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Environmental Technology Edition

MITSUBISHI ELECTRIC

Changes for the Better

A Quarterly Survey of New Products, Systems, and Technology
●Vol. 96/December 2001 Mitsubishi Electric **ADVANCE**

Environmental Technology Edition

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Cover Story
Our cover features the symbol mark for the environmental activities of the Mitsubishi Electric Group that was created in 1993. It uses the leaf to represent nature within the environment of the world.

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Overview

Environmental Technologies for Sustainable Development

*by Susumu Hoshinouchi**

The century of the environment has dawned. In Japan, the new century began with enactment of the Basic Law for Establishing the Recycling-Based Society and the Law for Promotion of Effective Utilization of Resources. These represent policies intended to lead to an environmentally responsible society and express the international concern for sustainable development. As such, they necessarily involve us in the major reforms required to create a new social system.

Enterprises, too, must undergo a process of renewal that will change corporate frameworks and processes into forms compatible with the environment in the recycling-based society. This will require not only the consistent implementation of new basic environmental technologies but also revolutionary reforms and advances. Here, we recognize the need to go beyond the conventional approach of making piecemeal improvements to each of the individual processes involved, and to adopt instead a holistic, integrated or systematic approach. Mitsubishi Electric uses the acronym MET as a keyword in its efforts to develop comprehensive environmental technologies, adopting a two-pronged approach embracing both products and manufacturing processes. MET stands for materials (the effective use of material resources), energy (the efficient use of energy resources) and toxicity (eliminating the threat posed to the environment by toxic substances).

In the first year of the new century, the Mitsubishi Electric Group's corporate statement is "Changes for the Better." The group's commitment is to exploit its outstanding technologies and creative strengths to make a wonderful future. ❑

Susumu Hoshinouchi is with the Corporate Environmental Management Planning Department.

A Review of R&D in Environmental Issues

*by Fumiaki Baba**

Sustainable development is essential for the recycling-based society of the 21st century, in which resource and energy conservation are carried out on an unprecedented scale. The Mitsubishi Electric Corporation is conducting research and development in the four areas of environmental creation, environmental support, environmental harmony and recycling, aimed at "co-creating" [1] the recycling-based society at the heart of the company's environmental philosophy. Highlights of these R&D activities are introduced here.

Environmental Creation

Promoting energy saving and introducing clean energy are important ways of reducing so-called greenhouse-gas emissions in order to prevent global warming. At COP3, the conference on global warming held in Kyoto in December 1997, Japan made an international commitment to reduce carbon dioxide emissions by the year 2010 to six percent below 1990 levels. Systems that generate electrical power from new energy sources and energy load-leveling systems hold out the promise of providing stable energy supplies while they protect the environment. Clean-energy fuel cells, using hydrogen fuel and producing no harmful waste material, along with power-storage systems using rechargeable batteries that charge and discharge with high efficiency, will be important as decentralized power supplies, and are the object of intensive R&D by Mitsubishi Electric. The use of these decentralized power supplies will have a major effect on reducing carbon dioxide emissions by improving the efficiency of electric power generation and transmission. Batteries for power storage use make it possible to implement demand-side management, investing in power generating facilities based on average demand, and operating the facilities at fixed output levels regardless of load fluctuations.

Fuel cells have great potential as decentralized power supplies serving the local community, as household power supplies, and for powering electrical automobiles. Among the most promising of these are polymer electrolyte fuel cells (PEFC), which are well on the way to achieving practical applicability for use in small buildings, homes, and electric vehicles. In fiscal 1996, the corporation began development of a 10kW portable generator fueled by methanol, and in 2000 produced a prototype 10kW portable generation system and tested it in automobiles. As a household PEFC the company developed an original 1kW fuel cell with natural gas reformer. This is now in test operation in preparation for a practical household PEFC system (see Fig. 1).

In the area of rechargeable batteries, Mitsubishi Electric is developing batteries for use on the move, targeted specifically at electric vehicles. R&D is aimed at developing the key core technologies to achieving practical use of large-scale lithium-ion batteries, including improved safety, new electrode materials, and at simulating battery characteristics. Already, a 3kWh module has been developed with energy density of 140Wh/kg and power density of 770W/kg.

In R&D aimed at energy saving, Mitsubishi Electric is carrying out comprehensive development of new materials applications, inverter technology, sensing and control technology, reducing standby power use, high-efficiency motors and other core technologies. The goal is to develop total energy-saving systems.

Environmental Support (environmental technology for the 21st century)

Public infrastructure systems and production systems in the 21st century are destined for transformation to a recycling-based society and zero emissions, as illustrated in Fig. 2. Environmental R&D at Mitsubishi Electric is focusing on technologies that will make possible a new kind of society, one that is able to support an abundant and convenient lifestyle while preserving the environment, as well as technologies for building zero-emission clean factories in harmony with the environment.

An important theme for the 21st century is how to maintain a sound water environment. Taking advantage of the strong oxidizing power of ozone, the corporation's researchers are developing technologies and equipment for generating high concentrations of ozone to remove toxins, odors and coloration from water and wastewater and to break down endocrine disrupters into harmless substances. Using hydrogen peroxide in addition to ozone, they are

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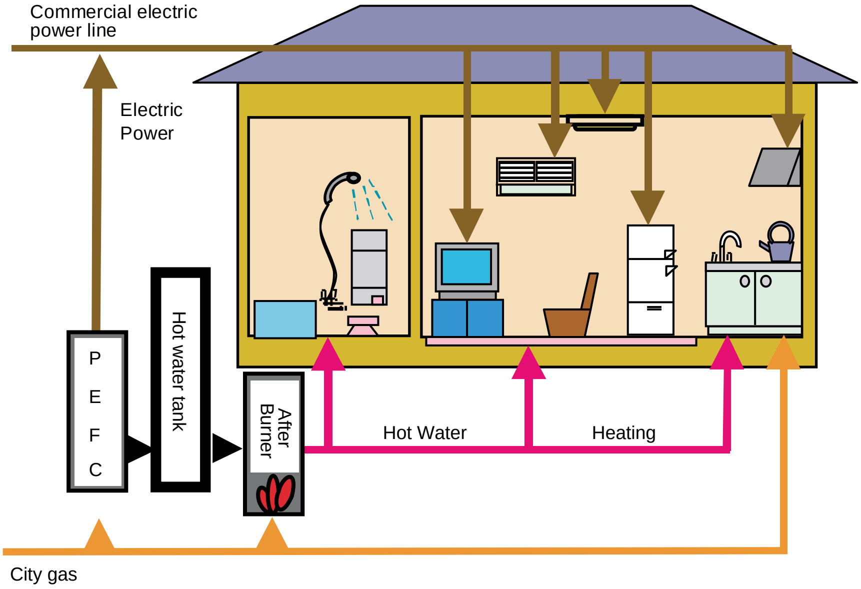

Fig. 1 Installation of a home PEFC power supply

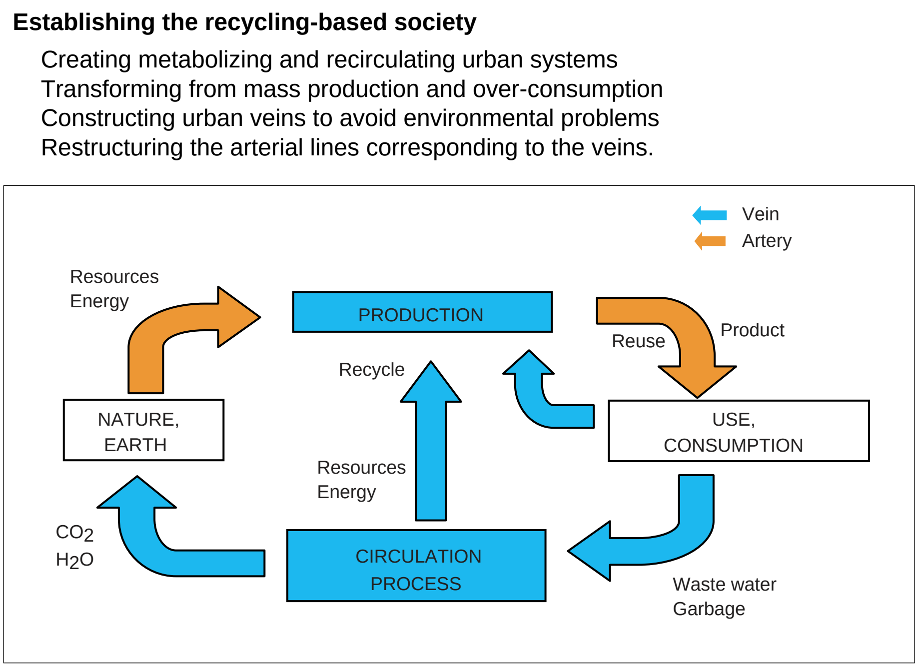

Fig. 2 Recycling-based society of the 21st century

also developing ways of promoting oxidation to decompose harmful substances that have hitherto resisted breakdown. This technology is applicable to water recycling systems that remove organic substances from wastewater.

The problem of eutrophication, caused by nitrogen and phosphorus in wastewater treatment plants, is being tackled by developing highly accurate techniques for monitoring ammonia and phosphate levels. The corporation has also developed algorithms that are able to calculate control settings precisely, using neural networks, to implement systems that operate on the minimum necessary energy. To combat air pollution, our researchers are developing technology that makes use of nitrogen radicals to break down concentrated oxides of nitrogen into nitrogen and oxygen.

Environmental Harmony

A major part of creating a recycling-based society consists of developing products specifically with environmental and resource conservation in mind. The Mitsubishi Electric Group is carrying out environmental planning, setting targets for environmental activities on the basic theme of MET (Material: using resources effectively; Energy: using energy efficiently; Toxic: preventing pollution due to the release of harmful materials). To realize zero-emission factories, on-going R&D is being directed at achieving loss-free and waste-free manufacturing processes.

In semiconductor production, processes such as washing, photoresist removal, development and surface improving typically involve the use of strong chemicals such as organic solvents, concentrated acids and highly alkaline solutions. Some processes today also use substances such as fluorides and heavy metal aqueous solutions, which impose a heavy burden on the environment.

The corporation has developed a system that uses ozone water in place of toxic substances in processes that require chemical solutions, and has applied this technology to equipment that removes photoresist from liquid crystal display elements, expanding environmentally friendly wet processes in the semiconductor industry. In addition to resist removal, ozone water is applicable to processes like those shown in Fig. 3, replacing harmful chemicals now used to wash high-precision parts or for surface improvement, etc.

Semiconductor manufacturing processes also make heavy use of perfluorocarbons (PFCs) such as CF_4 and C_2F_6. Mitsubishi Electric is developing equipment that uses high-pressure plasma to break down PFCs into hydrofluoric acid (recoverable) and

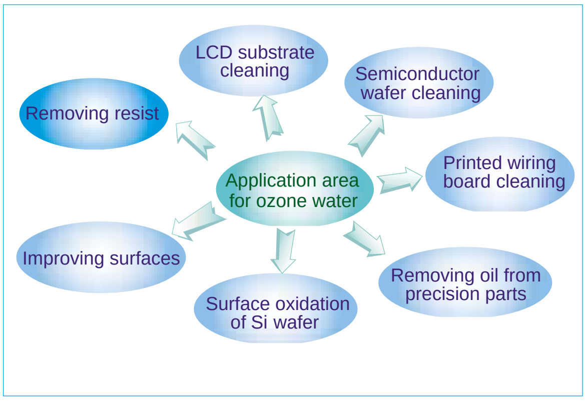

Fig. 3 Applications of ozone water

CO_2 in order to protect the ozone layer from further destruction by these substances.

Fig. 4 shows how Mitsubishi Electric is working to make plastics into eco-materials. Applying life cycle assessment (LCA), the corporation is obtaining quantitative measurements of environmental impact throughout the life cycle of products, from manufacturing through transportation, use and disposal, and is promoting activities to minimize this impact over the entire life cycle.

Since the corporation's electrical products are used all over the world, they must conform to regulations on toxic substances not just in Japan but also in each country where they are sold.

Alternative technologies are being developed to reduce the use of lead and other heavy metals and of halogen flame retardants. In order to avoid toxicity, it is important to be able to analyze very small trace amounts. The corporation is developing technologies that will make possible ultra-trace analysis, at sensitivities higher than those required for analyzing very minute amounts. To this end, the concentration techniques and contamination-free analysis techniques used in clean rooms are being applied.

Recycling

A new law mandating the recycling of specified home appliances took effect in Japan in April 2001. It requires the recycling (removing parts and materials and reusing) of refrigerators, air conditioners, TVs and washing machines. Mitsubishi Electric is currently recycling materials such as metal and glass, for which recycling technology has already been established. As the regulations become stricter in the future, the law is expected to apply to a wider range of products and to require a higher recycling ratio. This means it is important to develop technologies for recycling the plastic materials used so widely in home appliances, especially general-purpose plastics such as polypropylene, high-impact polystyrene, and ABS resin (acrylonitrile-butadiene styrene ter-polymer).

Even with the most careful selection of recycled materials, however, it is difficult to avoid the presence of small amounts of contaminants. Mitsubishi Electric is carrying out development along two main fronts to counter this problem. One is in the area of materials improvement through compounding, such as by mixing in new material to offset the expected effects of contaminants, or by adding impact modifiers. The other is the development of sandwich molding techniques, using new material for the skin layer and recycled materials as the core.

