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Life Cycle Assessment in Polymer Industry Toward the 21st Century

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LIFE CYCLE ASSESSMENT IN POLYMER INDUSTRY TOWARD THE 21ST CENTURY

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ABSTRACT

Life cycle assessments to protect global environment and to control waste in the polymer industry are reviewed. The focus is on 1) environmentally sound technology, 2) energy conservation, and 3) recycling of industrial products. The competitiveness of a nation depends on how it balances economic development of sustainable growth and responsible care of the global environment in a borderless economy. It fully depends on the development of both environmentally sound manufacturing and effective recycling technologies for the products. Current environmental issues of the Japanese chemical industries as well as Toray's performance and new products development for environment business are reviewed: 1) Energy conservation and technology of the Japanese manufacturing industry, 2) Development of environmentally sound technology, 3) Effective products recycling technologies, and 4) Sustainable growth in the new chemical age. The future issues of life cycle assessment and environmental protection in manufacturing industries are discussed.

VISION OF RECYCLE SOCIETY

From an industrial ecology perspective, recent Japanese trends in changing environmental policy of manufacturing industry are overviewed. Highlighted as the basic framework for the new policy direction is the latest legislation, the Basic Environmental Law in 1993 in Japan. The goal of improving the overall environmental efficiency was identified as a global sustainable society in the context of the Seaborg's "cycle society." There are two types of approaches currently in use to improve the environmental attributes of products. One, called Design for Environment (DFE) or Product Assessment (PA) in Japan, requires environmental and recycling considerations at the stage of molecular design, product design, and engineering design. Another approach is Product Life-Cycle Assessment (PLCA). It is based on a rigorous inventory analysis. This paper reviews efforts to protect the global environment and to control waste in the polymer industry, focusing on 1) environmentally sound technology, 2) energy conservation, and 3) recycling of industrial products. The competitiveness of a nation in our borderless economy of rapid change fully depends on the development of both environmentally sound manufacturing and effective products recycling technologies [1-3].

Current environmental issues of Japanese chemical industries as well as Toray's performance in environmental projects are reviewed: 1) Energy conservation and technology of the Japanese manufacturing industry; 2) Development of environmentally sound technology; 3) Effective product recycling technologies; 4) Sustainable growth in the new chemical age.

Special attention is devoted to 1) the reduction of materials in industry and 2) reduction of waste. The recent advancement of environmentally sound technology is indispensable along with product recycling and waste control for the sustainable growth of the polymer industry. We must ride the wave of technological innovation and move steadily toward globalization. An effective management strategy is discussed that introduces environmentally sound manufacturing and energy conservation technologies through technological innovation in the borderless global economy. Three types of possible resources recovery and recycling process in the materials industry are summarized in Table 1.

Several future issues of environmental problems in manufacturing industries are discussed. 1) Active participation in the development of an international framework for environmental protection. 2) Promotion of lifetime assessment and standardization of environmental protection, monitoring, and research and development.

1. Energy conservation and technology of the Japanese manufacturing industry
2. Development of environmentally sound technology
3. Effective product recycling technologies
4. Sustainable growth in the new chemical age.

Over the past several years, industry, governments, and the public have increasingly recognized that fundamental changes of society as well as concerted efforts are definitely needed in order to attain the goals of sustainable development as we approach the 21st century. In this regard, Japan is no exception. From an industrial ecology perspective, recent Japanese trends in changing the environmental policies of both industry and the government were overviewed.

TABLE 1. Three Types of Possible Resources Recovery and Recycling Process

Type	Process	Items
1. Thermal Recycle	1-1. Energy recovery Storable and transportable (pyrolysis, hydrogenation)	1-1-1. Reuse-derived Fuel recovery, storable
	1-2. Direct energy Recovery (thermal, electrical)	1-1-2. Reuse-derived Fuel recovery, transportable. (pyrolysis, hydrogenation)
2. Material recycle	2-1.Conversion material recovery (separation, refining)	2-1-1. Raw material Recovery and renovation
	2-2. Conversion material recovery (chemical, biological)	2-1-2. Raw material recovery
3. Land reclamation	3-1. Land reclamation and utilization (landfilling, seashore filling, covering, construction)	

In Table 2, major issues of national and collaborative joint research projects for environmental protection in the Japanese chemical industry are summarized for five projects. The ratio of environmental research expenditures are compared with energy-related projects in Table 3. Highlighted as the basic framework for this new policy direction is the latest legislation, the Basic Environment Law (1993). The goal of improving the overall environmental efficiency was identified as a global sustainable society in the context of Seaborg's "recycle society" [4].

