1.01 m Ω cm^2 at a 700 V (Vg=-12 V) withstand voltage has been achieved, which is lower than that of the IEMOSFET mentioned above and is the lowest of any such devices.

These prototype SiC switching devices outperform by far Si-IGBTs and are expected to make contributions to further reduction in loss in inverter operations.

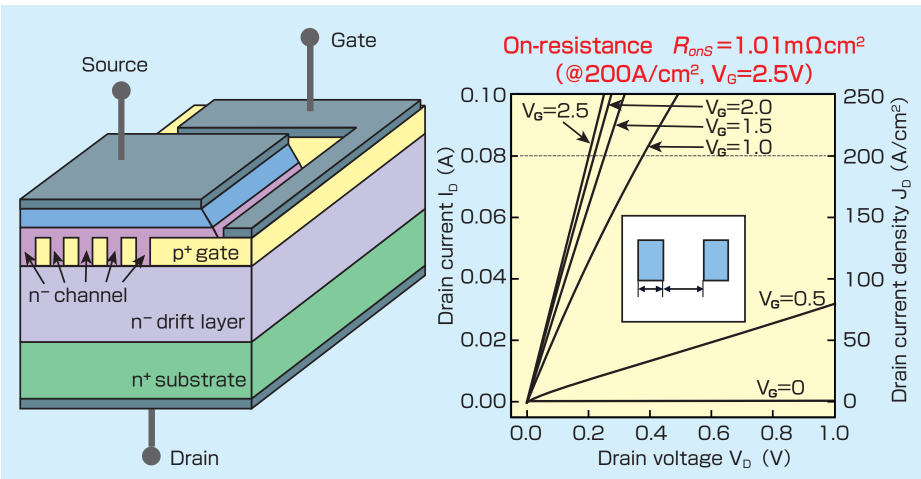

Fig. 2 : Device structure (left) and output characteristics (right) of an SiC-SIT prototype

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Hajime Okumura

Four-terminal Double-gate MOS Device

Simultaneous Pursuit of Low Power and High Speed

Problems associated with the miniaturization of semiconductor circuits

It is no exaggeration to say the spectacular progress of semiconductor (silicon) integrated circuits (Si-VLSI), which has been the key to the hardware infrastructure of today's information technology (IT) society, owes a great deal to the miniaturization of MOSFET configuring VLSI. The technology node of semiconductors has already entered into 90 nanometer generation.

The advancement of such miniaturization, on the other hand, has given rise to concerns about deterioration of device performance due to the short channel effect as well as an increase in power consumption due to the substantial increase in current leakage. In particular, the problem of increased power consumption has become serious.

Evolution of MOSFET

While a conventional bulk MOSFET (Fig. 1 (a)) has reached the limit of miniaturization, the double-gate MOSFET (DGFET) structure (in this case the fin-type) enables tight shielding of the drain electric field using the double-gate, thus reducing the short channel effect that is caused by the interference between the drain and the source due to miniaturization. For this reason, DGFET has received worldwide attention as the device structure which is most suitable for miniaturization. This structure was first proposed as XMOSFET by Electrotechnical Laboratory (today AIST) in 1984.

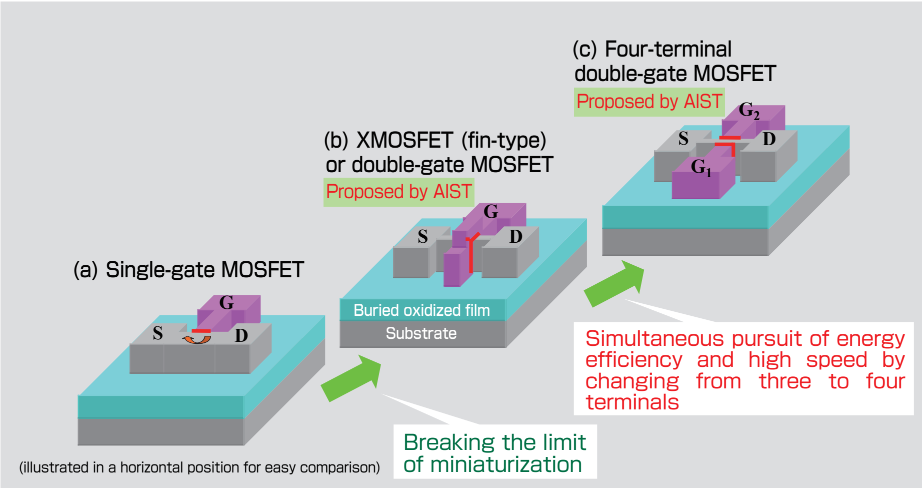

Fig. 1 : Evolution of MOSFET
(a) Ordinary planar bulk MOSFET (illustrated in a horizontal position for easy comparison), (b) Double-gate MOSFET (DGFET) (fin-type); originally named XMOSFET, (c) Four-terminal double-gate MOSFET (4T-DGFET).

Excellent energy-saving device proposed by AIST

AIST has proposed the four-terminal double-gate MOSFET (4T-DGFET) that is the next generation device after the DGFET and has two independent gates as illustrated in Fig. 1(c). The threshold voltage V_{th} for the switch action of one of the gates can be freely controlled by the gate voltage of the other gate (Fig. 2). During stand-by, excellent energy-saving can be realized by keeping V_{th} high to reduce the off-current significantly; during operation, V_{th} is lowered to keep the on-current high to ensure high speed operation. Enabling ultra-miniaturization as well as ultra energy-saving through dynamic power management, we think 4T-DGFET will become the mainstay of future VLSI devices.

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Eiichi Suzuki

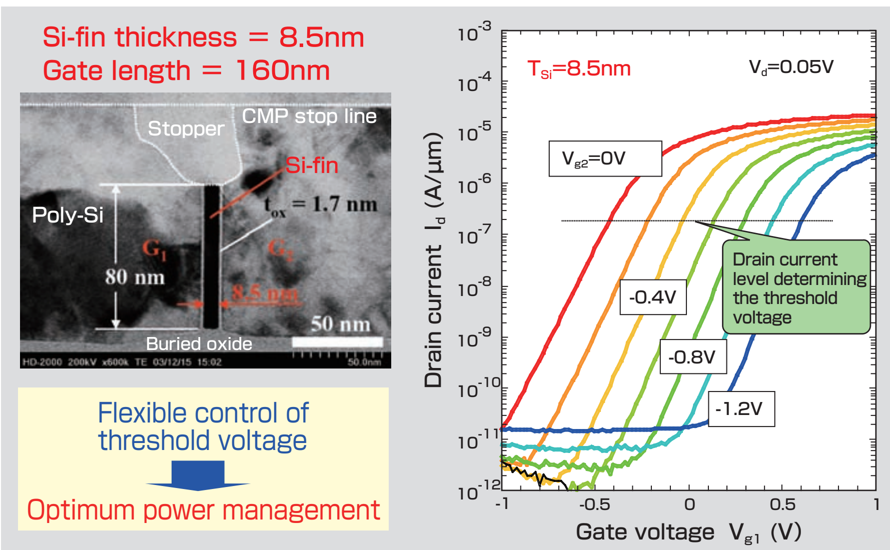

Fig. 2 : Threshold voltage control characteristics of a prototype four-terminal double-gate MOSFET (4T-DGFET)
Flexible control of the threshold voltage allows an extremely low off-current (low power consumption) and high on-current (high speed) at the same time.