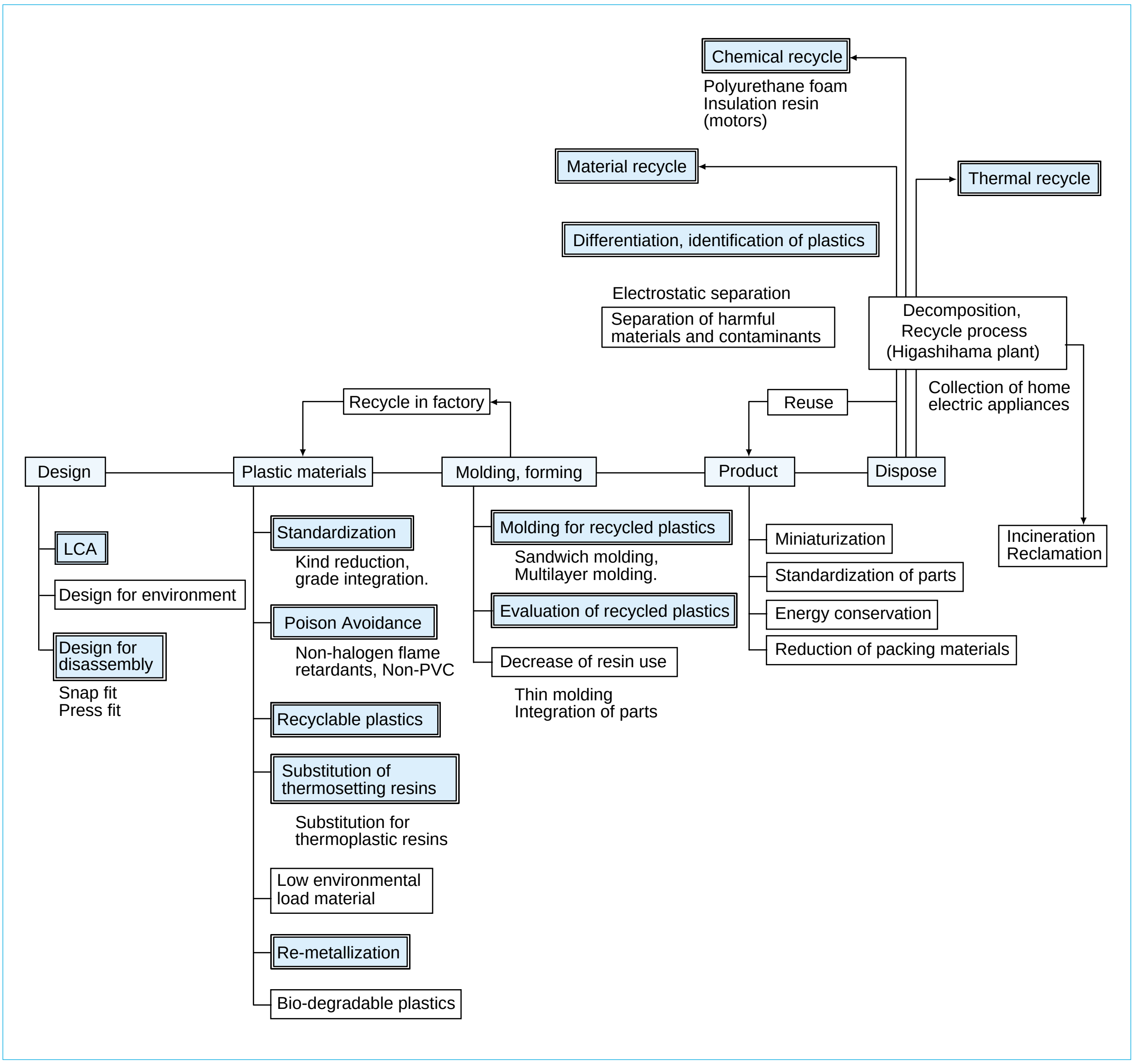

Fig. 4 Making plastics into eco-materials

The polyurethane foam used as an insulator in refrigerators cannot be recycled like ordinary plastics, since it undergoes chemical reaction and heat curing in the foaming process. Chemical recycling technology is therefore being developed to break it down into its raw material polyol. Similar chemical recycling techniques are being developed for use with electrical insulation resins in the motors used in nearly all household appliances.

The ease of recycling is largely determined at the product design stage. DFE (Design for the Environment) is a key concept for future product design, and the corporation is working to realize a more advanced product assessment, bringing together the company's expertise on environmental measures by drawing up in-house guidelines on environmentally suitable product design.

In setting development targets for core technologies needed to fulfill the 21st century mandate of lessening environmental impact (Reduce, Reuse, Recycle, Save energy, etc.), Mitsubishi Electric considers market, society and legal trends as it continues its ongoing efforts to integrate technologies and to meet its commitment to contribute toward the realization of a recycling-based society. ❑

Note: *The R&D projects introduced here on polymer electrolyte fuel cells, decentralized power-storage technology, and the basic technology for polyurethane recycling, were funded in part by the New Energy and Industrial Technology Development Organization (NEDO).*

Reference

[1] Mitsubishi Electric Corporation, Environmental Sustainability Report 2000, 2001.

Technology for Recycling Plastic Materials

by Osamu Murakami*

A sandwich injection-molding process stacking new and recycled materials is being developed in order to establish plastic material recycling technology. The thicker the core of the "sandwich," made of recycled material, the larger the amount of recycled material that can be used with this method. A key to success is controlling the viscosity of the new and recycled material in the molding process.

Difficulties with Recycling Plastics

Methods of recycling plastic, summarized in Table 1, can be classified broadly into materials recycling, chemical recycling, thermal recycling, or feedstock recycling. Thermal and feedstock recycling are consumptive processes (i.e., they turn the recycled material into energy rather than into usable materials), and thus do not conform to the reuse-ratio requirement of the Japanese law on recycling appliances. Materials recycling and chemical recycling, on the other hand, are closer to the ideal in that they produce materials that can be reused. Of the two, materials recycling is especially effective because it uses less energy and has a smaller environmental impact than chemical recycling.

The issues affecting increases in the amount of recycled material used are the properties of the recycled material, the presence of contaminants, the properties of mixed waste plastics, and process development.

The appliances to which the present recycling law applies have the material composition shown in Fig. 1, while Fig. 2 shows their typical plastic materials composition. Refrigerators and washing machines tend to use a high percentage of plastic materials, over 20 percent of the total composition. By type of plastic used, washing machines use polypropylene (PP), air conditioners use PP and polystyrene (PS), and TVs use PS and PVC (polyvinyl chloride). Refrigerators use more different types of plastics than other appliances, including PS, acrylonitrile butadiene styrene (ABS) resins, and PVC in addition to polyurethane foam. The last makes up around half of the plastic used in refrigerators but is not suitable for materials recycling, making it important to achieve a high degree of accuracy in disassembling refrigerators and separating their materials. A chemical recycling method that can reduce polyurethane foam to its raw material is being developed in cooperation with materials manufacturers.

Table 1 Recycling Methods for Waste Plastics

Recycling methods	Description
Materials recycling	Using discarded plastic as the raw material for new moldings.
Thermal recycling	Burning waste plastic and recovering the thermal energy.
Feedstock recycling	Breaking down waste plastic thermally or chemically for use as blast furnace reductant, etc.
Chemical recycling	Breaking down waste plastic thermally or chemically for use as petrochemical raw materials.

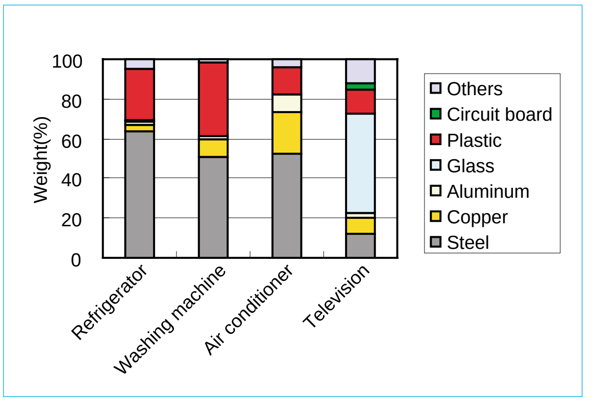

Fig. 1 Material composition of home electrical appliances

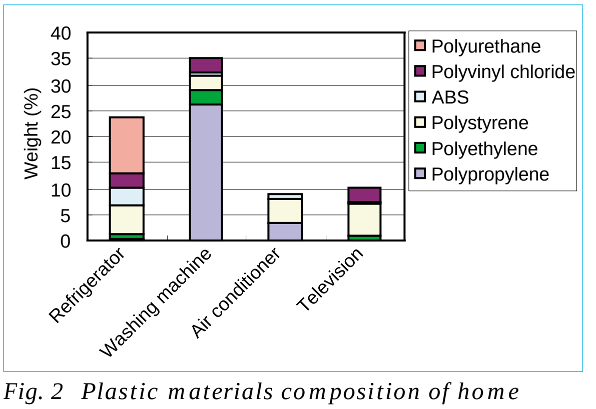

Fig. 2 Plastic materials composition of home electrical applicances

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Table 2 compares the mechanical properties of injection-molded parts, made of recycled material recovered from an electrical appliance disposed of after actual use in a household and disassembled, separated, washed and pulverized, with those of similar parts made of all-new materials. The mechanical strength of the parts made from recycled material, with the exception of impact-absorption energy, is not much below that of the new materials and undergoes little deterioration with time.

The polystyrene recovered from an air conditioner is contaminated by printing over its entire surface, and has only around a tenth of the impact absorption energy of its new counterpart. Many of the recycled plastics used up to now have been waste materials discarded by the factory as leftovers, etc., from the molding process, which are clean and of a uniform quality grade. In contrast, the poorer impact strength of recycled materials recovered from actual pulverized household appliances is due not so much to any degradation of the materials themselves as to the presence of contaminants.

An effective way of improving the quality of recycled materials contaminated by other admixtured materials is by compounding them with new materials. Fig. 3 shows the change in impact strength when polystyrene with printed material on it from a room air conditioner is compounded with new material. If the percentage of recycled material in the mix is no more than 30 percent, degradation of impact strength ceases to be a problem.

Because of the different types of plastic used in household appliances, techniques for accurately separating the different materials recovered from appliances are important. It will be some time, however, before such technology becomes practical. In the meantime, ways of recycling various plastic mixtures are needed. The compatibility of different mixtures of plastics is shown in Table 3, where it is clear that some combinations are quite incompatible. In Fig. 4, different ratios of ABS resin and polystyrene in recycled material recovered and processed at the recycling plant of Green Cycle Systems Corporation vary in impact strength as shown.

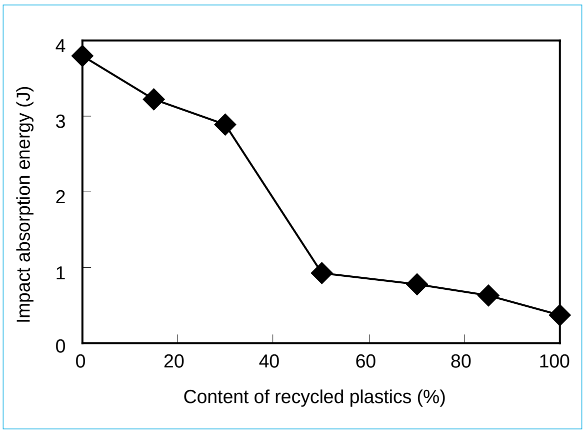

Fig. 3 Impact strength of injection moldings made from new polystyrene mixed with recycled polystyrene (recovered from air conditioner and including printing materials)

When just five percent polystyrene is mixed with ABS, whether in recycled or new material, the impact strength drops to one half; and at a level of 10 percent the strength degrades sharply to one tenth that of the original. A transmission electron microscopy (TEM) photomicrograph of a cross-section of this material (10% PS) in Fig. 5

Table 3 Compatibility of Plastics

	PP	PS	ABS	PVC
PP	O	O	X	X
PS	O	O	X	X
ABS	X	X	O	O
PVC	X	X	O	O

O: Good compatibility, X: Poor compatibility

Table 2 Mechanical Properties of Waste Plastics

			Tensile strength (MPa)	Bending strength (MPa)	Bending modulus (GPa)	Impact absorption energy (J)
Air conditioner	Polystyrene	Recycle material (Printed)	32.8	72.7	2.74	0.3
		New material	30.9	64.8	2.54	3.8
Refrigerator	Polypropylene	Recycle material	27.8	48.3	2.09	14.2
		New material	27.8	47.1	2.05	16.3
Television	Polystyrene	Recycle material	26.6	58.6	2.46	4.5
		New material	24.6	51.0	2.37	4.6

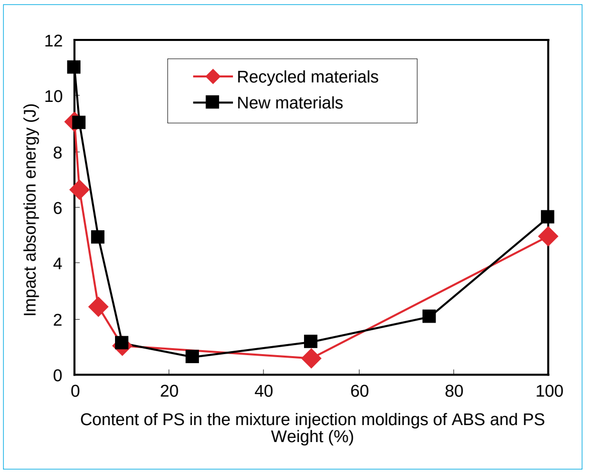

Fig. 4 Polystyrene content of mixed injection moldings made of ABS resin and polystyrene

shows that the ABS and PS completely fail to blend, with the PS itself acting as a contaminant and causing cracks to appear between the ABS and PS layers that result in poor impact strength.