To cope with new trends in environmental concerns, industry appears to have made a big change in its environmental policy since 1989. As early as April 1990, Keidanren (The Federation of Economic Organizations), representing more than

TABLE 2. National and Collaborative Projects for Environmental Protection in Japanese Chemical Industry

1. Replacement of mercury process by nonmercury ones in caustic soda and chlorine industry (completed)
2. Basic research in carbon chemistry (1980–1987)
3. Development of alternatives to CFC
4. Chemical and biological fixation of carbon dioxide
5. Development of biodegradable polymers

TABLE 3. Comparison of R&D Expenditures of Japanese National Projects with Environmental Protection (in billion yen)

Item	1985	1987	1988	1989
Environment	150	156	170	200
Energy savings	265	313	318	353
New energy	38	34	29	28
Biotechnology[a]	45	50	49	57
Aerospace	150	170	178	200

[a]For resources and environment.

1000 sectoral organizations of private industry and business, released a document entitled *Keidanren's View on Global Environmental Issues*, which showed a newer approach of industry's environmental policy. In November 1990 this was followed by another document, *Agenda for Improvement of Waste Management*, which reviewed existing waste management practices in major industries and proposed a new, responsible approach.

As an extension of this comprehensive upstream approach, in April 1991 Keidanren with the consensus of member organizations issued a *Global Environment Charter* outlining a policy of corporate environmental actions. The 24 recommendations in 11 corporate environmental policy areas include not only the implementation of internal environmental auditing and management but also improvement of environmental attributes of products. Although the *Charter* is not binding in its nature, currently almost all corporations, in particular leading firms, are making strenuous efforts in their own ways to improve the environmental performance in compliance with the *Charter*.

Aspects of environmental sound design are summarized in Table 4.

The impact of action taken in material substitution is less load at extraction, and process modifications and engineering controls result in less use of toxic material and built-in reliability. "Recycle Society in the 21st Century," conceptualized as a goal by the Japanese Environmental Agency's Study Committee and shown schematically in Fig. 1, is essentially the same as what Seaborg envisioned 20 years ago.

TABLE 4. Aspects of Environmentally Sound Design

Action	Impact
Material substitution	Less load at extraction
Process substitution	Less use of toxic materials
Process modification	Containment and removal of toxic materials
Engineering control	Built-in reliability
Just-in-time materials	Less storage of hazardous reagents
End-of-life modification	Less load at disposal

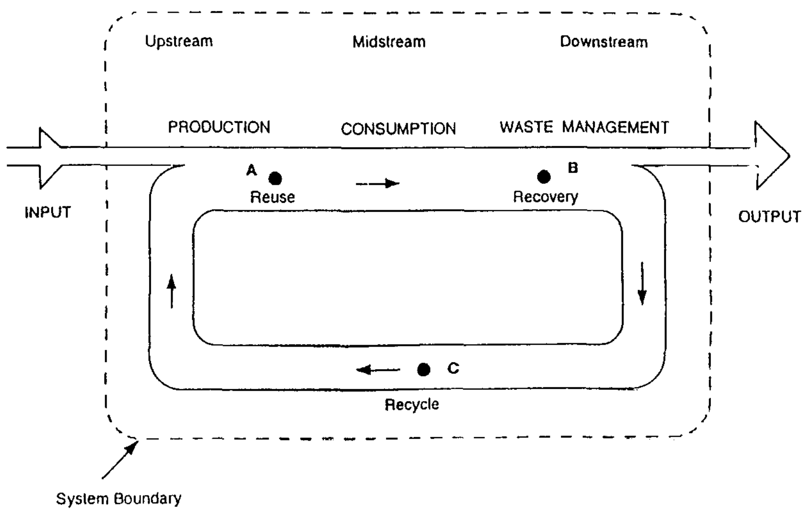


FIG. 1. Basic model for the "Recycle Society."

In this society, with both technical and economic mechanisms built-in and well developed in its infrastructure, people and industry are facilitated to seize every opportunity to recover, recycle, and reuse materials and energy to the maximum degree thermodynamically feasible. International standards of environmental protection, such as ISO, should be established for objective evaluation. A checklist of such evaluation factors as recyclability, items to be evaluated, and criteria of evaluation by Japanese consumer electronics businesses are summarized in Table 5.

TABLE 5. List of Evaluation Items and Criteria of Consumer Electronics in Japan[a]

Factor	Item to be evaluated	Criteria
Product weight	Weight of materials and parts in use	Weight reduction
Recyclability	Replaceable parts. Use of other material	Substitution by other parts. Use recyclable material
Crushability	Ease of being shredded, crushed	Easily shredded material
Disintegrability	Fabrication or dismantling	Design for easy handling
Separability	Coding of plastics and parts	Plastic coding clearly marked
Transportability	Easy handling for transportation	Design for easy transportation
Safety and health	Toxicity, hazard	Safety after retirement
Packaging	Packaging size and weight	Minimize material
Recycling information	Well informed of disposal and recycling	Availability of disposal and recyclability

[a]Source: Association of Consumer Electronics, Japan (1993).

The way the current economic society of industrialized nations is being run and developed is probably not sustainable. For example, Japan's latest material balance (1990) is shown in Fig. 2.