Energy-saving Window Glass that Controls Solar Heat Automatically

Toward the Commercialization of a Dream Window Glass that Functions in Harmony with Seasonal Changes

Window glass and energy efficiency

Window glass has a very important role to play in the reduction of air conditioning load of houses and commercial buildings. For example, a study showed that windows account for 71% of heat penetration in summer and 48% of heat escaping in winter.

If windows are made to display sunlight-shielding property in summer and heat insulation property in winter, significant energy efficiency can be realized. If in addition the inflow and outflow of light and heat through the window are made controllable according to the seasons and the requirements of the occupants, a considerable amount of energy will be saved without sacrificing comfort.

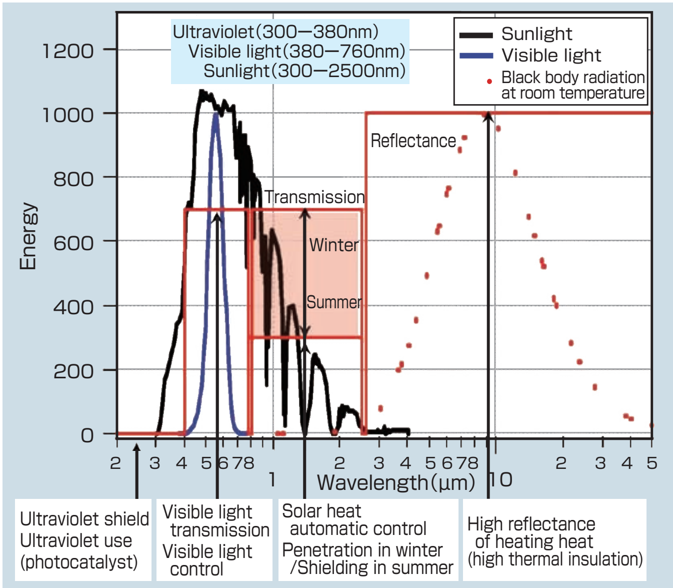

Fig. 1 : Control or utilization of light and heat according to the wavelength

Energy efficiency system proposed by AIST

Here we present a revolutionary energy-saving glass that is capable of controlling or utilizing the flow of light and heat according to the requirements in terms of light wavelength.

Fig. 1 shows the details of the wavelength control. Ultraviolet light (300 - 380 nm), which is harmful to health and promotes the degradation of articles indoors, is shielded almost entirely. Simultaneously, the energy of ultraviolet rays in sunlight is absorbed by a photocatalytic film to be used for the self-cleaning of the glass surface and environmental detoxification. Visible light (380 - 760 nm) is allowed to pass through at all times to ensure transparency, the fundamental function of a window. The amount of penetration of the infrared portion (0.8 - 2.5 μm) of solar heat is controlled automatically according to the season. People are known to sense heat or warmth most from infrared region, especially around 1.5 μm. Solar heat is made difficult to enter in summer and made easy in winter, and the switchover is made automatically according to the ambient temperature. In this way, both a comfortable living environment and energy efficiency are realized. The window is designed to have high heat insulation properties by having high reflectance constantly in the far infrared region. In summer the entry of heat radiation is prevented and in winter the thermal outflow of house heating is avoided. Fig. 2 shows a sample of glass manufactured by AIST and its optical characteristics.

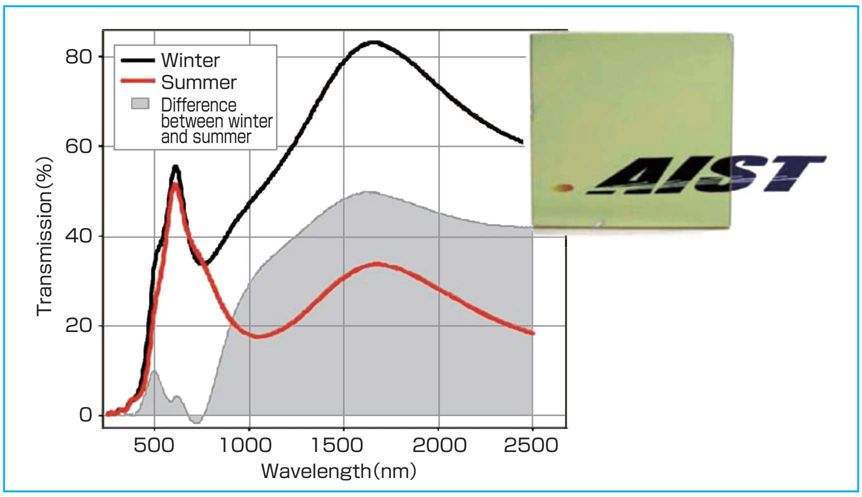

Fig. 2 : Transmission spectra and the appearance of the glass sample

In pursuit of commercializing the dream glass

A glass that, with a single structure, can control or utilize the entire spectrum of wavelength related to energy efficiency and living comfort will indeed be a “dream window glass.” The first step towards its commercialization has been made recently in cooperation with the industry.