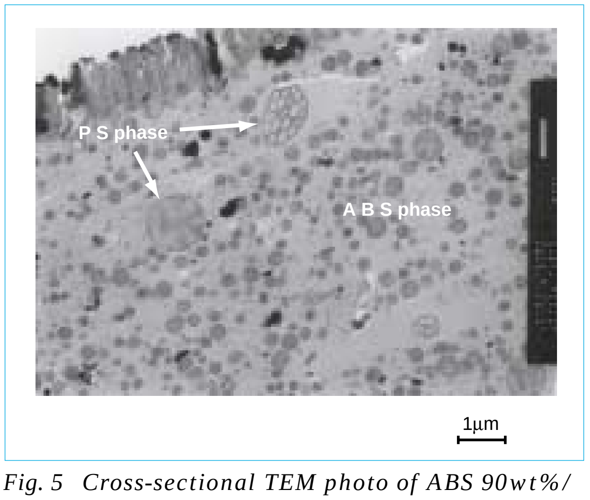

Fig. 5 Cross-sectional TEM photo of ABS 90wt%/ PS 10wt% mixed injection molding

Technology for Recycling Plastic Waste Materials

A SANDWICH INJECTION-MOLDING PROCESS USING WASTE PLASTIC. Materials modification is one approach to expanding the use of recycled materials, but also important is process development. One promising method of the latter type is multi-layering. Sandwich injection molding is a multi-layering technique applied to one of the most common ways of producing plastic parts, injection molding.

Sandwich injection molding forms a multi-layer structure by simultaneously injection molding materials with different properties. It envelops the recycled material in new material, forming a three-layer structure consisting of skin (new)/core (recycled)/skin (new) as in Fig. 6. Since the skin of new material completely encapsulates the recycled material, the esthetic problems caused by contaminating materials or dirt and discoloration are solved.

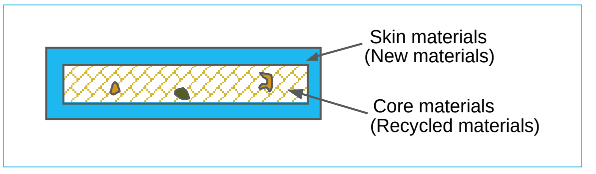

Fig. 6 Cross-sectional schematic drawing of sandwich molding

An example of the molding process is shown in Fig. 7. Using an injection-molding machine with two cylinders converging within one nozzle, first the skin material, then the core material and finally once again the skin material are injected into the mold cavity in rapid succession to form the three layers.

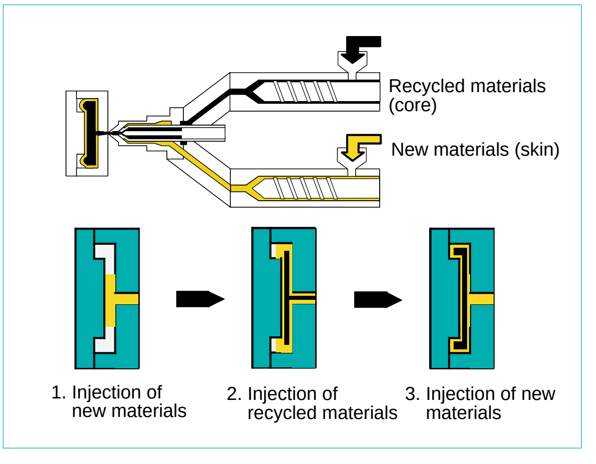

Fig. 7 Process of sandwich injection molding

To increase the amount of recycled material used, it is important that the core be made thick and constitute as large a percentage of the total as practical. At the same time, application to electrical products requires a thin sandwich structure with a plate thickness of around 2mm. The layer structure of sandwich-molded parts depends on several factors, including the material properties, the molding conditions, and the shape of the part.

The biggest factor affecting the amount of core material content is the viscosity of the core and skin materials. Fig. 8 shows the relation between the thickness and content of the core material

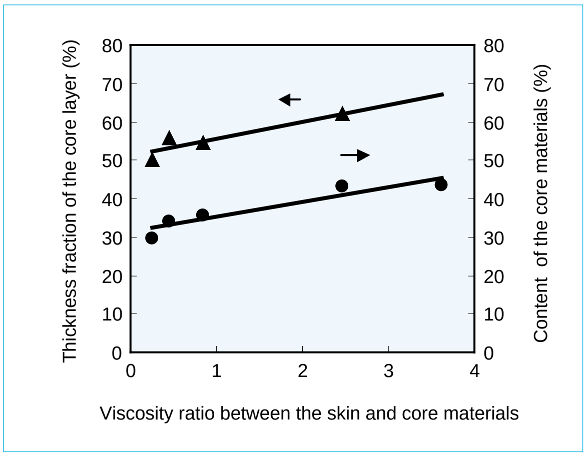

Fig. 8 Relationship between the thickness and content of the core materials and viscosity ratio (difference of viscosity between skin and core materials)

and the viscosity ratio of the skin and core materials (skin material viscosity/core material viscosity). By controlling this factor so that the skin material viscosity is lower than the core material viscosity, the core layer can be made thick and the skin layer thin, with a core material content of 40 percent or more.

MATERIAL MODIFICATION TECHNOLOGY. By using a functional material as the skin layer with the sandwich injection-molding method, molded plastic parts using recycled material can be produced with high added value. For example, using a recycled material combining ABS and PS with relatively poor impact strength as the core, with a new ABS material with high impact strength as the skin layer, the resulting part has much higher impact strength as well as a more pleasing appearance than an ordinary molded part using only recycled material. Impact strength can be improved even further by the use of an additive designed to raise the impact strength of compound recycled materials (see Fig. 9).

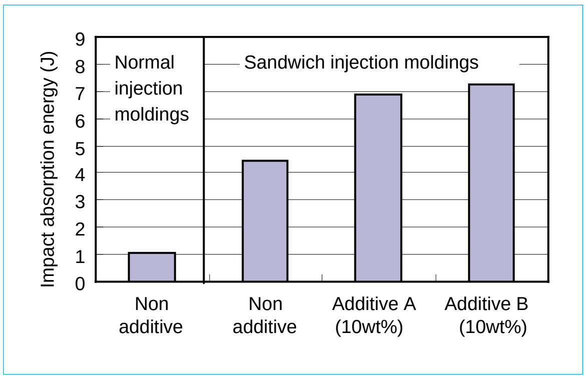

Fig. 9 Impact stength of injection moldings containing additives

Fig. 10 shows a prototype sandwich injection molding 2mm thick, and a close-up cross-sectional photo of the layers. The core layer includes complex portions of the object as well as the corner areas and makes up more than 60 percent of the thickness.

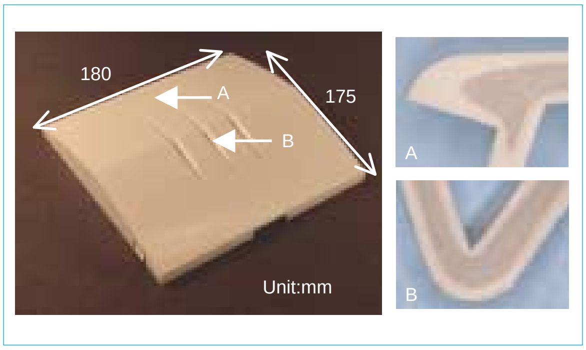

Fig. 10 Sandwich injection molding using recycled materials for the core (appearance and cross-section view)

The remaining issues to be resolved for practical implementation of this technology are reductions in the product cost and obtaining a stable supply of recycled materials. ❑

Photoresist Removal for LCD Production Using High Ozone Concentrations

by Hideo Horibe & Seiji Noda

We have developed photoresist removal equipment that uses high concentrations of ozone and controls the amount of water supplied with the ozone to achieve a removal rate approximately an order of magnitude faster than with conventional ozone-based technology. Environmental impact is reduced to less than one tenth, and running costs to less than one fifth of the conventional methods that use costly chemical solvents harmful to the environment. The ozone water also cleans the substrate, eliminating the need for a separate substrate washing process and reducing the equipment footprint by half.

Cost and Environmental Issues with Current Photoresist Removal Technologies

The removal of photoresist material from substrates in the semiconductor manufacturing process conventionally makes use of single-substrate oxygen plasma ashing[1] or a batch process using sulfuric acid/hydrogen peroxide/deionized water (SPM). In LCD production, the substrate size is larger than that in semiconductor manufacturing and too large for uniform resist removal to be achieved with ashing, making it necessary to use chemical stripping. A chemical solvent commonly used for LCD resist removal is called solution 106 (monoethanol amine + dimethyl sulfoxide).[2] The main issues here are the amount of resist removal liquid used and the removal of resist that has gone through the dry etching process. The first of these is a major issue not only because of the high running cost of using expensive chemicals but also from the standpoint of working-environment safety. The second issue is of growing importance now that facilities using RIE (reactive ion etching) as the dry etching method are on the increase. RIE causes the resist surface to become less malleable, requiring some means of making the resist more easily removable.

Using ozone water instead of chemical solvents for resist removal has the advantage of reducing environmental impact as well as the amount of water necessary for chemical washing.[3] Using a high ozone concentration at or below a processing temperature of 100°C, a removal rate of 0.1µm/minute is achieved.[3] By further rotating the processed substrate at high speed (250 to 1,000 rpm), the dispersion rate of the ozone (in water) supplied to the substrate is improved, further doubling the removal rate.[4] This is still not fast enough, however, to meet the throughput needs of today's LCD production lines. Moreover, the large size of the LCD substrate requires a special mechanism for high-speed rotation, adding to the complexity of the equipment structure.

Development of a Photoresist Removal Method Using Moist Ozone Gas

CONDITIONS FOR EVALUATING RESIST REMOVAL BY MOIST OZONE GAS. Our research team built prototype resist removal equipment that transports single LCD substrates and we studied its performance. We used two samples for the tests, one consisting of cresol novolac positive photoresist applied to the entire surface of a glass substrate (520 by 410mm) at an initial thickness of 1.45µm, and the other an actual device substrate (with an initial thickness of 1.2µm and coating ratio of around three percent).

The resist removal equipment (7,000 by 1,500 by 1,800mm high) consists of a loader section, hot-air chamber, ozone-processing section, rinsing and drying section, and unloading section. The substrate is fed in at the loader end and heated in the hot-air chamber to the required temperature. In the ozone-processing section, ozone gas moisturized by steam flows onto the resist on the substrate. In the rinsing section, the resist is removed by a hot-water shower (50°C) and then air-dried. After this series of processes had been repeated several times, the resist film thickness was measured at between three and six places on the substrate surface with a contact-type surface profiler (Dektak 3030) to determine the resist removal rate. The transport speed of the substrate was controlled at 1.5m/minute, and the substrate was kept in the ozone-processing section for a period of one minute.

**Hideo Horibe and Seiji Noda are with Advanced Technology R&D Center.*

RELATION OF RESIST REMOVAL RATE TO PROCESSING TEMPERATURE. Resist removal rate was evaluated at an ozone-gas density of 230g/m³ (standard state) and substrate temperature conditions of 53.5°C, 72°C and 83°C. At a substrate temperature of 53.5°C, the resist thickness of the fully coated test substrate varied with ozone processing time as shown in Fig. 1. Resist thickness was reduced in proportion to the processing time, and an average removal rate of 0.47µm/minute was calculated from that trend. Since the resist removal rate is uniform along the direction of resist thickness (equivalent to processing time), the reaction of resist to ozone proceeds sequentially from the top of the resist film and can be expected to produce a similar reaction along the thickness direction. Raising the substrate temperature to 72°C and 83°C caused the average removal rate to increase to 0.51 and 0.59µm/minute, respectively.

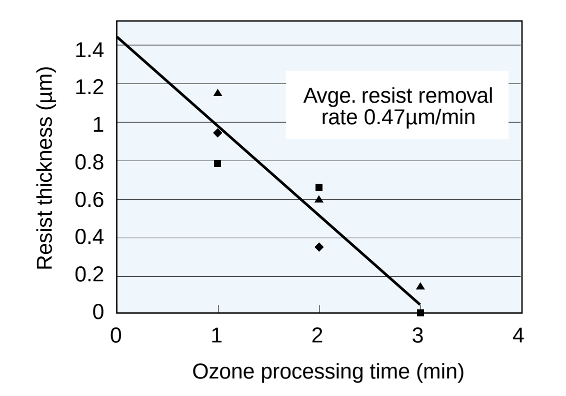

Fig. 1 Relationship of resist thickness to ozone processing time with initial thickness of the resist 1.45µm, substrate temperature 53.5°C, ozone concentration 230g/m³, and ozone flow rate 12.5 liters/min.

