Japanese Technology Evaluation Center

JTEC

JTEC Monograph on

Biodegradable Polymers and Plastics in Japan: Research, Development, and Applications

Robert W. Lenz

March 1995

International Technology Research Institute
JTEC/WTEC Program
Loyola College in Maryland
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JTEC MONOGRAPH ON BIODEGRADABLE POLYMERS AND PLASTICS IN JAPAN

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The Japanese Technology Evaluation Center (JTEC) and its companion World Technology Evaluation Center (WTEC) at Loyola College provide assessments of foreign research and development in selected technologies under a cooperative agreement with the National Science Foundation (NSF). Loyola's International Technology Research Institute (ITRI), R.D. Shelton, Director, is the umbrella organization for JTEC and WTEC. Paul Herer, Senior Advisor for Planning and Technology Evaluation at NSF's Engineering Directorate, is NSF Program Director for JTEC and WTEC. Other U.S. government agencies that provide support for the program include the National Aeronautics and Space Administration, the Department of Energy, the Department of Commerce, and the Department of Defense.

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Depending on the study, the ITRI staff at Loyola College may help select topics, recruit expert panelists, arrange study visits to foreign laboratories, organize workshop presentations, and edit and disseminate the final reports.

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ABSTRACT

A fact-finding team of American scientists and engineers visited Japan to assess the status of research and development and applications in biodegradable polymers. The visit was sponsored by the National Science Foundation and industry. In Japan, the team met with representatives of 31 universities, government ministries and institutes, companies, and associations.

Japan's national program on biodegradable polymers and plastics evaluates new technologies, testing methods, and potential markets for biodegradables. The program is coordinated by the Biodegradable Plastics Society of Japan, which seeks to achieve world leadership in biodegradable polymer technology and identify commercial opportunities for exploiting this technology.

The team saw no major new technology breakthroughs. Japanese scientists and engineers are focusing on natural polymers from renewable resources, synthetic polymers, and bacterially-produced polymers such as polyhydroxyalkanoates, poly(amino acids), and polysaccharides. The major polymers receiving attention are the Zeneca PHBV copolymers, Biopol®, poly(lactic acid) from several sources, polycaprolactone, and the new synthetic polyester, Bionolle®, from Showa High Polymer. In their present state of development, these polymers all have major deficiencies that inhibit their acceptance for large-scale applications.

JTEC/WTEC

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FOREWORD

The National Science Foundation (NSF) has been involved in funding technology assessments comparing the United States and foreign countries since 1983. A sizable proportion of this activity has been in the Japanese Technology Evaluation Center (JTEC) and World Technology Evaluation Center (WTEC) programs. NSF has supported more than thirty JTEC and WTEC studies over a wide range of technical topics.

As U.S. technological leadership is challenged in areas of previous dominance such as aeronautics, space, and nuclear power, many governmental and private organizations seek to set policies that will help maintain U.S. strengths. To do this effectively requires an understanding of the relative position of the United States and its competitors. The purpose of the JTEC/WTEC program is to assess research and development efforts in other countries in specific areas of technology, to compare these efforts and their results to U.S. research in the same areas, and to identify opportunities for international collaboration in precompetitive research.

Many U.S. organizations support substantial data gathering and analysis efforts directed at nations such as Japan. But often the results of these studies are not widely available. At the same time, government and privately sponsored studies that are in the public domain tend to be "input" studies; that is, they provide enumeration of inputs to the research and development process, such as monetary expenditures, personnel data, and facilities, but do not provide an assessment of the quality or quantity of the outputs obtained.

Studies of the outputs of the research and development process are more difficult to perform because they require a subjective analysis performed by individuals who are experts in the relevant technical fields. The NSF staff includes professionals with expertise in a wide range of disciplines. These individuals provide the technical expertise needed to assemble panels of experts that can perform competent, unbiased, technical reviews of research and development activities.

Specific technologies, such as telecommunications, biotechnology, microelectromechanical systems, and nuclear power, are selected for study by government agencies that have an interest in obtaining the results of an assessment and are able to contribute to its funding. A typical assessment is sponsored by two to four agencies. In the first few years of the program, most of the studies focused on Japan, reflecting concern over Japan's growing economic prowess. Studies were largely defined by a few federal mission agencies that contributed most of the funding, such as the Department of Commerce, the Department of Defense, and the Department of Energy.