Materials Research Institute for Sustainable Development
Ping Jin
Masato Tazawa

Energy Efficiency Technology for Homes

System Sophistication through a Better Understanding of Consumption Patterns

Difficulty of energy efficiency in homes

Households account for approximately 13% of total energy consumption in Japan and this share is on an increasing trend. Making appliances more energy efficient, raising awareness about the importance of energy consumption and other measures are required. Household energy consumption is characterized by a high demand for heat. Therefore energy efficiency through cogeneration has good potential, but is not yet popular. Recently improvements have been made in fuel cells, gas engines and other technologies that can be applied to household cogeneration more easily. However, household demand fluctuates rather significantly. For instance, the use of a microwave oven, hair dryer and other relatively heavy energy-consuming appliances is for a short time and is hardly predictable; the ratio of the maximum and minimum power demand in a day can exceed 10. The household demand also varies considerably from one household to another. For these reasons, the design and operation of cogeneration and other equipment are very difficult and the capacity utilization tends to be low. Coupled with the problem of high cost relative to its durability, this difficulty has prevented wide acceptance of home-use cogeneration and other equipment. Furthermore, electric power, gas and oil companies are competing in the development of household energy equipment. Some fear that this tough fight for market share might lead to increased energy consumption rather than efficiency.

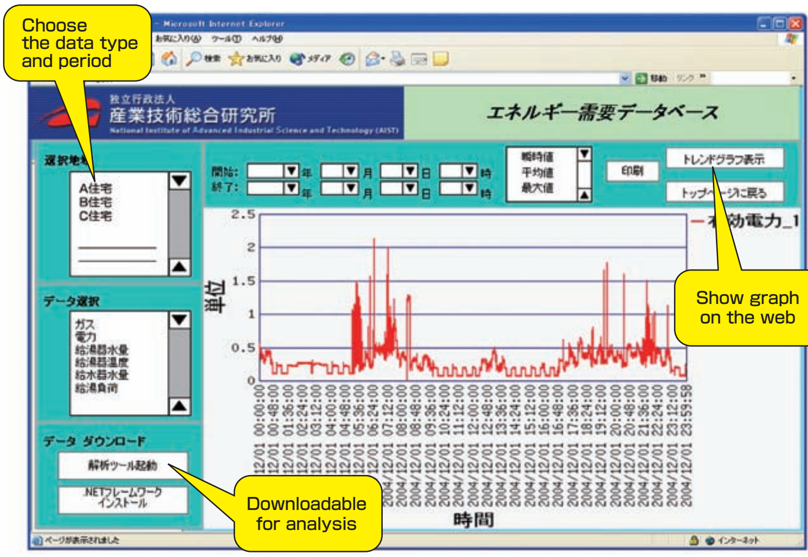

Fig. 1 : Household energy demand database constructed by AIST

Understanding home demand and the response

Objective and accurate data on actual energy demand and appliance performance are indispensable for studies to promote energy saving at home. Such data, however, are hardly ever available in the public domain due to regulations on personal or private information. We are taking records of energy consumption in independent and complex houses to construct a database (Fig. 1). The database is used in research on cogeneration systems for home and other objectives. For example, demand in one household may not be predictable, but data on ten households show certain patterns (Fig. 2) and give useful clues to efficient system operation.

Future energy demand in homes

Most of conventional energy supply equipment for home use is designed and structured based on the concept of responding to arbitrary energy consumption. Cost reduction and energy efficiency are pursued only within the confines of this concept. To achieve higher energy efficiency in the future, the approach of controlling demand without compromising convenience should be taken.

Energy Technology Research Institute
Tetsuhiko Maeda

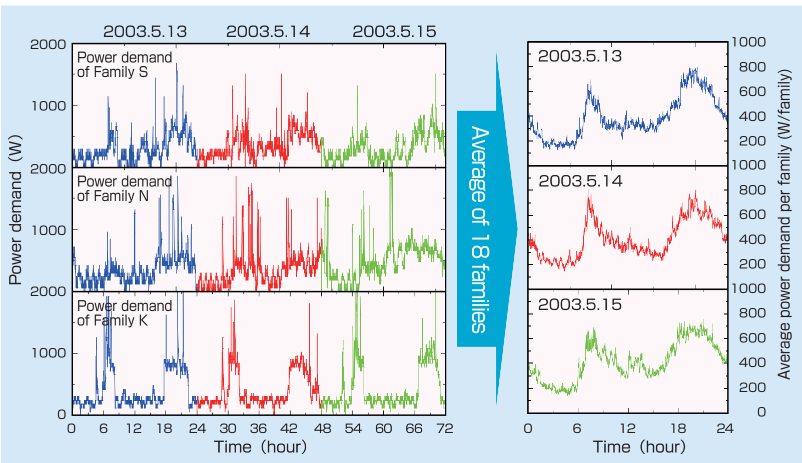

Fig. 2 : Demand leveling effect (3-day demand in three households → average demand of 18 households, including the three)

Energy-efficient Desiccant Air Conditioning System

A Technology to Achieve Both Living Comfort and Energy Efficiency

Energy-efficient air conditioning system

Desiccant air conditioning and humidity control systems which utilize the water adsorption/desorption to porous materials have been attracted much attention as an environment-friendly and energy-efficient air conditioning system. Ordered mesoporous materials (MCM-41, FSM-16, etc.), which have been studied extensively in recent years, are considered as the optimum adsorbent for adsorption/desorption-based air conditioning systems since their water adsorption property (Fig. 1) due to their highly ordered porous structure : the uniform nanopores with ordered arrangement.

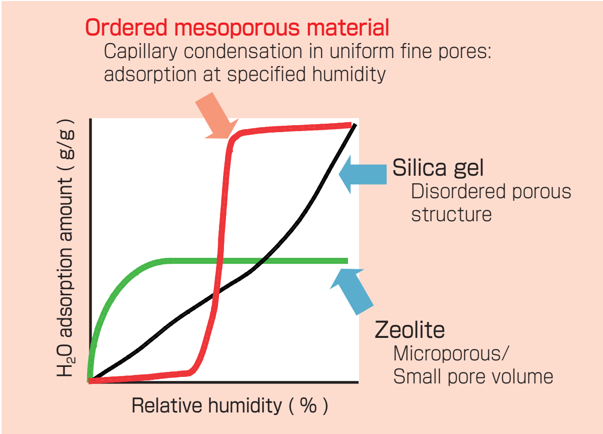

Fig. 1 : H_2O adsorption characteristics of porous materials

Synthesis of highly ordered mesoporous materials

Highly ordered mesoporous materials are synthesized using the self-assembling structure of surfactant molecules as a structure directing agent. There are two major pathways by which these ordered mesoporous materials are synthesized: (1) a hydrothermal synthesis in which the products precipitate from inorganic surfactant aqueous solutions under alkaline or acidic conditions at temperatures as high as 100 degC and (2) a solvent evaporation method in which the source solution is concentrated with the evaporation of the solvent to form an ordered inorganic surfactant mesostructure.