RELATION OF RESIST REMOVAL TO OZONE CONCENTRATION AND SUBSTRATE EVALUATION. At a substrate temperature of 72°C, the rate of decrease in resist thickness on the fully coated test substrate was measured while the ozone concentration was varied between 90 and 230g/m³ with the results as shown in Fig. 2. This indicates an increase in average resist removal rate in proportion to ozone concentration, with an overall speed increase of 1.8 times from the lowest to highest concentrations. In other words, the higher the ozone concentration, the faster is the rate at which the resist layer is removed.

Next, the actual device substrate was processed at a substrate temperature of 83°C. Resist was removed at a high rate of 1.2 to 1.4µm/minute, fast enough to enable complete removal of a 1.2µm resist within one minute. The reason the actual device substrate showed a faster resist removal rate than the fully coated test substrate is probably due to the smaller resist coating ratio of the device substrate. Inspection of the substrate with an optical scanning microscope after processing revealed a clean surface free even of micron-order residue. The device properties were also confirmed to be normal.

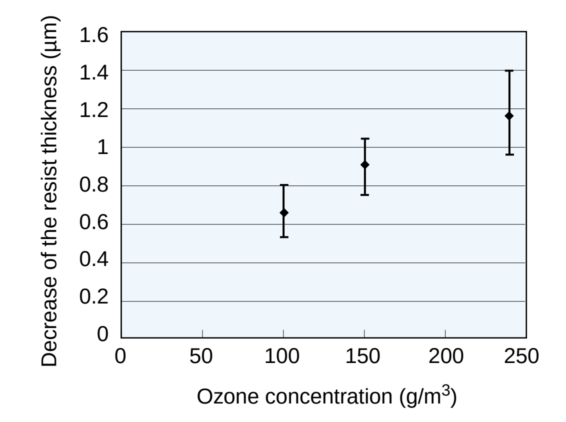

Fig. 2 Relationship of ozone concentration to decrease in resist thickness with initial thickness of the resist 1.45µm, substrate temperature 73°C, ozone processing time 2 min. and ozone flow rate 12.5 liters/min.

RESIST REMOVAL PERFORMANCE OF MOIST OZONE GAS VS OZONE WATER. The photoresist removal performance of moist ozone gas and that of ozone water were compared. The removal rate using moist ozone gas at a concentration of 230g/m³ varies with temperature as shown in Fig. 3. (Here it is assumed that the ozone gas used in ozone water manufacture has a steady concentration of 230g/m³ and that the ozone water concentration has reached saturation.) In the case of ozone

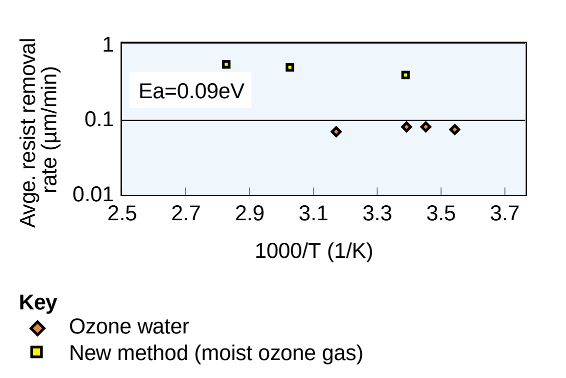

Fig. 3 Influence of substrate temperature on resist removal rate with an ozone concentration of 230g/m³ and the initial thickness of the resist 1.45µm

water, the reaction between ozone and resist increases with a rise in temperature, but at the same time the solubility of ozone gas in water decreases, causing the resist removal rate to peak at 0.1μm/minute. Using moist ozone gas, on the other hand, a speed more than four times that of ozone water is achieved. Moreover, based on the Arrhenius activation law, the apparent active energy is approximately 0.09eV, with a loose dependency on temperature.

Normally ozone gas does not dissolve readily in water (dispersion coefficient of 0.25 at room temperature) and disperses slowly in water (its dispersion coefficient in liquid is approximately 10^{-5} that in gas). The reason for the fast resist removal rate by the moist ozone gas method is first of all that the ozone gas does not dissolve in water and is fed to the substrate without a drop in concentration. Second, the water content of moist ozone gas is small and the rate of ozone gas dispersion on the substrate surface is relatively fast. With ozone gas alone, on the other hand, it has already been reported that near room temperature the oxidizing reaction of the resist does not progress and it is not broken down.[5] Accordingly, water is required for oxidization of the resist by ozone. In this moist ozone gas method, it was possible to raise the rate of resist removal by supplying a small amount of water along with the ozone gas.[6]

Performance of the Resist Removal Equipment

RUNNING COSTS. Around 80 percent of the running cost of conventional equipment for removing photoresist used in LCD production (for a substrate size of 520 by 410mm) is the cost of the chemical solvents. The resist removal equipment developed in this project (Fig. 4) does not require expensive chemicals and therefore reduces the running cost to approximately one fifth that of conventional equipment (Fig. 5). Generating ozone from oxygen does incur new running costs for gas and electricity, but these are much lower than the cost of the liquid chemicals used conventionally, resulting in a substantial cost reduction overall.

ENVIRONMENTAL IMPACT. As an indicator of environmental impact we looked at the total organic carbon (TOC) content of waste liquid. In the case of resist removal using chemical solvents, potential sources of TOC are first, the resist removal chemicals, and second, the photoresist itself. Of these, the resist removal chemicals account for 93 percent of the TOC. Since the newly developed equipment breaks down the photoresist without using chemical solvents, the only source of TOC in the waste liquid is the dissolved photoresist. Accordingly, the environmental impact is reduced to approximately a tenth of that from conventional processing.

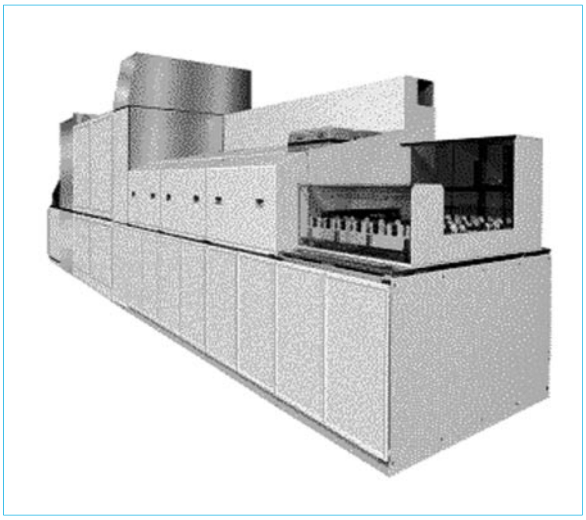

Fig. 4 Equipment using high-concentration ozone for resist removal in LCD production

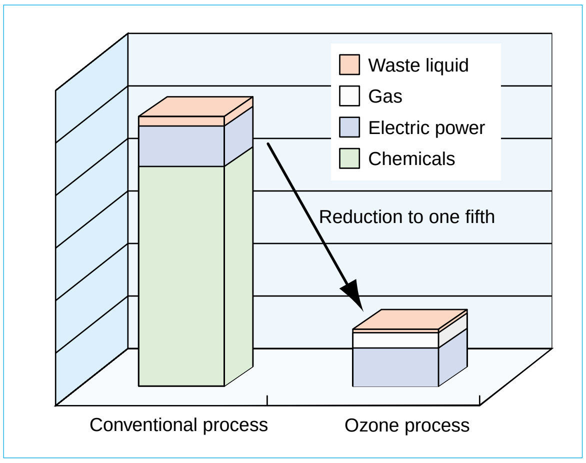

Fig. 5 Comparison of the running costs of ozone and conventional processes

EQUIPMENT FOOTPRINT. Resist removal using chemical solvents tends to leave small amounts of organic residue on the substrate, requiring additional equipment for washing and treatment with ultraviolet light (Fig. 6). Ozone has powerful oxidizing ability, and ozonated water is a recognized substitute for SPM as an agent for removing organic residues.[7] When ozone is used for resist removal in the moist ozone gas method, it has the same washing effectiveness as ozonated water, eliminating the need for separate

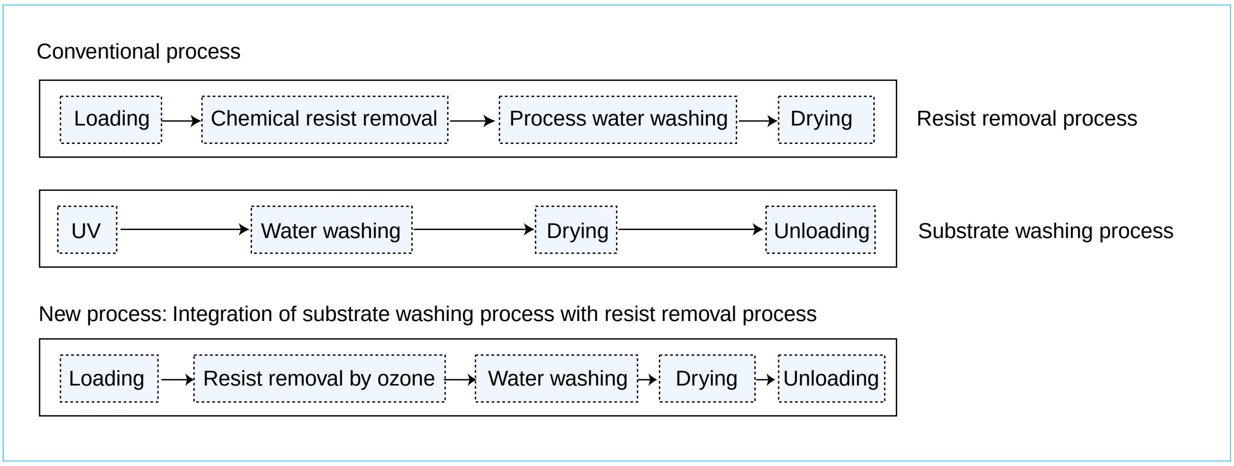

Fig. 6 Comparison of the conventional process with the newly developed process

washing equipment to clean the substrate after processing. As a result, the equipment footprint is reduced by half.

In the future we plan to apply this technology not only to the LCD production process but also to resist removal in semiconductor manufacturing and to the wafer-washing process. ❑

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Ground-Water Purification by the Ozone-Hydrogen Peroxide Method

*by Seiji Furukawa and Nozomu Yasunaga**

Mitsubishi Electric Corporation has developed a high-speed, highly-efficient reactor to instantaneously decompose organic chlorides in ground water using the powerful oxidation effect of OH radicals generated from hydrogen peroxide and ozone. This article describes the results of computer simulation analyses and of validation tests performed at a contaminated site and reports on the effectiveness of a ground-water purification device incorporating the reactor.

High-Speed/High-Efficiency Reactor for an Ozone-Hydrogen Peroxide Process

Because trichloroethylene and cis-1,2-dichloroethylene and other organic chlorides are not only extremely toxic but are difficult to remove biologically, once these compounds have seeped into ground water, the contamination endures for extended periods of time. Despite the ban on discharging these substances into the ground that has been in effect since 1989 in Japan, contamination of the order of one mg/L to tens of mg/L of these organic chlorides is still reported every year.

Until now, the process used to purify ground water has been typically to aerate the ground water and absorb the aerated organic chlorides using activated carbon. However, in this method not only is it necessary to regenerate the activated carbon after use, but the aeration process produces a great deal of noise, making it less-than-ideal for a contaminated site.

The corporation has developed a high-speed, highly efficient reactor for instantaneously decomposing organic chlorides in ground water using the strong oxidizing effect of OH radicals generated from hydrogen peroxide and ozone. This ejector-type reactor, as shown in Fig. 1, generates large volumes of high-density OH radicals through the injection of ozone. This makes it possible to decompose organic chlorides extremely quickly, in the order of seconds.

The mechanisms for generating and reacting the OH radicals are extremely complex, and in the series of reactions the OH radicals tend to decompose compounds other than those useful in processing materials, such as ozone and other radicals. The corporation is also engaged in developing new reactors that will reduce this kind of inefficiency.[1]

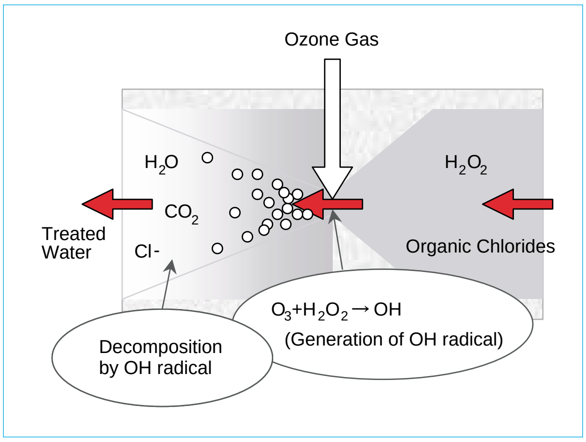

Fig. 1 Ejector-type reactor for the ozone-hydrogen peroxide method

Simulation Analysis of Trichloroethylene Decomposition

A computer simulation was used to investigate the operating conditions that would decompose the maximum amount of trichloroethylene while suppressing, as much as possible, the amount that is stripped. In the simulation, modeling assumed that the trichloroethylene stripping process was incorporated into the existing reaction model for the ozone-hydrogen peroxide method previously reported.[2] The distribution coefficient established by V. Linek *et al*[3] was used. The transfer speed constant from the liquid phase to the gas phase was found experimentally using batch experiments based on oxygen stripping. Table 1 shows the simulation conditions.