Japanese Industry consumes more than 2 billion tons of virgin natural resources every year, of which less than 10% is recycled. It is said that an average Japanese consumes 46 times more natural resources than an Indonesian. Another example is consumption of the world's commercial energy resources. In 1990, industrialized nations, with about 22% of the world's population, consumed about 82% of the world's commercial energy, which was equivalent to 8.1 billion tons of oil [5].

ENERGY CONSERVATION AND ENVIRONMENTAL PROTECTION TECHNOLOGY

The trends in unit energy requirements of major industries such as steel, paper and pulp, cement, and petrochemicals in Japan in 1973–1991 are shown in Fig. 3. Compared with energy consumption between 1973 and 1991, Fig. 3 shows the reduction of energy consumption of major Japanese industries was 15% in steel up to 40% in the petrochemical industry in the period.

The integrated energy statistics of the Japanese manufacturing industries in 1973–1992 are reviewed in these items. The trends of average rate and projection of reduction in unit requirement of energy consumption of these industrial sectors in 1973–2010 are summarized in Fig. 4.

The annual energy consumption of chemical industry (100 in 1973) decreased to 70 in 1987, and dropped from 41.3 to 28.9 × 10^{12} kcal by introducing a variety

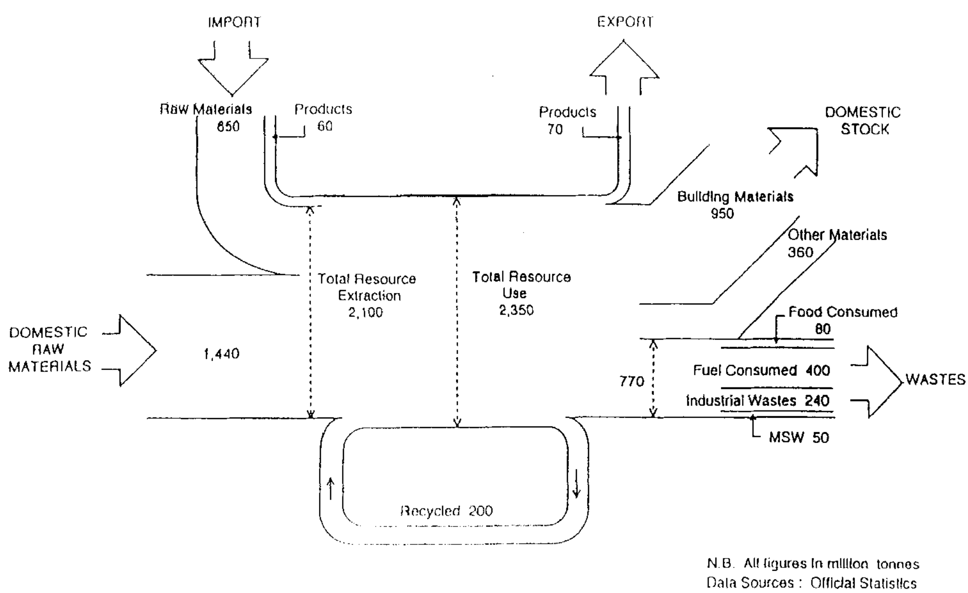
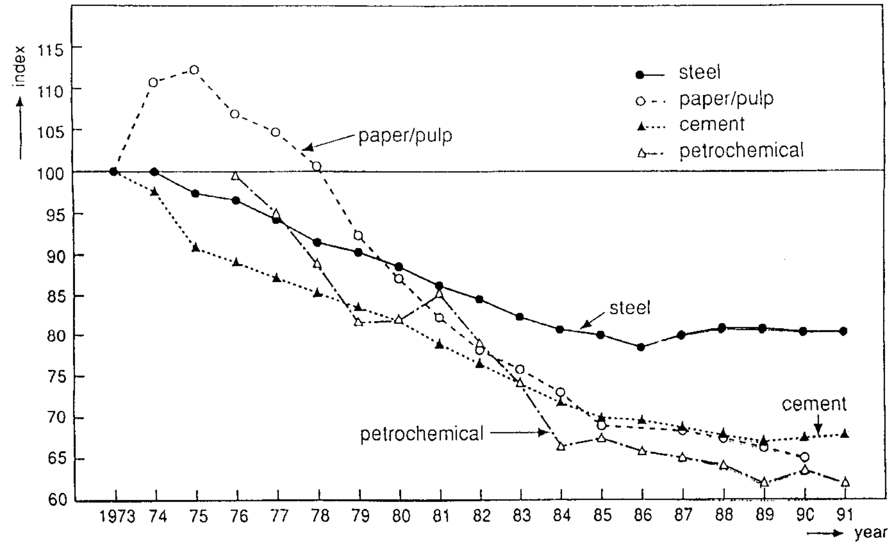


FIG. 2. Japan's annual material balance of industry in 1990.



(Source) MITI
1) Index 1977 = 100 for petrochemical industry
2) Steel industry, adjusted for production condition of 1973
3) Others nominal unit energy requirement

FIG. 3. Japanese trends of unit energy requirement of major industries in 1973–1991.