We used the solvent evaporation method for the production of ordred mesoporous silica since it enables continuous synthesis at low temperatures and mass production. Our efforts are also focused on the improvement of the stability toward water vapor. There are two rate processes in our synthesis method: (1) the rate of solvent evaporation, which induces the self-assembly of the surfactant micelles and (2) the rate of polycondensation of the silicate species. It is considered that the well-ordered mesostructure can be obtained only when these two rate processes are well balanced. To produce the large amount of the products within a short time, it is necessary to evaporate the solvent rapidly without changing the “balance” of the above-mentioned rate processes. We have developed a technology to produce a large quantity of high-durability products over a short period by controlling the solvent evaporation rate and the sol-gel reaction.

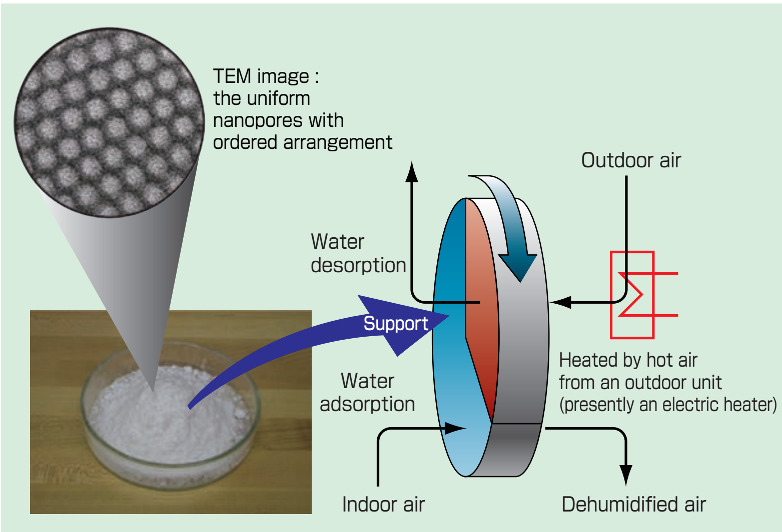

Fig. 2 : Desiccant rotor supporting ordered mesoporous materials

Towards the commercialization of energy-efficient adsorption systems

We are engaged in R&D for commercialization of desiccant cooling system under the joint research with a private company. The dehumidifying rotor (Fig. 2) that supports the highly ordered mesoporous material has an enough stability toward water vapor and adsorption capacity in comparison with conventional adsorbents such as zeolites, silica gel, etc. Furthermore, effective regeneration is possible with at temperatures as low as 50 degC. Therefore, this system can be operated using exhaust heat from the refrigerator. Early commercialization of this highly energy-efficient air conditioning system based on a low-temperature regeneration adsorbent is indeed expected.

Research Institute for Innovation in Sustainable Chemistry
Akira Endo

Energy-saving Engine Exhaust Treatment Based on Waste Heat Power Generation

Direct NO_x Decomposition in an Electrochemical Reactor

Coexistence of automobile exhaust purification and energy efficiency

Promotion of energy efficiency in the transportation sector in particular is an impending challenge in order to attain the CO_2 emission reduction goals under the Kyoto Protocol. In Europe, for example, there are high expectations for the improved fuel efficiency of diesel engine and vigorous studies are underway on engine combustion control and exhaust purification in order to clear the increasingly stringent emission regulations. Development of high efficiency exhaust purification technology is an important challenge to realize both environmental protection and energy saving.

Deterioration of the fuel economy is inevitable with the exhaust purification catalysts currently in use. This can be avoided by the NO_X reduction purification method using an “electrochemical reactor” since the direct decomposition of NO_X eliminates the need for a reduction agent, and this makes it possible to have ideal exhaust purification without adverse impacts on fuel economy. However, this method had been considered unfeasible commercially due to the large amount of power that has to be consumed to remove the disturbance from the oxygen that is contained in large amounts in diesel engine exhaust. This energy consumption has nothing to do with the NO_X purification reaction itself.

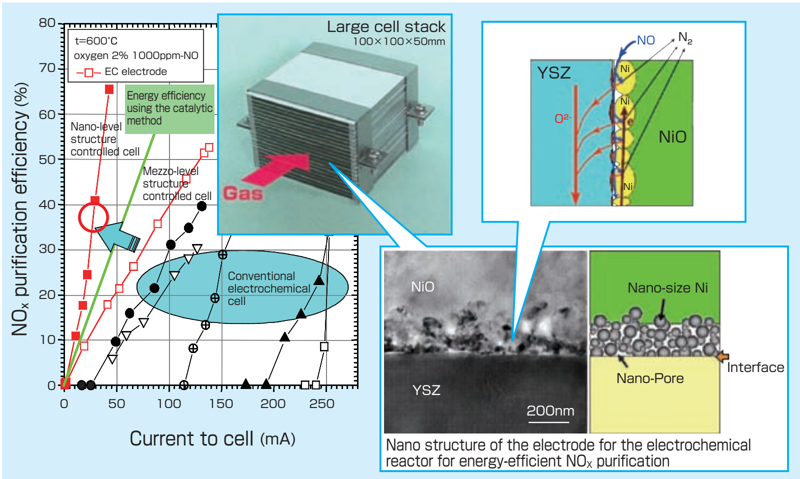

Fig. 1 : Electrochemical reactor with a structure controlled at the nano scale

We have controlled the reactor structure at the nanometer levels and have successfully produced selective decomposition reactions of NO_X molecules inside electrodes. Even in the presence of hundreds of times as many oxygen molecules, highly efficient purification of NO_X was achieved with less than half of the energy consumed by the presently available methods (Fig. 1).

Prospects for energy-efficient autonomous continuous purification

With a view to making use of the “oxidation/reduction” that takes place simultaneously at the electrodes at both ends of the electrochemical cell, we have made further improvements to the electrodes so that strong oxidation activity will occur due to the radical oxygen on the anode side in addition to NO_X reduction on the cathode side. As a result, the decomposition of particulate matter (PM: soot-like mass) in exhaust gas has become possible. Unlike the DPF (a filter) that is in common use today, our technology has substantial potential as an energy-saving purification method to remove NO_X and PM simultaneously, independent of the engine operating conditions and be capable of being activated on demand (Fig. 2 top right).

Additional energy saving is expected with this technology through the utilization of waste heat energy in the exhaust gas. We incorporated a thermoelectric conversion ceramic module to convert waste heat into electric energy, which is used to activate the NO_X purification reactor (Fig. 2 below right). In this way, we have successfully demonstrated for the first time that a NO_X purification reactor can be run without energy input from outside.