The early JTEC methodology involved assembling a team of U.S. experts (usually six people from universities, industry, and government), reviewing the extant literature, and writing a final report. Within a few years, the program began to evolve. First we added site

visits. Panels traveled to Japan for a week and visited twenty to thirty industrial and research sites. Then, as interest in Japan increased, a larger number of agencies became involved as cosponsors of studies. Over the ten-year history of the program, fifteen separate branches in six agencies of the federal government (including NSF) have supported JTEC and WTEC studies.

Beginning in 1990, we began to broaden the geographic focus of the studies. As interest in the European Community (now the European Union) grew, we added Europe as area of study. With the breakup of the former Soviet Union, we began organizing visits to previously restricted research sites opening up there. These most recent WTEC studies have focused on identifying opportunities for cooperation with researchers and institutes in Russia, the Ukraine, and Belarus, rather than on assessing them from a competitive viewpoint.

In the past four years, we also have begun to substantially expand our efforts to disseminate information. Attendance at JTEC/WTEC workshops (in which panels present preliminary findings) has increased, especially industry participation. Representatives of U.S. industry now routinely number 50 percent or more of the total attendance, with a broad cross section of government and academic representatives making up the remainder. JTEC and WTEC studies have also started to generate increased interest beyond the science and technology community, with more workshop participation by policymakers and better exposure in the general press (e.g., *Wall Street Journal*, *New York Times*). Publications by JTEC and WTEC panel members based on our studies have increased, as have the number of presentations by panelists at professional society meetings.

The JTEC/WTEC program will continue to evolve in response to changing conditions in the years to come. NSF is now considering new initiatives aimed at the following objectives:

- Expanding opportunities for the larger science and technology community to help define and organize studies.
- Increasing industry sponsorship of JTEC and WTEC studies. This study on Japanese biodegradable plastics and polymers R&D is one example. Twelve industrial firms provided over half of the funds.
- Providing a broader policy and economic context to JTEC/WTEC studies. This is directed at the need to answer the question, "So what?" that is often raised in connection with the purely technical conclusions of many JTEC and WTEC panels. What are the implications of the technical results for U.S. industry and the economy in general? An economist has joined the current JTEC study on optoelectronics in Japan as part of a new effort to address these broader questions.

In the end, all government-funded programs must answer the question, *How has the program benefited the nation?* A few of the benefits of the JTEC/WTEC program follow:

- JTEC studies have contributed significantly to U.S. benchmarking of the growing prowess of Japan's technological enterprise. Some have estimated that JTEC has been responsible for over half of the major Japanese technology benchmarking studies conducted in the United States in the past decade. JTEC reports have also been widely cited in various competitiveness studies.
- These studies have provided important input to policymakers in federal mission agencies. JTEC and WTEC panel chairs have given special briefings to senior officials of the Department of Energy, to the National Aeronautics and Space Administration (NASA) Administrator, and even to the President's Science Advisor.
- Studies have been of keen interest to U.S. industry, providing managers with a sense of the competitive environment internationally. Members of the study on satellite communications have been involved in preliminary discussions concerning the establishment of two separate industry/university consortia aimed at correcting the technological imbalances identified by the panel in its report.
- Information from JTEC and WTEC studies also has been valuable to both U.S. and foreign researchers, suggesting a potential for new research topics and approaches, as well as opportunities for international cooperation. One JTEC panelist was recently told by his Japanese hosts that, as a result of his observations and suggestions, they have recently made significant new advances in their research.
- Not the least important is the educational benefit of the studies. Since 1983 over 200 scientists and engineers from all walks of life have participated as panelists in the studies. As a result of their experiences, many have changed their viewpoints on the significance and originality of foreign research. Some have also developed lasting relationships and ongoing exchanges of information with their foreign hosts as a result of their participation in these studies.

As we seek to refine the JTEC/WTEC program in the coming years, improving the methodology and enhancing the impact, program organizers and participants will continue to operate from the same basic premise that has been behind the program from its inception: the United States can benefit from a better understanding of cutting-edge research that is being conducted outside its borders. Improved awareness of international developments can significantly enhance the scope and effectiveness of international collaboration and thus benefit all of the United States' international partners in collaborative research and development efforts.