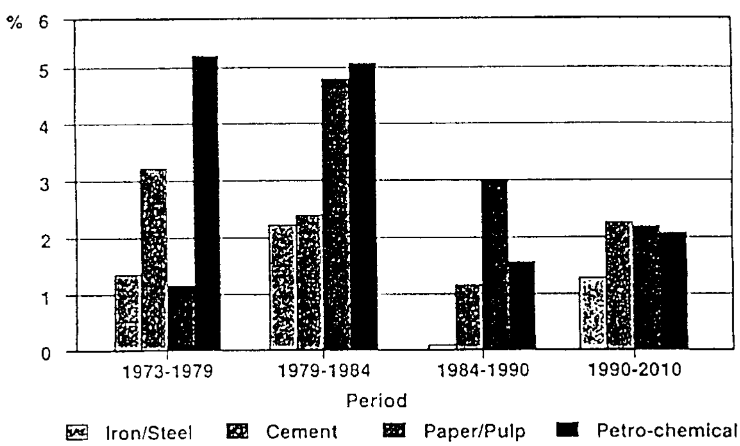


FIG. 4. Japan's average rate of reduction in unit energy requirement in percent per year projection in 1973–2010.

of modifications in the energy conservation process and incremental manufacturing technologies in every step of the production system. In the petrochemical industry the unit energy requirement dropped to 60% from the index of 100 in 1977 compared to a 18% reduction in the steel industry. When the ratio of energy consumption per GDP is traced for 1973–1991, it shows a drop from 199.6 kL of fuel oil/0.1 billion yen in 1973 to 125.3 kL of fuel oil/0.1 billion yen in 1991.

A comparison of trends of the energy consumption index (1975 = 100) of major OECD countries, Canada, the United States, and Japan in 1975–1987 is shown in Fig. 5.

The energy consumption index of Japan dropped to 67 (33% reduction), and Japan is among the best, whereas the index of the United Kingdom and the United States decreased to 75 (25% reduction) within 13 years. Analysis of risk assessment and risk management shows research of risk characterization is necessary in terms of hazard identification and assessment. The management paradigm is shown in Table 6.

We must solve these global environmental issues through international cooperation based on the basic concept of *economic symbiosis*.

Japan's environmental standards and statistics of cases exceeding regulations between 1971 and 1990 are summarized in Table 7. The number of violations of the Japanese pollution requirements of toxic substances, such as mercury and chlorohydrocarbons, was checked by the Environmental Agency of the Japanese Government, and the data were recently compared for periods of 14 to 19 years in Table 7. It was confirmed that essentially there were no violations and that pollution controls were well established in the Japanese manufacturing industry [6].

Concerning capital investments for pollution prevention in the Japanese manufacturing industry, the percentage of pollution control investment out of total

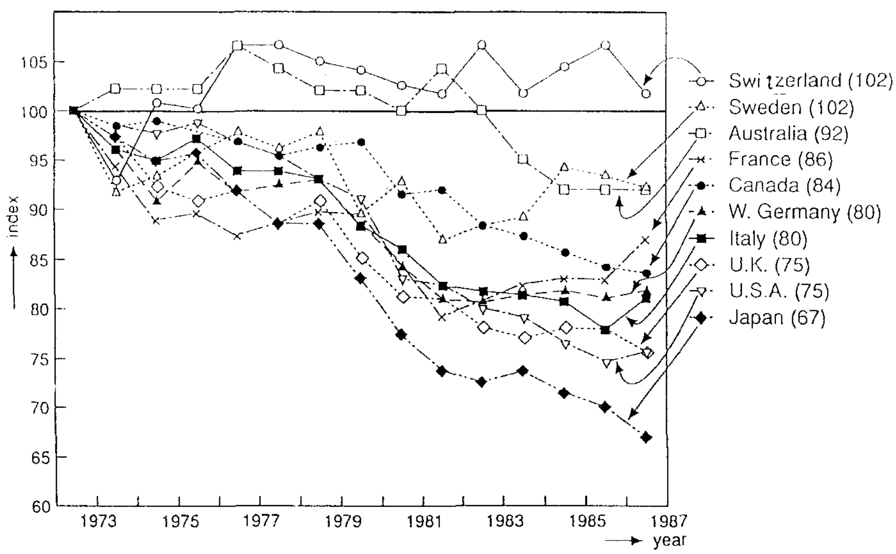
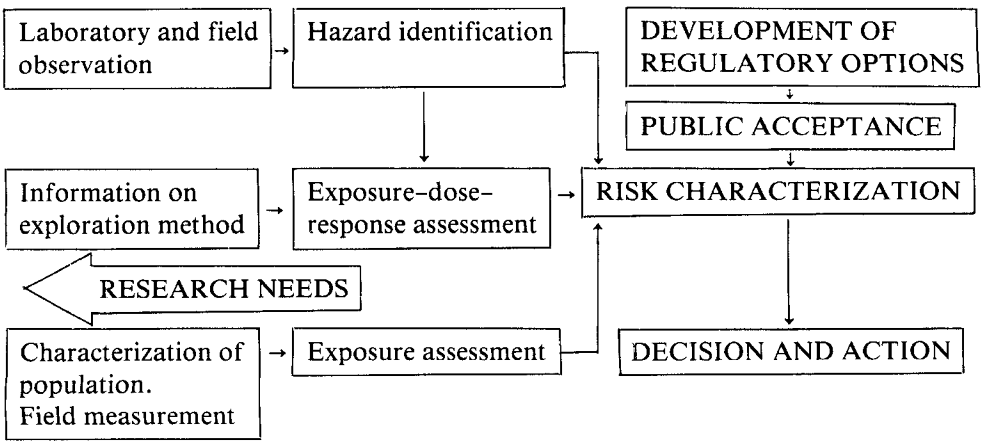