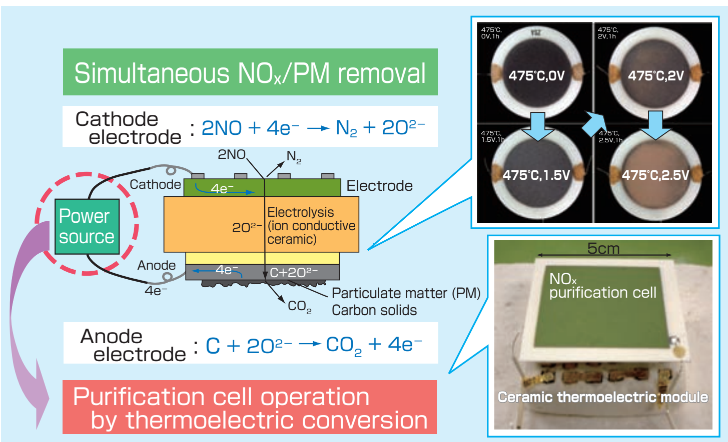

Fig. 2 : Energy-efficient autonomous continuous purification through simultaneous NO_X/PM removal and thermoelectric power generation from waste heat

Advanced Manufacturing Research Institute
Masanobu Awano

Rechargeable Lithium and Lithium-ion Batteries for Hybrid Vehicles

Development of New Materials and Evaluation Technology to Promote Wider Use

Approximately 20% of Japan's final energy consumption is by automobiles. The vehicle efficiency of today's passenger cars is approximately 16%, leaving much room for improvement in energy consumption. The hybrid technology that combines a secondary battery and an electric motor improves the vehicle efficiency more than twice, and has begun to spread in foregin countries as well as Japan.

AIST is energetically engaged in basic research and development that will contribute to cost down and improved safety of rechargeable lithium and lithium-ion batteries. Since fiscal 2002, we have been engaged in R&D on new battery materials and battery evaluation technologies by participating in a NEDO project[1] that aims to develop rechargeable lithium and lithium-ion batteries for fuel cell vehicles and hybrid vehicles.

Development of new battery materials

In the development of battery materials, we are working to develop new materials in the search for a breakthrough. For the positive electrode, which is the key to cost down, we have focused on $Li_{0.44+x}MnO_2$[2] and iron-containing Li_2MnO_3[3] as candidate low-cost element compounds. Among the former group we have developed $Li_{0.63}MnO_2$, which has a discharge capacity of 170 mAh g^{-1}, approximately 1.7 fold that of the spinel structure manganese oxide that is in commercial use as a low-cost positive electrode. In the latter group we have succeeded in developing $Li_{1+x}(Fe_{0.4}Mn_{0.4}Co_{0.2})_{1-x}O_2$ that, though a 3V class, has a discharge capacity of 233 mAh g^{-1}, surpassing that of conventional positive electrodes (Fig. 1). Studies to achieve larger discharge capacity are underway.

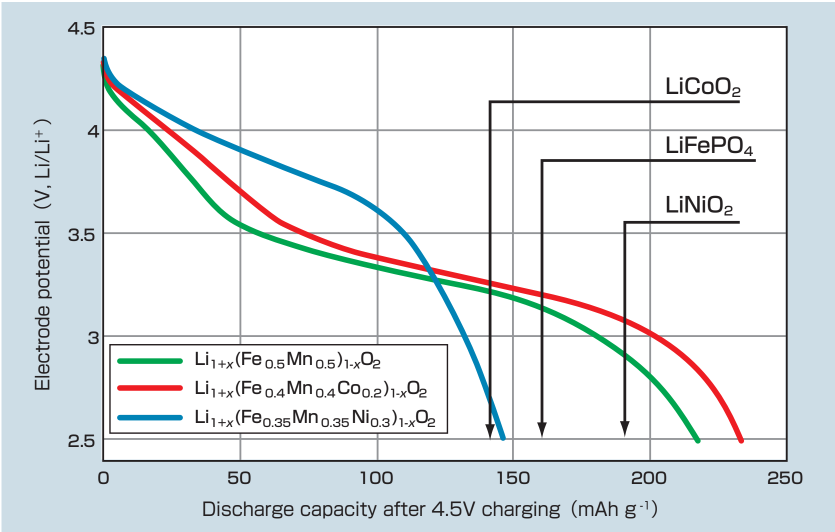

Fig. 1 : Discharge curve of a developed high-capacity $Li_{1+x}(Fe_{0.5}Mn_{0.5})_{1-x}O_2$ positive electrode and the effects of Co and Ni addition
Discharge capacities of typical positive electrode materials ($LiCoO_2$, $LiFePO_4$ and $LiNiO_2$) are shown.

With respect to electrolytes, which are the key to safety improvement, we have developed a cyclic quaternary ammonium-based ionic liquid electrolyte which is not decomposed reductively by lithium metal. In addition, we have confirmed that in this electrolyte the dendrite recrystallization at charge, a problem associated with lithium-metal negative electrode, is suppressed[4] (Fig. 2).

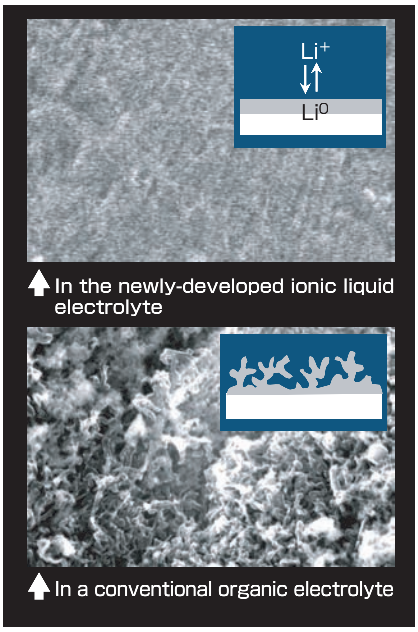

Fig. 2 : images of lithium-metal negative electrodes after charge in the newly-developed ionic liquid electrolyte (top)[4] and a conventional organic electrolyte (bottom)

Based on these basic developments and findings, we are engaged in finding solutions to the challenges of the commercialization of the battery materials.

Efforts in battery evaluation technology

Currently we are engaged in a study to elucidate the degradation mechanism of rechargeable lithium-ion batteries. With particular reference to the power degradation that poses a major problem in hybrid vehicles, we have applied various diffraction and spectroscopic methods and have begun to discover that chemical changes in the vicinity of the surface of positive electrode materials influence the degradation.