Table 1 Simulation Conditions

Ozone gas concentration (g/m^3)	0~100
Gas flow rate (L/min)	0.01~0.4
Liquid flow rate (L/min)	0.4
Initial trichloroethylene (mg/L)	10
Hydrogen peroxide dosage (mg/L)	1.25~2.5
Reactor volume (L)	1

*Seiji Furukawa and Nozomu Yasunaga are with the Advanced R&D Center, Environmental Technology and Systems Department.

Fig. 2 shows the results of the simulations. Fig. 2 (a) shows the amount of trichloroethylene decomposed, the amount of trichloroethylene stripped, and the concentration of the trichloroethylene in the processed water as a function of the ozone injection rate. The ratio of gas flow to fluid flow (G/L) was set at 0.5, and the ozone injection rate was varied by adjusting the ozone concentration.

We established that the amount of trichloroethylene decomposed could be increased, while suppressing the amount that was stripped, by increasing the ozone injection rate. In particular, with an ozone injection rate of 10mg/L (an ozone concentration of 20g/m^3), not only was the trichloroethylene in the influent completely decomposed but the amount stripped from the liquid phase to the gas phase was zero. In other words, even though the G/L ratio was large, increasing the concentration of the ozone supplied made it possible to decompose the trichloroethylene faster than it was stripped.

The implication of having to inject ozone at 10mg/L in order to completely decompose trichloroethylene at 10mg/L is that the trichloroethylene can be completely decomposed by the OH radicals as long as the ozone that is injected has at least the same concentration as the trichloroethylene in the untreated water.

On the other hand, Fig. 2 (b) shows the results of simulations when the ozone injection rate was held constant at 2.5mg/L and the G/L and supplied ozone concentration were varied. Here, the horizontal axis shows the gas/liquid (G/L) ratio. Note that lower G/L ratios correspond with higher ozone concentrations and vice versa.

It is evident that when the ozone injection rate is small in comparison with the trichloroethylene concentration in the untreated water, increasing the G/L ratio only increased the amount of trichloroethylene that was stripped without increasing the amount that was decomposed. This is because the rate at which trichloroethylene is stripped increases as the gas flow is increased, stripping any trichloroethylene not decomposed. From this, we conclude that the amount of trichloroethylene decomposed can be increased, while suppressing the amount stripped, by using high-concentration ozone with a low G/L ratio.

Validation Tests at a Contaminated Site

Validation tests were performed using purification equipment incorporating an ejector-style reactor at a contaminated site. Three wells with depths ranging between 3 and 18m were used to draw a total flow of 3m^3/h of water, which was supplied to the purification equipment. Table 2 shows the main operating conditions.

Table 2 Operating Conditions

Inflow rate (m^3/h)	3.0
Ozone gas concentration (g/m^3)	150
Gas flow rate (L/min)	0.4
Ozone injection rate (mg/L)	20
Hydrogen peroxide dosage (mg/L)	5.7

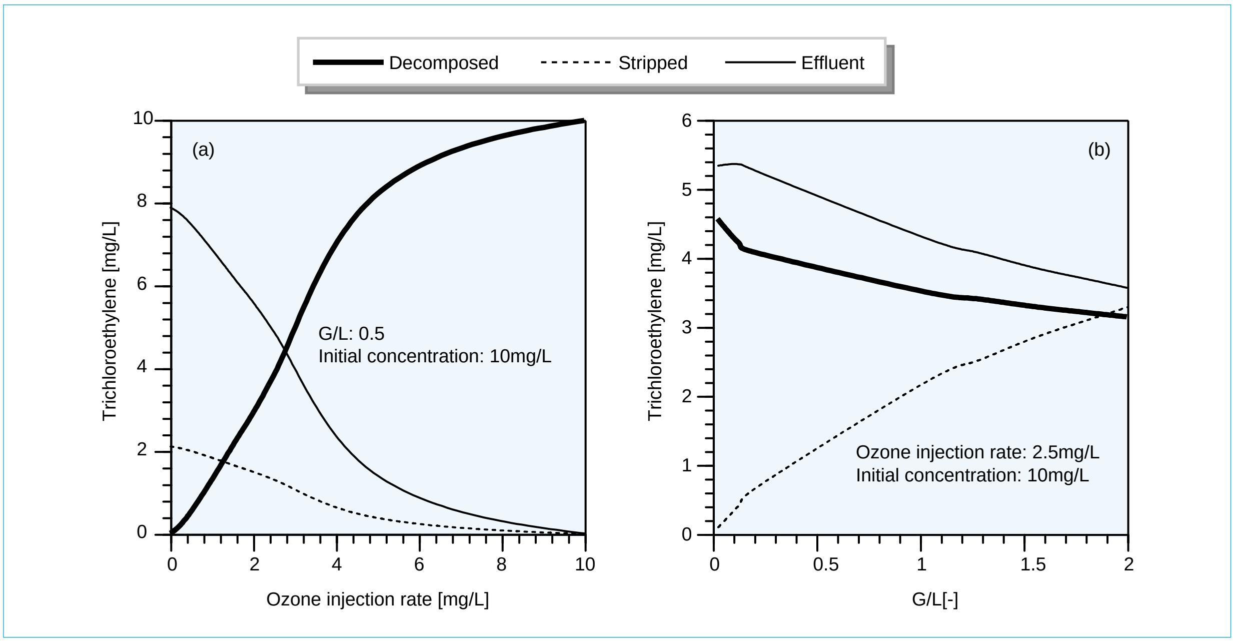

Fig. 2 Relationship between the amount of trichloroethylene decomposed and the amount stripped.

Fig. 3 is a graph of the densities of cis-1,2-dichloroethylene and of trichloroethylene in the water before and after treatment as a function of time. Initially, the untreated water contained 2.2mg/L of cis-1,2-dichloroethylene and 0.65mg/L of trichloroethylene; however, it was seen that these densities gradually declined during the purification process. After five months, the cis-1,2-dichloroethylene was reduced to 0.79mg/L, and the trichloroethylene was reduced to 0.2mg/L, about one third of their initial densities. Additionally, their densities in the treated water were lower than the environmental standards (0.04mg/L for cis-1,2-dichloroethylene and 0.03 mg/L for trichloroethylene) throughout the period of the experiment.

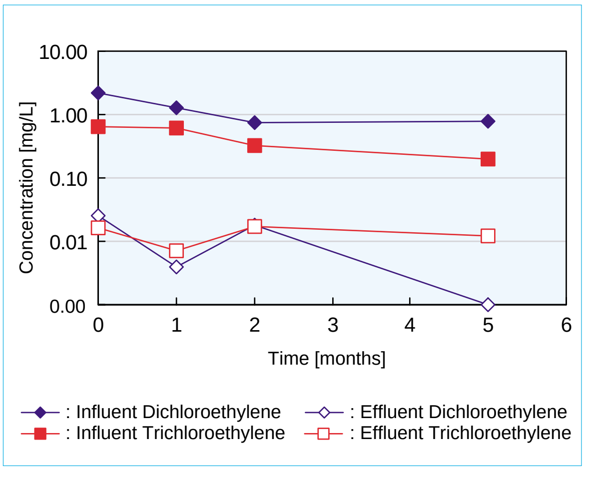

Fig. 3 Changes in the concentrations of di- and trichloroethylene

This purification equipment is extremely well suited as a future technology for groundwater purification. Mitsubishi Electric will be actively pursuing these possibilities in further development work. ❑

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Environmentally Friendly Product Strategies

*by Tetsuya Takahashi, Atsuhiro Yabu and Yasuto Iseki**

This article introduces the various guidelines applied consistently throughout Mitsubishi Electric Corporation in the design, development, manufacture and recycling of products.

DFE Guidelines

Using the opportunity presented by the enactment of the 1991 Law for Promotion of Utilization of Recyclable Resources, the corporation is implementing product assessments in all product categories. It is determined to accelerate environmental protection measures for products within a framework of implementing life cycle assessments (LCAs), using green procurement, etc., as set out in the corporation's Third Environmental Plan for the Environment announced in 1999, and in doing so has established fundamental guidelines for design for the environment (DFE), see Fig. 1.

The guidelines establish partnerships with government, green consumers, and other parties. These are as indispensable as the corporation's own efforts if a sustainable society is to be achieved. The corporation has established DFE and other activities for structuring a sustainable society by reducing the impact on the environment throughout entire product lifecycles.

To flesh out the concept, DFE guidelines were established in March 2000, and have been deployed and fully established throughout the corporation. These guidelines are intended to

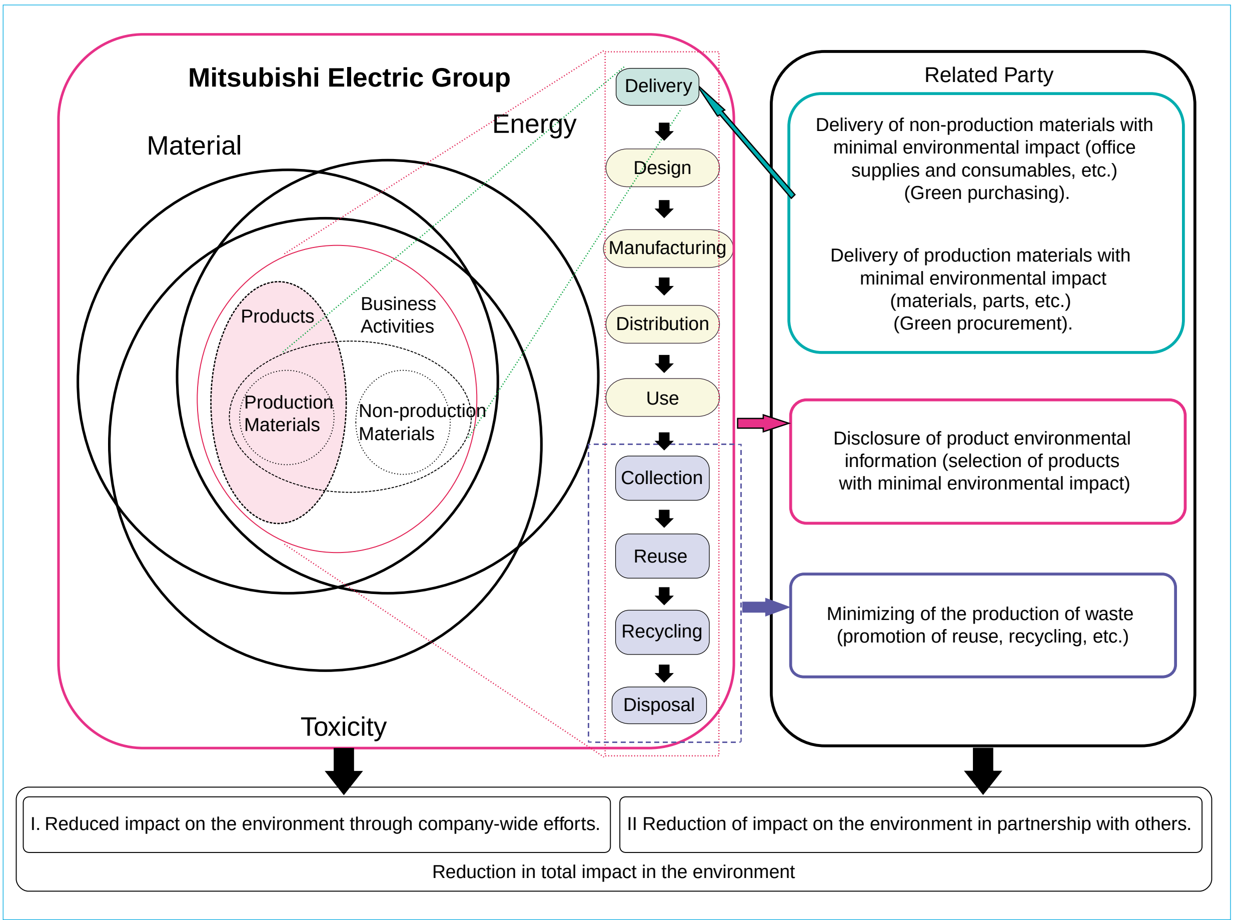

Fig. 1 The fundamental philosophy of DFE in the Mitsubishi Electric Group

*Tetsuya Takahashi is with the Environmental Protection Department and Atsuhiro Yabu and Yasuto Iseki are with the Home Appliances Recycling Business Development Office.

move from the assessments that were performed in the past, which focused on avoiding the generation of waste, to a next-generation assessment that evaluates quantitatively the three indices. Known as MET, they stand for Materials - the effective use of materials; Energy - the efficient use of energy; and Toxicity - the avoidance of releasing materials that pose a risk to the environment, and they apply to entire product lifecycles. There are 12 major categories of items evaluated in the assessments, extending to 45 mid-level evaluation topics.