FIG. 5. Trends in the energy consumption index of major OECD countries in terms of unit GNP (energy consumption per GNP).

TABLE 6. Research Need for Risk Assessment and Risk Management, and Management Paradigm[a]

Research	Risk assessment	Risk management



[a]Source: National Research Council (1994).

capital investments was 4% in 1985 whereas in the United States, it was 3.4%. The ratio of pollution control investment over GNP is 1.0% in Japan, 0.4% in the United States, and 0.3% in Sweden. The ratio of budget of pollution protection over national budget in Japan is about 1.4–1.5%.

The relationship between capacity and the number of pieces of desulfurization treatment equipment is shown in Fig. 6. This value has increased in 20 years to 178.8 Nm^3mil./h (1843 pieces of equipment) in 1990 from 5.4 Nm^3mil./h (102 pieces of equipment) in 1970.

Regarding capital investments for pollution prevention in the Japanese manufacturing industry, the relationship between capacity and number of pieces of equipment for denitric acid treatment of acid rain in Japan increased in 14 years to 160 Nm^3mil./h (430 pieces of equipment) in 1989 from 1.2 Nm^3mil./h (5 pieces of equipment) in 1972.

The number of analytical tests of toxic substances wastes, including cadmium, alkylmercury, and chrome (6 valencies), in 1976–1990 in Japan is summarized in Table 7. A drastic decrease of violations of environmental regulations were confirmed in the manufacturing plants of Japan in the last 25 years. With the aim of improving mainly the environmental attributes of products, nearly a dozen life-cycle schemes and procedures have been proposed to date. Broadly, they may be classified into two approaches. The first approach, based on practical engineering experience in industry, and often called by such names as Design for Environment (DFE) (Allenby in Richards and Fullerton, 1994), Design for Disposability (DFD), Design For Recyclability (DFR) (Henstock, 1988), or simply Eco design in different countries of Europe, usually requires a qualitative evaluation of a target product by means of checklists, scoring sheets, and reviews of relevant process flow charts. In Japan this approach is generally known as Product Assessment (PA). In conjunc-

TABLE 7. Environmental Standards of Japanese Industry and Statistics of Cases Exceeding Regulations between 1971 and 1990

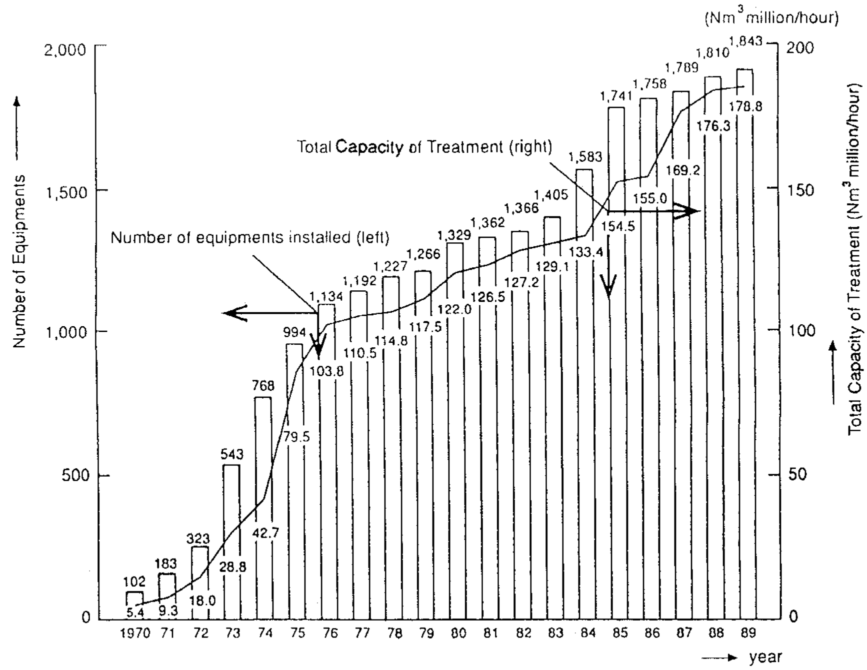
Items	Fiscal year	Number of samples (A)	Number of samples exceeding environmental regulations (B)	Ratio (%) (B)/(A)
Cadmium	1971	15,944	114	0.72
	1990	25,485	11	0.04
Cyanide	1971	12,453	142	0.14
	1990	21,755	1	0.00
Organic phosphorus compounds	1971	5,116	11	0.22
	1990	7,183	0	0
Lead	1971	14,515	202	1.39
	1990	25,493	3	0.01
Chrome (6 valencies)	1971	11,532	15	0.13
	1990	22,414	1	0.00
Arsenic	1971	11,530	48	0.42
	1990	23,275	3	0.01
Alkylmercury	1971	5,624	0	0
	1990	6,399	0	0
Polychlorinated biphenyl (PCB)	1975	3,130	12	0.38
	1990	3,765	0	0
Total	1971	76,714	532	0.69
	1990	135,769	19	0.01