Research Institute for Ubiquitous Energy Devices
Kuniaki Tatsumi

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1) New Energy and Industrial Technology Development Organization (NEDO), Development of Lithium Battery Technology for Use by Fuel Cell Vehicles
2) J. Akimoto *et al*., Electrochem. Solid-State Lett., 8, A554-557 (2005).
3) M. Tabuchi *et al*., Chem. Mater., 17, 4668-4677, (2005).
4) H. Sakaebe, H. Matsumoto, Electrochem. Commun., 5, 594-598 (2003).

Energy-efficient Distillation Technology with Internal Heat Integration

Next-generation Distillation Column on the Verge of Commercial Operation

Need for energy saving in chemical complexes

Most of the tall towers that are seen in today's large chemical complexes are continuous distillation columns. This basic technology was established in the early 20th century. Ever since, the distillation column has been in wide use with its basic structure essentially unchanged since this relatively simple equipment can achieve high-accuracy separation and can be easily scaled up for large quantity processing.

Distillation is a typical energy-consuming process; it accounts for approximately 40% of total energy consumption by the chemical industry, which in its turn accounts for 31% of total energy consumption of all industries, ranking as a major energy-consuming industry along with steel, paper and pulp, and cement. The extent of energy efficiency in the chemical industry has a major impact on the outcome of Japan's commitments under the Kyoto Protocol.

Development of energy-efficient distillation columns

The Heat Integrated Distillation Column (HIDiC) is a new technology that aims to achieve substantial energy saving through the reuse of self-generated heat in the distillation process. In the conventional distillation process, an external heat source is used to cool and heat the mass flow for phase change at the top and bottom of the column.

In HIDiC, the column is divided into two sections above and below the raw material feeding point, and the upper section is kept under a higher pressure than the lower section. According to the principle of the heat pump as illustrated in Fig. 1, cooling in the upper section and heating in the lower section proceed simultaneously with the input of hardly any external heat.

In a fiscal 2002 - 2005 NEDO project, a pilot plant based on AIST patents (Photo 1) achieved stable continuous operation for 1,000 hours with a real industrial product. With regard to energy consumption, in comparison with conventional columns, a reduction of approximately 60% in CO_2 emissions has been experimentally confirmed even after accounting for the energy required for compression.

As a result, a fund provision-type joint research program began in fiscal year 2006 in cooperation with five private companies including Mitsubishi Chemical Corporation with the target of achieving commercial operation by the end of fiscal 2008.

Research Institute for Innovation in Sustainable Chemistry
Masaru Nakaiwa

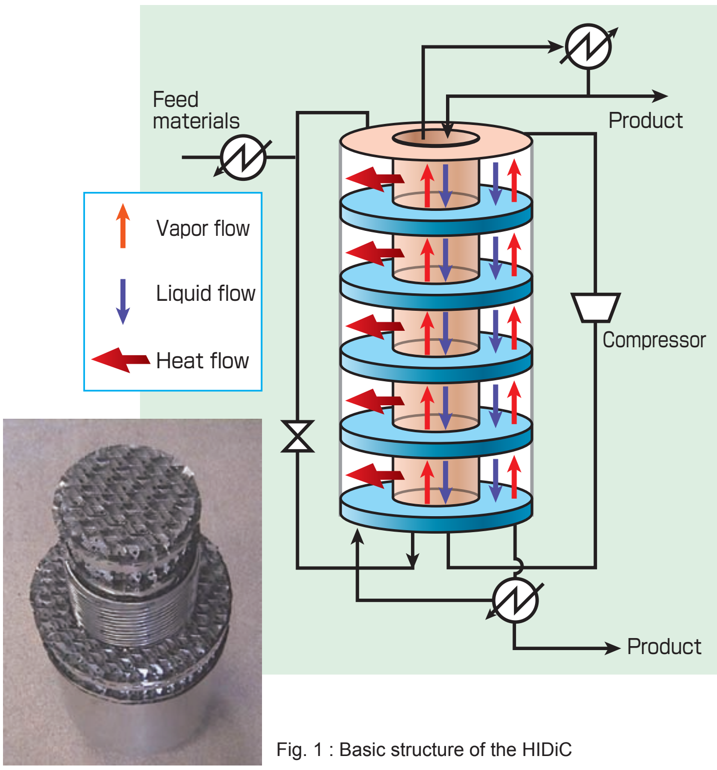

Fig. 1 : Basic structure of the HIDiC

Photo 1 : Pilot plant (contains seven of the units shown in Fig. 1)
Chiba Plant of Maruzen Petrochemical Co., Ltd. (November 2005)

Development of Energy-efficient Waste Water Treatment Technology

Utilization of Biodegradabiliy Improvement Function of Ozone

Decolorization of dyehouse waste water

Establishment of decolorization technology for waste water from the dyeing industry is important because the discharges of waste water have a strong color even though the quality may be in full compliance with the environmental regulations. Furthermore, dyestuffs contained in the discharged waste water are often persistent chemicals and give rise to concerns about post-discharge retention and accumulation in the environment.

Decomposition of dyes with ozone

Ozone has an extremely strong oxidizing power and is known to possess the functions of oxidizing and stabilizing organics, converting poisonous or hazardous substance into inorganic components and improving the biodegradability of persistent organics. Attempts have been made to utilize such functions of ozone for the removal of dyes remaining in waste water after biological or coagulation treatment.

Our focus was on the possibility of increasing the performance of conventional biological treatment through the use of the enhancement in biodegradability of ozone. As part of the NEDO Project "Development of Energy-saving Wastewater Treatment Technology," we have developed a system technology with the combined use of ozone and biological treatments for the purpose of the highly effective removal of persistent hazardous chemicals in dyehouse waste water (Fig. 1).