Environmental EOL (End of Life) Considerations

Here we introduce Mitsubishi Electric's home-appliance recycling technology, particularly the processing performed at the corporation's Higashihama Recycling Center. As shown in Fig. 2, the flow at this plant begins with manual disassembly to separate critical parts in advance, followed by pulverization and recovery of marketable materials through a combination of mechanical and chemical separation processes. The kinds of parts subject to manual

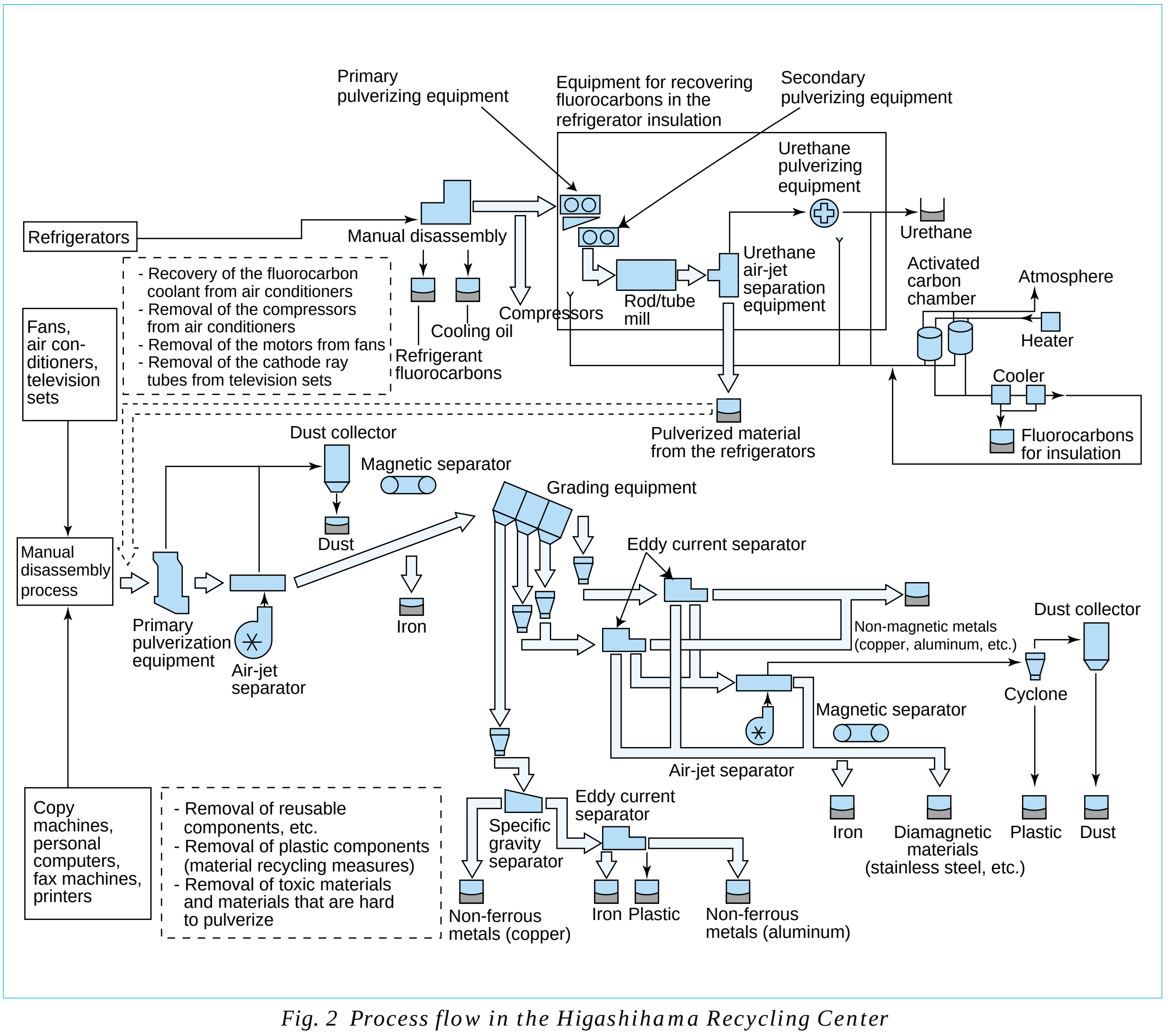

Fig. 2 Process flow in the Higashihama Recycling Center

disassembly, and the reasons for their selection, are as follows:

- Hard materials impervious to impact pulverization: for example, motors and compressors.
- Components having recoverable value: for example, cathode ray tubes, compressors, and motors.
- Components that are removed for environmental considerations: for example, fluorocarbon refrigerants and printed circuit boards.
- Components that would be damaging in subsequent processes: for example, oil, rubber magnets, glass, salt water.

The remaining materials after the manual disassembly process are fed into an impact-type pulverizer. The pulverized pieces are first subjected to magnetic sorting to recover large pieces of iron, and then the pieces are graded by size. Afterwards, the materials are separated into iron, copper, aluminum, plastic, diamagnetic materials, and dust, with the materials recovered in density separators, eddy current separators, magnetic separators, etc. There are no incineration or scrubbing processes in the pulverization/separation processes, but rather all processes take the environment into consideration, such as the equipment provided for recovering fluorocarbons in insulation from refrigerators, as discussed below.

The plastic recovered at this stage is a mixture of various types of plastic, copper wire, pulverized circuit boards and metal plating, and polyvinyl chlorides (from the electrical insulation on wires), and is thus unusable. The corporation, however, has developed a technology for removing metals and PVC by grinding the plastics into grains measuring several

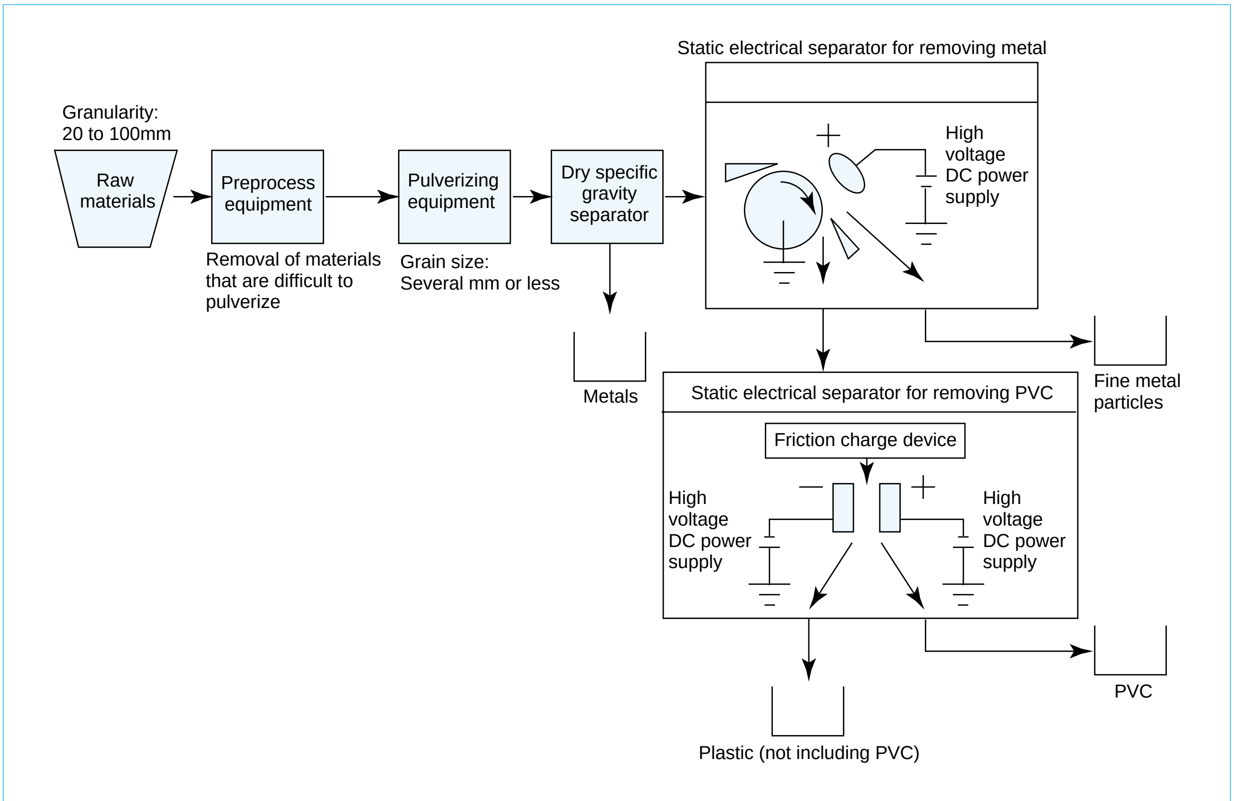

Fig. 3 Removal of PVC and metals from residual plastics

millimeters and then using density separation and static electrical separation, as shown in Fig. 3. These plastics can be used as the base reducing materials in blast furnaces and the metal components can be used as a source of copper.

In the refrigerator recycling system, two sets of cutting-type pulverizing mills process the refrigerator units and send the scrap to a fine cutting mill. Next, any urethane foam attached to the iron plate or plastic inner panels is stripped through an impact process, and the urethane foam and the metals are separated using an air-jet separator. The light urethane foam is then broken down more finely and the fluorocarbons that had been used as the foaming agents are absorbed by activated carbon. After heating the activated carbon chamber, the fluorocarbons that are out-gassed are recovered through liquefaction by a cooling process and then are disposed of by an outside contractor.

In order to protect the ozone layer, cyclopentane has been replacing fluorocarbons as the foaming agent in thermal insulation since the late 1990s. As a result, refrigerators that use the new thermal insulators have gradually begun to come into the plant, so the corporation has installed equipment that is able to process both the new and old refrigerants.

Case Study of Design for the Environment Taking MET Into Consideration

EFFECTIVE USE OF MATERIALS. When the indices for resource recovery, ease of product pulverization processing, and ease of product dismantling were established, the Higashihama Recycling Center had knowhow concerning the issues of manual disassembly operations, pulverization/separation processes, and recycling. Given this, knowledge of how to increase the efficiency of operations within the plant and how to improve yields was fed back into the assessment tool, and topics to be evaluated as part of the assessment were established. These focus on whether the product can be recycled given the existing infrastructure within the industry as a whole and, in particular, whether the product can actually be recycled in the Higashahama Recycling Center.

One requirement was to achieve actual recycling of metal and glass materials according to the primary constituent material ratios of the large home appliances shown in Fig. 4, achieving the recycling rates established by law, and the corporation has also introduced recycling technologies for plastic in order to achieve an even higher recycling rate.

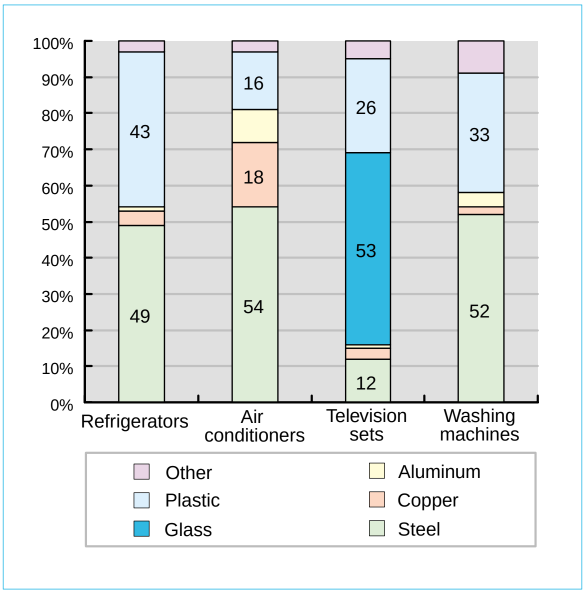

Fig. 4 Ratios of primary materials in home appliances

- At least 80% of the amount of primary plastic resins (PS, PP, ABS) purchased by the corporation was decreased to three unified grades for each resin.
- Display of reusability marks, and display of disassembly process guide marks on the components to be removed during manual disassembly (for all appliance types, Fig. 5).
- Changing all labeling materials and coating on plastic components to use the same material as the component itself (in air conditioners and television sets).
- The establishment of a salt-water extraction guide for liquid balancers, the provision of

drilling marks, and the reuse of salt-water contained in washing machines recovered at the Higashihama Recycling Center.

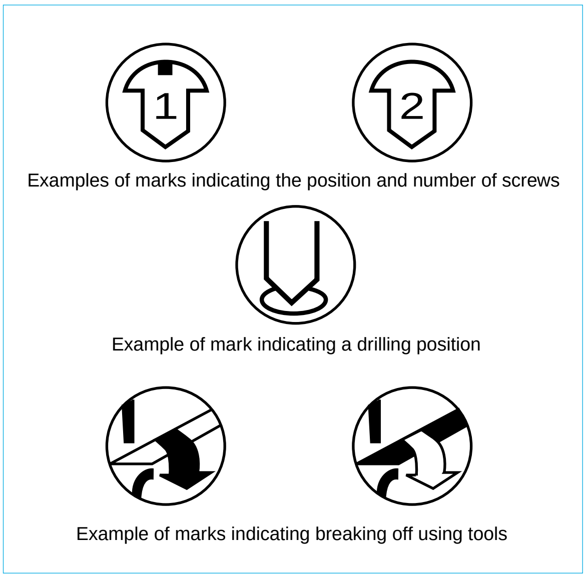

Fig. 5 Guide marks for disassembly

EFFICIENT USE OF ENERGY. As is shown in Fig. 6, the overall weight of air conditioner products had fallen through the mid-1990s, but has increased since then. Since the mid-1990s there has been an increasing need to prevent global warming (i.e., to conserve energy); hence the corporation has adopted an energy conservation strategy based on an overall view of the entire product lifecycle for air conditioners. This has meant adopting a strategy of increasing the size of the heat exchanger in the tradeoff of between reducing the resources consumed in producing the product itself or deriving greater benefit in terms of impact on the environment (energy conservation) in its use.