tion with designated products of the first kind as stipulated in the Japanese recycling law, for example, manufacturers of home electric appliances are required, during the early stages of planning and design, to perform a preliminary product evaluation on material use, product structure design, and recyclability at the time of retirement in accordance with MITI's guidelines (MITI Order No. 55, October 25, 1991).

The other approach, based on detailed material and energy balances of inventory taken at different stages of the product life-cycle, requires quantitative analysis and evaluation of a product and its associated processes or of a product system. The terms Life-Cycle Inventory (LCI), Life-Cycle Analysis (LCA), and Product Life-Cycle Assessment (PLCA, LCA), are examples of many terms which have been coined recently to denote this approach [4, 7].

Toray's Key Technologies of Environmentally Sound Industrial Products

In June 1991, Toray Industries set up the "Global Environmental Committee" headed by the Executive Vice President of the Manufacturing Division in the Head Office in Tokyo. The role of the Committee is to identify the environmental man-



(Source) Environmental Agency, Japan
1) Data of January 1 up to 1982.
2) Data of March 31 after 1983.

FIG. 6. Trends of number of equipment of desulfurization in 1977–1991.

agement strategy target for Toray to decide the basic management policy. At the same time, the Global Environmental Research Laboratory was established in the Research Department with 25 professional scientists among 150 scientists who actually engage in the R&D activities of specific environmental issues in the company [8, 9]. There are a variety of possibilities in new chemistry for the contribution of new materials for environmentally sound technology system. For example, there are membrane separation technology, clean energy by photocells, energy saving by lightweight advanced composites, reusable plastics, and biodegradable polymers as summarized in Table 8. The core technologies of Toray's new materials and systems

TABLE 8. Contribution of New Materials to Global Environmental Protection

Increase of carbon dioxide	Membrane separation technology
	Clean energy (by photo cell)
	Energy saving (by ACM)
Acid rain	Nonhalogenated plastics
Desertification	Highly water-absorbable polymer
Waste pollution	Reusable plastics
	Biodegradable plastics

for environmentally sound manufacturing (ESM) are summarized in Table 9 [10–12].

Solid–Liquid Separation System (Torayrom) for Environmentally Sound Manufacturing Technologies

Two types of new solid–liquid separation systems were commercialized based on Toray's proprietary technology of new filters made of ultrafine fibers for the new filtration systems.

(A) A continuous solid–liquid separation system with nonchemicals, Torayrom.
(B) A rotating drum filtration system, Torayrom RD. The filter material is made of a polyester microfiber woven in the traverse of fabrics, followed by a two-layer structure. It is formed by surface treatment of fibrilization and orientation in a certain direction with a nappy surface as shown in the SEM photograph of a filter element consisting of an ultrafine fiber and an ordinary thin fiber (Fig. 7).

A characteristic of the filter is a longer life than conventional filters. It traps microfloats of 5–8 μm diameter. The effective contact surface is 50–60 times larger than that of conventional filters. It is effective for filtering plankton and other microorganisms in water and industrial waste sludge.

Radioactive Metal Trapping Filter Ionex, Ion-Exchange Fiber of Radioactive Waste in Nuclear Reactor for ESM

Toray's Ionex is a composite fiber of high performance fibrous polystyrene ion-exchange resins with polyethylene reinforcement. As shown in Fig. 8, the characteristic features are large surface area, high exchange rate, and large absorption capacity, available in a variety of forms. Tokyo Electric Company successfully

TABLE 9. Toray's R&D Items of Environmental Research Projects

Item	Research and development
Cleanup of water	Cleaning and reclamation of wastewater and lakes by using filtering equipment: *Torayrom*
	Cleanup of circulating water and reduction of radioactive waste at nuclear power plants by using ion-exchange fiber: *Ionex*
Cleanup of air and gas	Air filter by using electret nonwoven fabric: *Toraymicron*
	Organic vapor separation membranes
Reduction of plastic wastes	Recycling of polyester and polyamide
	Biodegradable plastics
Other technologies for environmental preservation	Coating materials for protecting structures from acid rain
	Ultrafine fiber sheet for antifouling of marine structures