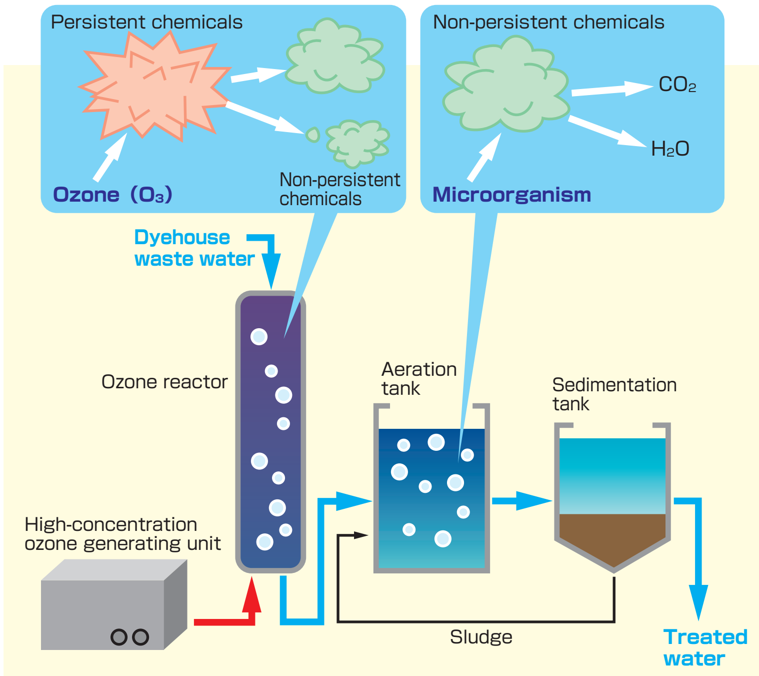

Fig. 1 : Concept of the combined use of ozone and biological treatments

Chemical removal effect and energy-saving effect of the new technology

The effects of this technology are shown in Fig. 2 using C.I. Reactive Yellow 3 as an example of a major persistent dyestuff. In the case of biological treatment alone, the removal of dissolved organic carbons (DOC) was basically dependent on the adhesion to bacteria. Through this new technology with pre-treatment by ozone, we have confirmed that DOC removal was considerably enhanced.

In cooperation with Saitama Industrial Technology Center and Ishikawajima-Harima Heavy Industries Co., Ltd., we tested the technology in a demonstration unit of 5 m^3/day capacity and have confirmed that more than 90% of persistent hazardous chemicals in dyehouse waste water were removed despite the water quality fluctuation.

In addition, energy consumption (in terms of crude oil) of the new technology was compared with that of a conventional technology (combined use of biological treatment and activated carbon adsorption) to obtain the same quality waste water. As a result, it was found that a more than 40% reduction in energy consumption was possible.

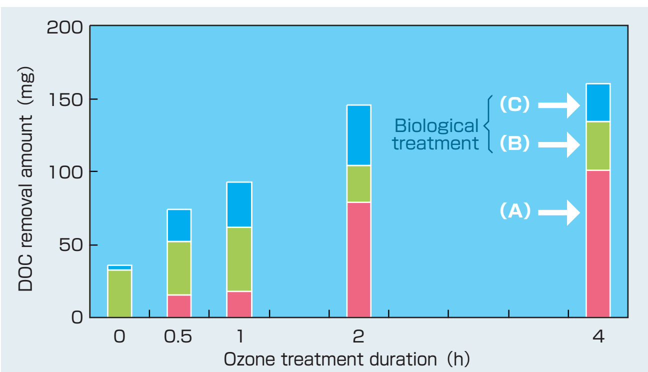

Fig. 2 : DOC removal using ozone and the biological treatment of dyestuff C.I. Reactive Yellow 3 solution
Removal fraction: (A) ozone treatment, (B) initial adsorption, (C) biological degradation

Research Institute for Environmental Management Technology
Nobuyuki Takahashi

R&D on Energy-efficient Green Processes

Membrane Reactor under a New Concept

Chemical processes that produce the greatest variety of chemical products that we benefit from in our daily life consist of many complex processes including reaction, separation and purification. In order to convert such chemical processes into more environment-friendly ones, we at AIST are promoting basic research to develop energy-efficient green processes using non-hazardous raw materials and introducing new materials and concepts.

Use of harmless raw materials

One example of our research in conversion to the use of harmless raw materials is the synthesis of polycarbonate from carbon dioxide. Polycarbonate is a general purpose engineering plastic that is produced in the largest quantity today and the demand for it is expected to continue growing. As illustrated in Fig. 1, the current commercial process involves the use of highly toxic phosgene obtained from chlorine and carbon monoxide as well as the use of dichloromethane as a reaction solvent. If phosgene can be replaced by carbon dioxide, numerous benefits will be obtained including: (a) no use of dichloromethane, (b) reduction of electric power to produce chlorine, (c) elimination of by-produced hydrochloric acid, and (d) chemical fixation of carbon dioxide. At present, improvements are being made to the catalyst and process with the aim of developing commercial-scale production technology.

New materials

In the area of new materials we are involved in the study of high-performance adsorption materials and separation membrane materials. Palladium (Pd) is known to be a high-performance material for selectively hydrogen permeable membranes. We have successfully developed a Pd compound membrane that shows a hydrogen permeability equivalent to the target value proposed by the US Department of Energy. In addition, we have pursued the development of non-noble metal amorphous alloy membranes and silica membranes for cost reduction and have successfully developed such membranes with a separation performance comparable to that of Pd membranes. The separation membrane technology involving these inorganic materials has potential applications not only for semiconductor fabrication and hydrogen production for fuel cells, but also for use in membrane reactors as described below.

New concept

Introduction of a new concept is being tried for oxidation processes. We have been engaged in the development of catalysts for selective oxidation that, with the use of hydrogen peroxide or oxygen, generate no byproducts other than water. As a result, we have discovered a gold nano particle catalyst system for the synthesis of propylene oxide (PO: main raw material for polyurethane foams) using a gas-phase one-step reaction in the presence of hydrogen and oxygen.

As a way of applying this catalyst system, we are studying a membrane reactor based on a new concept as illustrated in Fig. 2. It is anticipated that the use of the new membrane reactor in which hydrogen as a raw material is fed to the catalyst through a hydrogen permeable membrane will permit PO production at high yields without the risk of explosion even under varying reaction conditions. Through this process, PO has been obtained at a higher yield than the case of a catalyst alone, and further improvements are expected. Membrane reactors are expected to play a major role in making chemical processes more compact (see June 2005 issue of AIST Today), and they are believed to be one of the core technologies for energy-efficient green processes.