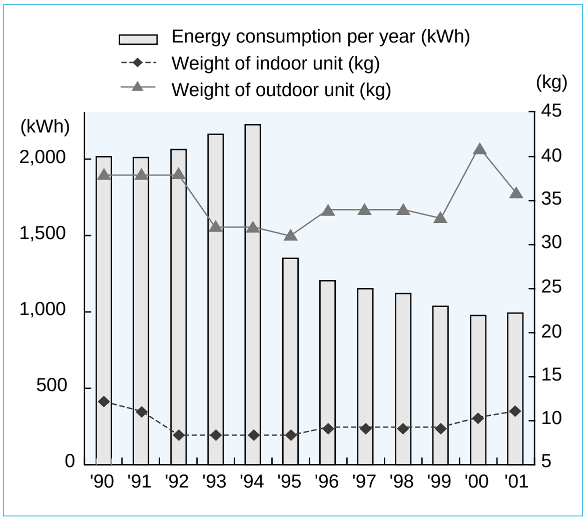

Fig. 6 Trends in the weight and energy consumption of air conditioners over time.

Generally, for household appliances with long lifecycles, reducing the amount of energy consumed during the product life is very effective in reducing the impact on the environment. So, for a broad range of products, the corporation is not only working to reduce the power consumed during the use of the products, but also to reduce that consumed while the products are standing by. The corporate guidelines have also added an evaluation index regarding the amount of energy required in manufacturing on a per-unit basis.

Avoidance of Releasing Materials that Pose Environmental Risks (Toxicity).

Although assessments have long been performed of direct human exposure to the chemical materials used in products, the corporation also performs assessments from the perspective of potential impact on the global environment. The European Union has announced its draft directive for restriction of hazardous substances, centering on heavy metals, affecting, for example, the lead solder used in printed circuit boards. A variety of approaches are being taken within the corporation targeting the firm establishment of lead solder replacement technologies by the end of fiscal 2001.

At Mitsubishi Electric, LCA will also be incorporated into the DFE Guidelines, and the corporation will establish Third-Generation Product Assessment methods that include the implementation of green procurement, so as to do its part in providing environmentally-friendly products. ❑

Design-for-Recycling of Household Appliances Using a Simple Design-for-Disassembly Method

*by Hideaki Nagatomo**

Since the full implementation of the Household Appliances Recycling Law in April 2001, the manufacturers of home appliances have had to become involved in recycling used home appliance products. They also have to incorporate technologies into products being developed today so as to achieve future increases in the percentage of components and materials that can be recovered for recycling from discarded appliances. In this situation, a simple design-for-disassembly (DFD) method has been introduced to analyze and evaluate the appropriateness of recycling-friendly design in the design engineering office, and to analyze the effectiveness of disassembly operations in the recycling plant.

Recycling Plant Operations

In May 1999, Mitsubishi Electric Corporation started to operate the Higashihama Recycling Center at Higashihama in Kawa City, Chiba Prefecture, making it the first plant in Japan compatible with the Japanese Appliance Recycling Law (The Law for Recycling of Specified Kinds of Home Appliances). The recycling center has been able to recycle electrical appliances while striking a balance between materials recovery rate, economics, and environmental friendliness in the manual disassembly (i.e., the removal of components through manual operations), and machine separation (the separation of materials through pulverization), see Fig. 1.

Of these, manual disassembly plays a critical role in high-efficiency recycling, with the objective being to remove, before machine separation, any parts that fulfill the following three criteria:

1. Parts or materials requiring specialized processing (such as toxic materials),
2. Parts whose recovery value would be reduced substantially by machine separation, and
3. Parts that cannot be physically/mechanically processed in machine separation.

Problems in the Design Office and the Recycling Plant

When research was done into the actual problems that are faced in design offices and recycling plants in research into actually increasing the level of environmental friendliness, the following issues were discovered:

1. How to identify the design criteria for ease of disassembly.

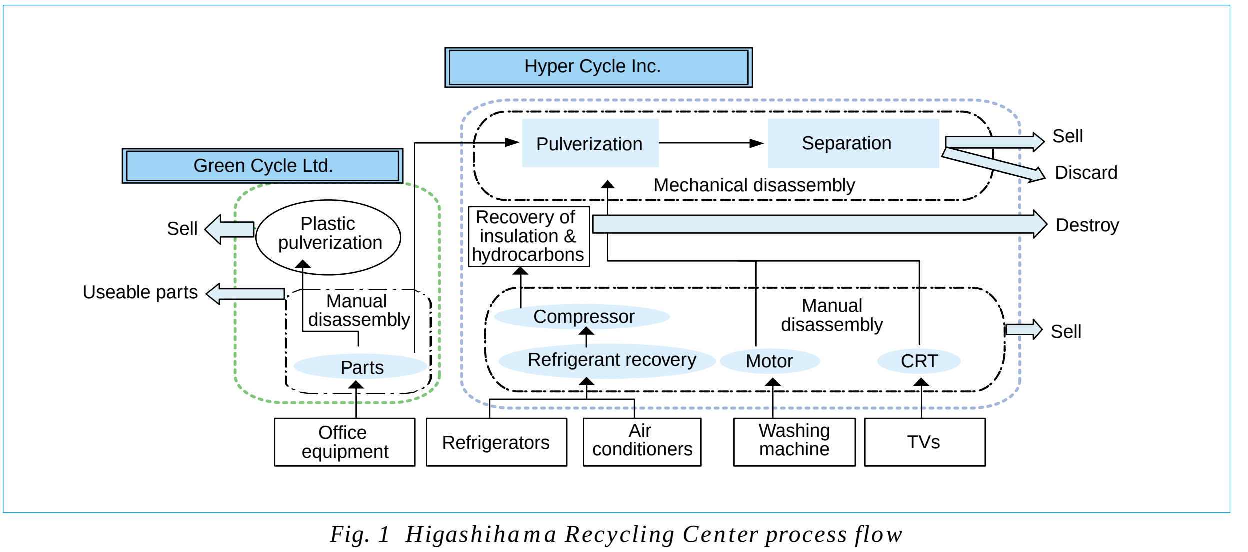

Fig. 1 Higashihama Recycling Center process flow

*Hideaki Nagatomo is with Shizuoka Works.

2. How to establish guidelines to identify components that should be made of alternative materials.
3. How to evaluate the effects of the improvements and how to evaluate their cost effectiveness.
4. How to balance the percentage of materials recovered with the processing cost.

Given these issues, it has been necessary to create support tools for the easy identification of the main points requiring improvements and to support recycling by quantitatively evaluating the effects of design changes.

Proposals for Simple DFD Tools

THE OBJECTIVE OF THE SIMPLE DFD TOOLS. Their objective is to evaluate quantitatively the effect on waste and the effects of improvements in design-for-recycling. The emphasis was placed on achieving the following:

1. Identifying problem areas when disassembling the current design.
2. Identifying critical and non-critical points in design.
3. Understanding the cost benefits of improvement strategies.

DEFINITION OF THE RECYCLING INFRASTRUCTURE. First, the Higashihama Recycling Center was set up as the standard recycling plant of the future based on the concept that it is impossible to design for ease in recycling without first defining the recycling infrastructure. Actual experiments in disassembling and separating various home electronic appliances were performed in the center, after which the resulting values for separation performance for the individual materials and for recovery rates obtained in the experiments were entered into a database.

INCORPORATING COSTS AND BENEFITS. In the Appliance Recycling Law, “recovery” is defined as “separating parts and materials from the waste in an appliance and either using them as raw materials and/or components for products or putting them into a form in which they can be transferred to a third party.” Given this, the materials recovered in the disassembly process can be categorized into those components and materials that can be recycled (i.e., the components and materials that have value), and those that are waste (i.e., without value). These can be defined as “revenues” and “costs” in the recycling operations, see Table 1.

DATA REQUIRED FOR CREATING SIMPLE DFD. Table 2 shows the data that is necessary in order to produce simple DFD. In this table, A (materials structural ratio by component) is determined by the design specifications. B, (manual disassembly process and time required) is obtained by actually disassembling the appliance and measuring the amount of time required to remove a unit component. Finally, C, (defining the final process for manual disassembly) is generally done by specifying the removal processes for those components that are difficult to disassemble (pulverize) by machine and those that include toxic materials. All of the above can be done at the product design stage if the standard recycling plant has been defined in advance.

Next, D, (the disassembly process by material separation yields) and E, (separated materials recyclable/non-recyclable assumed unit value) are particularly dependent on the machine separation performance of the standard plant,

Table 1 Costs/Benefits of Recycling Activities

Parameters	Materials Costs	Operating Costs	Revenues	Product Costs
Revenues	Recycling value	—	Total cost borne by user	—
Expenditures	Total of non-recyclables	Disassembly time	—	Countermeasure costs

*It is necessary to subtract from the total cost borne by the user the shipping costs, etc., in advance.

Table 2 The Data Required for Calculating the Simple DFD

Required Data	Department Providing the Data
A. Materials structural ratio by component	Design Department
B. Manual disassembly process and time required therein	Design Department
C. Defining the final process for manual disassembly	Design Department
D. The disassembly process by-material separation yields	Recycling Department
E. Separated materials recyclable/non-recyclable assumed unit value	Recycling Department
F. Unit value per labor hour in disassembly	Recycling Department

while F, (the unit value per labor hour in disassembly) is the labor cost and equipment operating cost for performing the manual disassembly and machine separation. Values D through F can be loaded into a database from the actual operations of the recycling plant.

THE METHOD OF SETTING UP THE SIMPLE DFD AND ITS OUTPUT. The simple DFD tool is a chart plotting the proposed disassembly procedures of time (horizontally) against expenses and recovery rates (vertically) using the data described above. In Fig. 2, an example of a chart for the manual disassembly process, the two dotted curves show the changes in recovery rates as the manual disassembly process advances and the changes in cumulative total value of the recyclable/non-recyclable materials obtained. The dots in the lines indicate the manual disassembly processes for each of the parts. Furthermore, the straight line that rises to the right indicates the operating cost that is required for the manual disassembly operations.

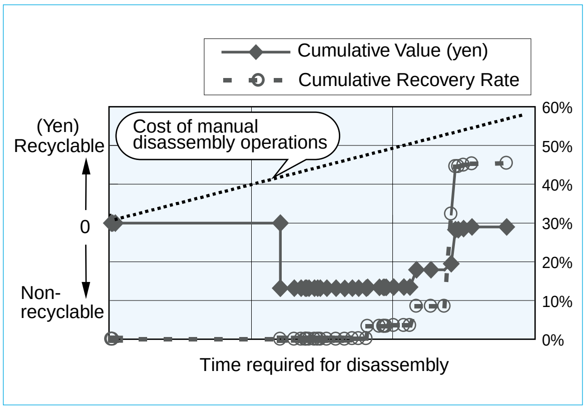

Fig. 2 An example of evaluating the simple DFD

The following is clearly evident from Fig. 2:

1. The total recovery rate obtained by the manual disassembly and machine separation must at least exceed the legal standard value.
2. The difference between the cost of the disassembly operations and the total value of the recyclable/non-recyclable materials can be thought of as the cost/benefit that is derived from the disassembly operations.
3. The processes shown by the dotted lines rising to the right indicate processes that are generating value, where the processes for which the lines slope downwards or are flat are loss-making processes. In other words, a key point in reducing costs is to implement product design and recycling equipment so that the processes that are shown by the lines rising to the right can be performed early in the manual disassembly process.

A simple chart based on a database obtained from the design and the recycling plant described above provides a ready means of visualizing the problem areas in disassembly and separability of target products, making apparent the issues on which improvement efforts should be concentrated at the design stage. This makes it possible to evaluate whether investments are commensurate with the improvements in revenue to be obtained from improved disassembly/separability. ❑

Approaches to Design for the Environment with Practical Examples

*by Toshiro Oyama & Etsuko Hirose**

The Nagoya Works of Mitsubishi Electric Corporation has 5,000 employees (including those of on-site contractors). The plant has been involved in various environmental protection activities for over two decades, including, for example, the recycling of scrap printed circuit boards. As a result, the plant is approaching the zero-emission level (zero-waste level), with just five percentage points of waste reductions required to reach that goal and further reductions already planned. As well as reducing waste and scrap, the plant is also working to conserve energy and to reduce paper consumption and toxic chemicals among other on-going environmental protection activities. This article discusses the rules of product design for the environment (DFE) in such practical activities.

Environmental Protection Activities in Products

Nagoya Works, as a business unit that produces factory automation equipment, handles the development and manufacturing of products in more than ten major product categories, including sequencers, inverters, AC servo units, programmable controllers, robots, laser numerical processing machines, electrical-discharge machines, and other electromechanical equipment, motors, transformers, and electromagnetic switches, as shown in Fig. 1.

When developing these products, attempts are made to reduce the burden on the environment in harmony with the corporation's fundamental philosophy for environmentally friendly design. Product-design activities take the environment into consideration, particular from the perspectives of effective utilization of resources, efficient use of energy, and avoiding contamination by environmentally threatening materials. These design activities are subsumed under "design for the environment" (DFE).