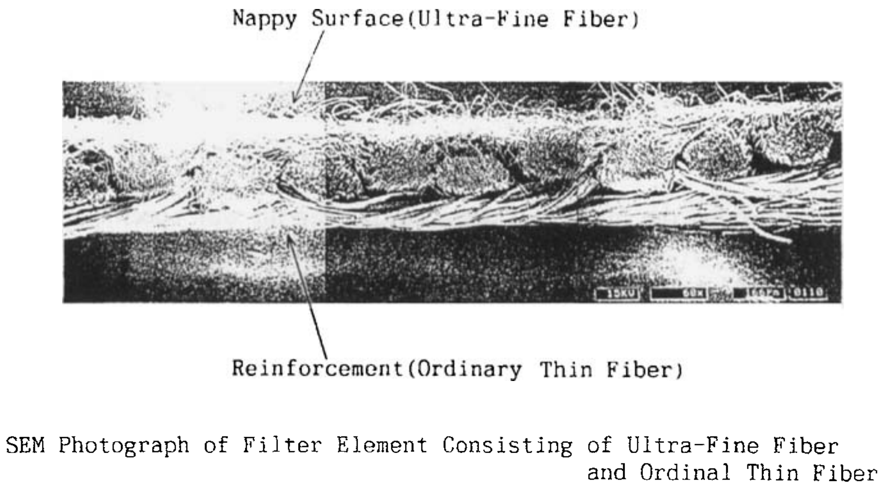


FIG. 7. SEM photograph of filter element consisting of ultrafine fiber and ordinary thin fiber. Torayrom filtering equipment with fabric filter element.

commercialized Ionex for filtration of radioactive waste of water-cooling system of nuclear generators. There are industrial applications for ultrapure water systems of electronic semiconductor manufacturing processes and new filter paper for chemical analysis as well as industrial water and air purification systems. Their merits are energy conservation through the low pressure drop of filtration.

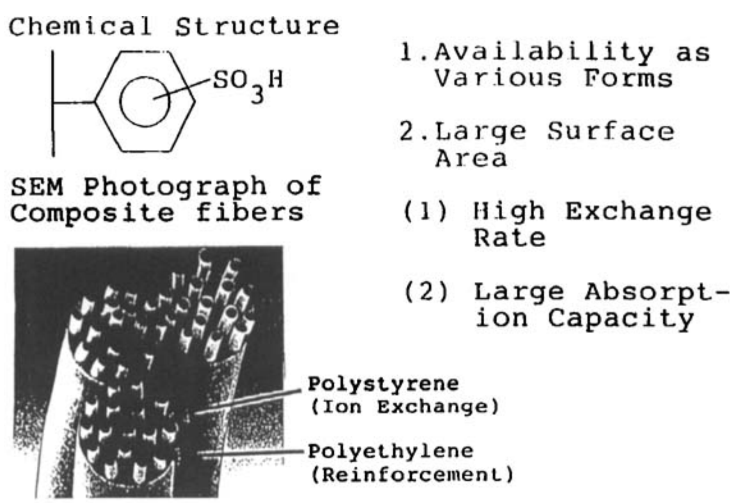


FIG. 8. Ion-exchange fiber (Ionex) for isotope trapping for nuclear generator cooling water system.

Cleanup of Industrial Gas and Air

Air Filter for Environmentally Sound Manufacturing Technologies. Toraymicron is an air filter made of electret nonwoven fabric of ultrafine fiber technology. The fabric is composed of ultrafine fiber of 2 μm diameter (fiber diameter of 350 km length per 1 g). Each fiber has a semiperpetual electric dipole which creates an electric field around the fiber. It is designed to clean air with specific functions. Conventional glass fiber filters use only their physical properties for filtration, but this new fiber uses both its physical properties and its electric properties. The characteristic features of the filter are its high trapping efficiency and its low pressure drop. Its pressure drop in terms of trapping efficiency is less than 5–50%, and it is effective for energy conservation. A new, advanced air filter for air cleaning systems is being developed at Toray.

Membranes of Organic Vapor Separation System. A separation membrane for specific organic vapors such as fluorohydrocarbons and other halogenated hydrocarbons such as trichloroethane is being developed. It will avoid wastewater treatment, offer compact equipment, and allow the recovery of thermally unstable gases.

Reduction of Plastics Waste

New Biodegradable Plastics. New types of biodegradable plastics, mainly of polyesters and polyamides, are being developed: products produced by microorganisms, naturally occurring polymers, and polymers from the chemical synthesis of petrochemicals.

New Plastic Recycle System. New synthetic fibers (Shingosen) are usually surface treated by alkali solution. The waste solution is treated by the activated sludge method and discarded into flowing water. The recoveries of terephthalic acid, alkalis, and other organic compounds are being studied.