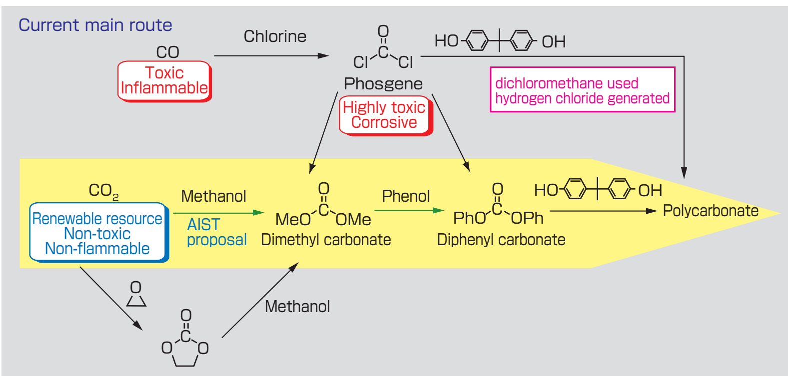

Fig. 1 : New polycarbonate production route

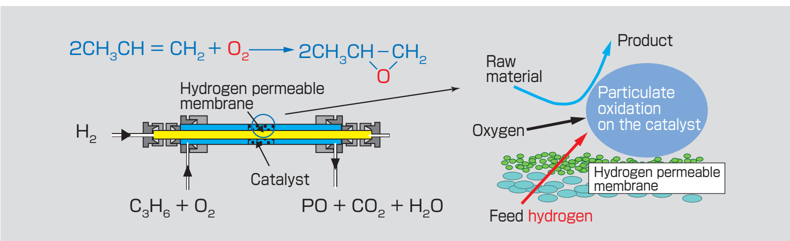

Fig. 2 : Conceptual diagram of the propylene oxide synthesis process with membrane reactor

Research Institute for Innovation in Sustainable Chemistry
Hiromichi Shimada

100 kW Power Generation System for Small Through Flow Boilers

High-efficiency Power Generation Using Small Steam Turbines

Small through flow boilers in increasingly wide use

Small through flow boilers have an operation pressure of no more than 1 MPa and a heat transfer area of no more than 10 m^2. Their heat efficiency is high, at no less than 95% and no boiler operator license is required. For these reasons, they have been introduced mainly into small and medium-size plants in food, paper and pulp, chemical, textile, glass and other industries at a rate of approximately 15,000 units per year. Some major plants are replacing large-capacity boilers with multiple installations of small through flow boilers. Consequently, around 80% of the total evaporation tonnage in Japan is accounted for by such small boilers.

The steam produced by the small through flow boiler is used under the conditions of 2 - 20 t/h in flow rate and up to 1 MPa in pressure. It is also common to use low-pressure steam.

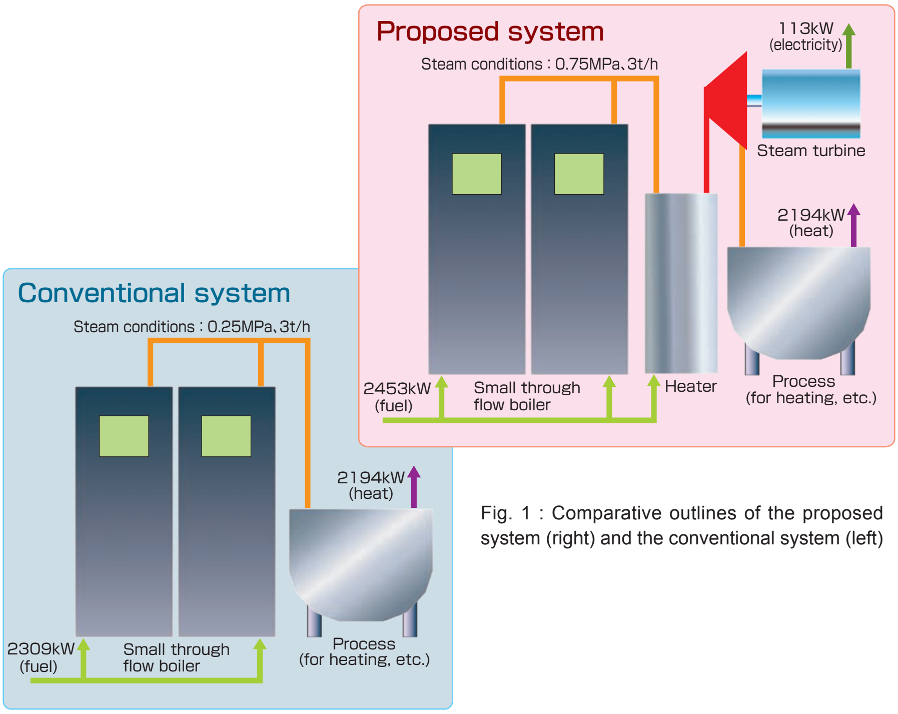

Fig. 1 : Comparative outlines of the proposed system (right) and the conventional system (left)

Newly proposed boiler power generation system

Fig. 1 illustrates an example of a power generation system for a 100 kW small through flow boiler. Presently the small through flow boiler is used as a heat source, as shown in the figure (left). In this example, 3 t/h steam at 0.25 MPa is used for the process between the two boilers. When the boiler heat efficiency is 95%, fuel input equivalent of 2,309 kW is required for a boiler output of 2,194 kW.

With the newly proposed system, the generated steam is first used to generate electricity in a small steam turbine and is then used as heat (Fig. 1 right). When the heat efficiency of the steam heater is 95%, the addition of the steam turbine now under development (heat insulation efficiency 77%) will generate 113 kW of electricity in addition to the thermal output of 2,194 kW.

Even though there will be an incremental input of 144 kW for the boiler and heater, an electricity output of 113 kW will be obtained. Looking at the ratio of incremental fuel (input) and electricity (output), this gives 78% efficiency, which is nearly double the efficiency of ordinary thermal power stations.

Stage of development

This R&D project has been implemented as a joint study for commercialization between NEDO and Kobe Steel, Ltd. since fiscal 2004. In the capacity of a research contractor, AIST is carrying out studies on steam regeneration technology, which will be the key to success. We are now at the stage of installing a 100 kW-class radial steam turbine system as the power station for the Kobe Corporate Research Laboratories of Kobe Steel, Ltd. and carry out test runs (Photo).

Photo :
Small through flow boiler power generation system
Courtesy of Kobe Steel, Ltd.

Energy Technology Research Institute
Hirohide Furutani

At the Forefront of Energy Efficiency Technologies

- For Global Warming Prevention and Stable Energy Supplies
  Planning Headquarters Kazuhiro Sayama
  Energy Technology Research Institute Katsuhiko Kadoguchi
  Research Coordinator for Environment & Energy Masayuki Kamimoto 2
- Energy Saving Effects from an Overhaul Project for Introducing Demonstration Plants for Distributed Energy Supply Systems
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- Development of a Base Technology for the Leveling of a Distributed Energy System
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- Demonstrative Study on Cogeneration
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- Development of Heat/Electricity Integrated Network Technology
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