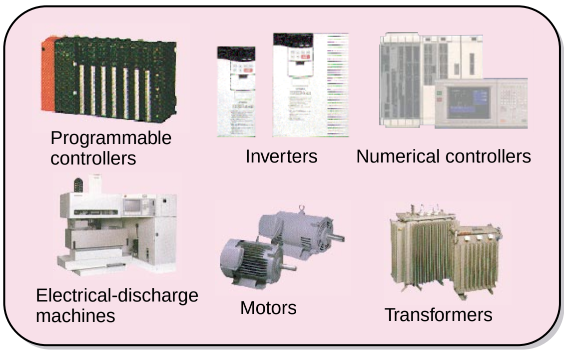

Fig. 1 Key products developed and manufactured at the Nagoya Works

The DFE Evaluation Method

Each time a product is developed or improved, the degree of environmental improvement of the new product over the previous product is evaluated. This evaluation uses a product assessment based on completing a check sheet for the improvements made in each of several categories. These categories include any move to renewable resources, ease of disassembly, reduction in the volume of resources consumed, durability, energy conservation, safety, information disclosure and packaging improvements. The method of evaluation was established in July 1997 by the Product Assessment Expert Committee, whose members were drawn from the development and design departments, and from the environmental protection departments established when the environmental management system was established. Evaluations are performed in all product development and improvement activities in the Nagoya Works.

Product Assessment Activities

When new products are developed, the product design process passes through a series of steps including a conceptual design review, a drawing design review, and a shipping design review. The evaluation based on the above product assessment is performed by the Design Department before the conceptual design review at the product planning stage, and is repeated by the Quality Assurance Department prior to the shipping design review in order to confirm the results of the evaluation performed by the Design Department.

Reviewing the Product Assessment Sheet

Because product assessments are effective in environmental improvements at the product

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development stage, the DFE committee established DFE guidelines in March 2000. The members of this committee come from all divisions in the corporation that perform product assessments. These company-wide guidelines eliminate a source of inconsistency in product assessments.

The product assessment sheet used in the Nagoya Works has been reviewed based on these guidelines, see Fig. 2 and Table 1.

DFE Education

To make designers thoroughly familiar with the basic concepts of DFE, the corporation's Environmental Protection Promotion Group has sponsored three-day DFE engineering seminars and sent the instructors from these seminars to the Nagoya Works to hold one-day seminars. The design departments have encouraged participation in these seminars.

The three-day seminars cover topics such as DFE trends in Japan and overseas, product assessment evaluation methods, policies and guidelines for selecting ecologically-friendly materials, and life-cycle assessment (LCA) theory, with hands-on investigations of environmental improvement issues by actually disassembling products. The one-day seminars feature lectures on the classroom learning part of the seminars.

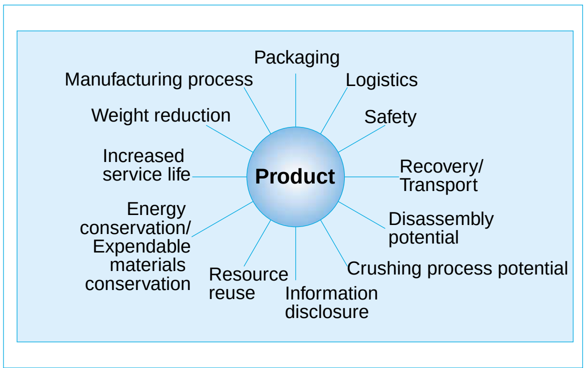

Fig. 2 Categories of DFE guidelines

Examples of Using Product Assessments

Because items of factory automation equipment have comparatively long product life cycles, DFE work focuses on topics such as product energy conservation, miniaturization, longer life expectancy (to contribute to reduced resource consumption and less waste), labeling of plastic materials (for renewable resources), etc., with reliability and improved functionality. Below, we discuss an example of the results of this product assessment.

Table 1 Product Assessment Sheet (guidelines)

Evaluation Item			Evaluation Standard	Evaluation Method	Weighting (X)	Standard Evaluation Points (Y)				
						3 points	2 points	1 points	0 points	−1 points
Materials	Resource Recovery	Possible Resource Recovery	Percent usage of recoverable materials	(Weight of recyclable materials/Total weight) x 100%	3	≧80%	≧50%	≧20%	≧0%	None
		Material Uniformity	Percent reduction in the number of plastic parts	[1-(New product/reference product)] ×100%	3	≧30%	≧20%	≧10%	≧0%	<0%
			Percent reduction in the number of metal parts	[1-(New product/reference product)] ×100%	3	≧30%	≧20%	≧10%	≧0%	<0%
			Percent reduction in the number of other parts	[1-(New product/reference product)] ×100%	3	≧30%	≧20%	≧10%	≧0%	<0%
			Percentage of plastic parts that are recyclable	(Number of recyclable parts/total parts)×100%	3	≧80%	≧50%	≧20%	≧0%	None
			Percentage of metal parts that are recyclable	(Number of recyclable parts/total parts)×100%	3	≧80%	≧50%	≧20%	≧0%	None
			Percentage of other parts that are recyclable	(Number of recyclable parts/total parts)×100%	3	≧80%	≧50%	≧20%	≧0%	None
		Use of Recyclable Materials	Percentage of materials used that are recycled	(Total mass that can be recycled/total mass)×100%	3	≧50%	≧30%	≧20%	≧0%	None
		Promotion of Recoverable Resources	Percentage reduction in the number of compound materials.	[1-(New product/reference product)]×100%	3	≧30%	≧20%	≧10%	≧0%	<0%

Table 2 Technologies Developed or Adopted for Better Environmental Performance

Improvement	Developed or adopted technology	Effectiveness
Making products more energy-efficient	- Smaller cooling fan for reduced windage loss - New motor coil for reduced copper loss - New core material for reduced core loss	Generation loss lowered by approximately 25 percent
Longer life	- New bearing grease developed	Longer lifetime achieved
Smaller size	- Adoption of steel plate frame	Size the same as standard dimensions achieved

MORE EFFICIENT INDUCTION MOTORS. In recent years, demand has risen for energy-saving/ high-efficiency equipment. In response, the corporation has developed the Super Line Eco series of energy-saving induction motors, including three-phase motors. Large improvements in energy consumption and increased life expectancy have resulted, winning the 1999 Japan Machinery Federation Chairman's Award.

Key points in product assessments include not only power conservation (to prevent global warming) but also extended useful product life (to reduce the burden on waste-processing facilities), and compatibility with standard motors (so that the products can be used in existing equipment). The technologies that were developed and used are shown in Table 2.

LCA EVALUATIONS. With the cooperation of the Mitsubishi Advanced Technology R&D Center, a life-cycle assessment (LCA) evaluation was performed for a standard induction motor in order to evaluate the effect on the environment of the power-saving "Eco" induction motor.

Conventionally, data for LCA is gathered in each of the processes from materials to manufacturing, distribution, use, and disposal/recycling; however, in this evaluation the LCA was limited to materials, manufacturing, and use (assuming ten years of operation and eight-hour days at 100% loads of 0.75 kW). SimaPro software (from the Pre-Consultants Company in the Netherlands) was used, using databases of the National Research Institute Resources and Environment for materials and manufacturing. Note that the environmental impact was calculated using "Eco-indicator 95", see Fig. 3.

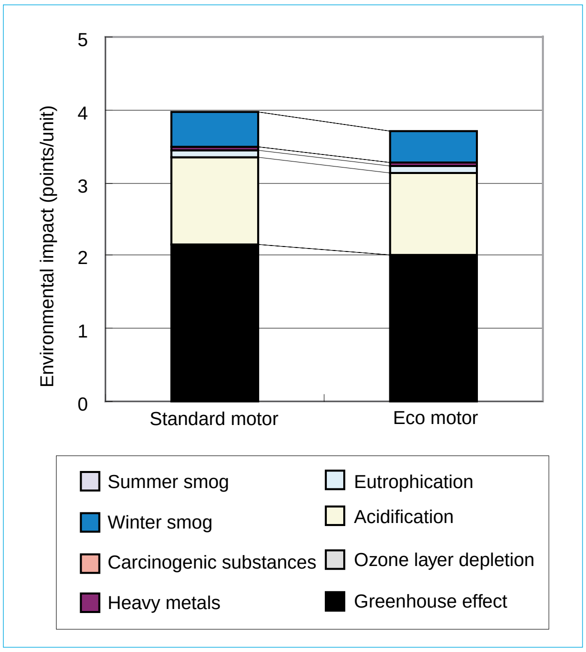

Fig. 3 Results of LCA (as environmental impacts)

The result is that even though the Eco Motor is slightly heavier than a conventional motor, the effects of energy conservation give the Eco motor an environmental impact superior to that of a standard motor. We confirmed that the Eco Motor, when used over an extended period of time, achieves effective environmental improvements due to the reduction in power consumption.

Nagoya Works is committed to providing a continuous succession of environmentally aware products, and the plant is continuing its efforts to develop products with enhanced energy conservation and extended life cycles. ❑

A Novel Fabrication Process for Polycrystalline Silicon Solar Cells

From the perspectives of cost and output, polycrystalline silicon solar cells are the primary type of photovoltaic cells used by the solar power generating systems that will serve as next-generation clean energy sources. While the solar power generator systems themselves are certainly sources of clean energy, it is also extremely important that active efforts should be directed at reducing the burden imposed on the environment by their manufacture. This article presents a manufacturing process developed by Mitsubishi Electric Corporation to reduce the environmental burden of manufacturing solar cells.[1]

In order to improve the efficiency of photovoltaic cells, the surface of the silicon substrate must be textured, giving it a rough structure to reduce its reflectivity. This texturing is typically done by an etching process using a solution of either sodium hydroxide or potassium hydroxide in isopropyl alcohol (IPA). While these chemical solutions have been used extensively in the past, they contain organic solvents and thus require special care in handling the wastes.

At Mitsubishi Electric, we have researched the use of new sodium carbonate (Na_2CO_3) solutions, which do not contain organic solvents, in the texturing process. The details of this process are described in Reference [1]: basically, the substrates are immersed for about ten minutes in an aqueous sodium carbonate solution (20% by weight) at a temperature of 95°C. When this process is used, the reflectance is strictly comparable with that produced by conventional processes.

Table 1 summarizes the photovoltaic properties of four different types of substrate, each measuring 15cm x 15cm. All of the substrates produced conversion efficiencies in excess of 16%, and the best achieved a 16.8% conversion efficiency (certified by a Japanese quality assurance organization). This value is among the highest in the world for this type of large-substrate photovoltaic cell. ❑

Table 1 Summary of Photovoltaic Properties

Supplier	Voc(V)	Jsc (mA/cm²)	FF	Efficiency (%)
Company A	0.613	33.57	0.784	16.13
	0.612	33.77	0.776	16.04
	0.614	34.38	0.772	16.28
	0.612	34.17	0.778	16.25
Average	**0.613**	**33.97**	**0.778**	**16.18**
Company B	0.624	34.59	0.769	16.61
	0.626	34.58	0.772	16.69
	0.626	34.84	0.757	16.53
	0.626	34.71	0.766	16.66
Average	**0.626**	**34.68**	**0.766**	**16.62**
Company C	0.620	34.28	0.777	16.53
	0.621	34.36	0.765	16.31
	0.622	34.43	0.774	16.59
	0.623	34.40	0.770	16.50
Average	**0.622**	**34.37**	**0.772**	**16.48**
Company D	0.624	34.28	0.762	16.31
	0.623	34.25	0.774	16.51
	0.620	34.15	0.766	16.22
	0.622	34.22	0.771	16.42
Average	**0.621**	**34.22**	**0.768**	**16.37**

Reference

1. S. Arimoto et al., Conference Record, 28th IEEE Photovoltaic Specialists Conference, 2000, September, Alaska, pp. 188-193

Integrated Environmental Information Systems

Given the recently increasing scale of social and global environmental problems, enterprises have been faced with increasingly strict environmental laws and regulations, and demands for fuller disclosure of information on their approach to environmental issues. Detailed daily control of environmental information has become indispensable throughout the Mitsubishi Electric Group, increasing the amount of work involved in environmental management activities.

In order to streamline these environmental management activities, Mitsubishi Electric Corporation launched a development project known as the Eco-Oriented Corporate Management System (ECOrates) in 1999 to establish an environmental information management infrastructure capable of responding rapidly to ever stricter laws and regulations and satisfying the expanded information reporting requirements. A system for the integrated management of environmental information within the group was developed and went into full-scale operation in July 2001.

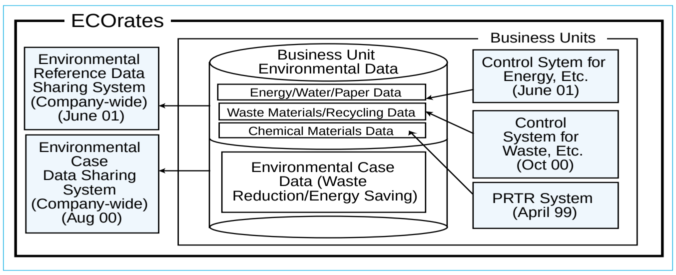

Fig. 1 Overview of the ECOrates Systems

ECOrates is configured from a number of subsystems, each handling different types of environmental information. At present, the subsystems include the PRTR system, which controls environmental impact and chemical property information, the Waste Control System, which controls information pertaining to waste and recycling, the Environmental Case Data Sharing System, which provides information and case studies about environmental improvements, and the Environmental Reference Data Sharing System, which performs integrated management of the environmental information from these subsystems along with other information about, for example, energy.

In the future, these subsystems will be deployed to related companies within the industrial group and there are also plans to enhance the PRTR system to improve chemical materials control at Mitsubishi Electric business locations in accordance with the implementation of PRTR/MSDS regulations. ❑

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