Environmentally Sound Manufacturing (ESM) System for Environmental Protection

Antifouling Ultrafine Fabrics. Ultrafine fiber sheets are applied for antifouling of marine structures in seawater. They protect against fouling shell and other marine organisms on the surface of the sheet in water.

Acid-Rain-Resistant Coating Materials. A new coating resin to protect against corrosion by acid rain of the surface of historic buildings, statues, and fine art objects.

New Fiber Materials as Asbestos Substitutes for ESM. As substitutes for asbestos, these new acrylic fibers have fiber reinforcement materials high modulus and a higher strength. They are used for cement reinforcement fibers, as brake components, and as gaskets.

FUTURE CHALLENGES OF INDUSTRIAL ECOLOGY

The UNCED Conference held in Brazil in June 1992 became the turning point for measures to resolve global environmental problems. This conference marked the twentieth anniversary of the 1972 UN Human Environment Conference. Increased carbon dioxide is said to cause global warming. One way to cope with this problem is by using new alternative systems and materials [13–15]. Regarding the environmental issues, the global chemical industry faces incalculable costs if we allow events to run their course without intervention. There are two scenarios for responding to the environmental challenge by the manufacturing industry.

The first is characterized by the presence of firms and trade associations on a national basis reacting with an ever more aggressive environmental agenda. In the process we appear defensive, self-serving, and obstructionist. We ultimately lose the issue and our credibility.

The second scenario has great appeal. Instead of responding to natural environmental mandates, why not preempt them by defining and implementing voluntary standards which are as global as we can possibly make them. This fits the definition of sustainable development. It confronts national and local regulations and administrators with a well thought-out address to clean air, clean water, solid waste, recycling, and incineration. It will carry the full weight, experience, and confidence of the global chemical industry.

While no one has the delusion that it will be easy, it can be done. Our experiences are in agreement with life cycle assessment, responsible care's code, and Keidanren's *Global Environment Charter* of 1991 (Federation of Economic Organization and ICC Charter). We can take the initiative from those who would inappropriately regulate by using our own appropriate self-regulations.

To be unwilling to take action on the premise that the lack of global standards makes us seem inconsistent at best, or at worst willing to operate at the lowest available standards. However, the rationale of global standards is not completely defensive. We have come to find out that environmental initiative can pay. The funds that were spent on self-initiated, annual investment costs and voluntary programs are actually yielding a return on investment and making the case that pollution prevention can pay. We reached the conclusion that waste reduction always pays.

The challenge of global environmental protection is shown in Table 10. We should respond to the challenge of global issues with chemical technology [16, 17].

TABLE 10. Challenge of Global Environmental Protection—The Challenge of Global Issues with Chemical Technology

Global issues	Chemical technology
Global warming crisis	Carbon-one chemistry
Depletion of ozone layer	Biotechnology
Acid rain problem	Photochemistry
Desertification and deforestation	Catalytic chemistry
Hazardous waste	Polymer and organic synthesis

Chemical technology has great potential to create new environmentally sound manufacturing technologies such as 1) carbon-one chemistry, 2) biotechnology, 3) photochemistry, 4) catalysis chemistry, and 5) organic and high polymer syntheses toward the 21st century as shown in Table 8.

For example, by using optical fibers we can promote carbon dioxide fixation by catalysis of live marine organisms in the deep sea. Creatures like shellfish and coral produce their shells by changing carbon dioxide into calcium carbonates. We can learn to produce ceramics from carbon dioxide. Semiconductors or solar cells are used to utilize the energy of the sun instead of coal and petroleum. Many experiences, technologies, and ideas can be used for this purpose, such as carbon-one chemistry, (National Research Project of Utilization of C-1 Chemicals, such as methane, carbon monoxide, and carbon dioxide as raw materials), biotechnology, photochemistry, catalytic chemistry, polymer chemistry, and organic synthesis.

A new mechanism for international collaboration in precompetitive research of environmentally sound technology (EST) should be established to promote global economic and technological development. In the author's view, Japan's economic strength lies in the way our human resources respond to adversity [18, 19].

Wise use of human resources can overcome the contradiction between economic growth and environmental preservation. Therefore, joint R&D of EST projects by industry, academia, and government by international teams should be the base of our industrial policy in Japan. Our key strategies for international collaboration of EST are:

1. EST technical service capabilities
2. EST manufacturing credibility and presence
3. Skilled human resources for EST
4. Cost-effective distribution of EST
5. Corporate identity and company images for EST

Through technological innovation, the next century may become the age of new materials based on environmentally sound manufacturing technology.

One goal of the new chemistry is the creation of new materials with a variety of functions for EST. This will come about by studying the polymer fine structure and the assembling of molecular aggregates on the molecular level.

Materials science has the ability to create new materials of an EST that can meet the demands for expanding human activities while conserving energy and other resources [20, 21].

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