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BACKGROUND

In August 1992, Professor Robert Lenz (Polymer Science and Engineering, University of Massachusetts, Amherst) and Dr. Graham Swift (Rohm & Haas Co.) met with Paul Herer of the National Science Foundation (NSF) to discuss possible NSF sponsorship of a fact-finding tour to assess the status of research and development and applications of biodegradable polymers and plastics in Japan. The proposed visit would also determine the status of and prospects for commercial development of biodegradable polymeric materials in Japan, and explore the potential impact of this field on the global economy.

In November 1993, six U.S. scientists and engineers visited Japan. The team represented active university, industry, and government research programs, and a wide range of interests in the field of biodegradable polymers and plastics. The trip, which was subsidized by grants from the National Science Foundation and twelve companies, enabled the team members to visit or meet with representatives of 31 universities, government ministries, institutes, companies, and associations in Japan over a three-week period. Participating organizations were selected based on their previous contacts with team members and the recommendations of the Biodegradable Plastics Society (BPS) of Japan. At the team's request, the BPS contacted and scheduled visits with interested Japanese organizations.

This report describes the organizations visited, and examines each organization's primary activities in the field of biodegradable polymers and plastics.

INTRODUCTION

Japan's highly effective national program on biodegradable plastics is coordinated by the Biodegradable Plastics Society. Funded by more than 70 companies and 3 government ministries, the BPS supports research in universities and government institutes throughout Japan. In close collaboration with the Ministry of International Trade and Industry (MITI), the BPS helps formulate the goals of the Research Institute of Innovative Technology for the Earth (RITE), which is the new Japanese national laboratory for the environment.

Japan's national program on biodegradable polymers began with BPS- and MITI-sponsored fact-finding teams. The teams traveled throughout the industrialized world to build a knowledge base. Japan used this base to rapidly establish many new approaches to the technology for synthesizing, testing, evaluating, and disposing of biodegradable polymers (many of which are produced from renewable resources). A principal goal of Japan’s program is to develop biodegradable polymers which are competitive technically and economically with traditional, petroleum-based polymers. The country's progress,

measured by numbers of patents and publications, leaves no doubt that Japan is now the world leader in this emerging technology.

Biodegradable plastics and polymers are certain to increase in importance as environmental contamination and waste disposal problems associated with plastics (and related products from synthetic polymers) become more severe. But the technological strides made by Japanese scientists are rapidly preempting U.S. scientists' ability to establish a proprietary position in the technology of biodegradable plastics and polymers. However, the problems of disposal and contamination shared by the United States and Japan provide a basis for cooperation.

To establish an effective, bilateral information exchange program with R&D groups in Japan, one objective of the team of U.S. experts was to initiate collaborations between industrial, university, and government laboratories in the two countries, as well as establishing relationships with important policy-setting organizations and ministries, especially BPS and MITI. The visit would focus on obtaining, organizing, and disseminating information on important aspects of biodegradable polymer technology, including: (1) types of polymers and polymeric systems under study; (2) processing and properties of biodegradable polymers; and (3) test procedures, applications, waste management of biodegradable products. It was also of interest to obtain information on the methods for establishing technology cooperation and information transfer between government, universities, and industry in Japan, and to compare their interactions with those of equivalent organizations in the United States. The survey would be conducted by a team of multidisciplinary U.S. researchers active in the field, including polymer chemists, polymer engineers, and biochemists from university, industry, and government laboratories.

Drs. Lenz and Swift submitted a formal proposal to NSF on September 1, 1993, and sent copies to fifteen companies to request supplemental support. NSF approved the proposal and provided funds for the trip as requested. Twelve companies responded with strong interest and supplemental financial support for the mission (see Acknowledgments).

All of the individuals named in the NSF proposal agreed to participate except Professor R. Clinton Fuller, who had to withdraw. Professor Fuller was replaced by Professor Steven Goodwin of the Department of Microbiology of the University of Massachusetts (see Members of the Visiting Team, Appendix A). On most days the team was divided into groups A and B. This way, two organizations could be visited in the morning and two in the afternoon of each day (see appendices A and B).

Before departing for Japan, the team asked each contributing U.S. company to provide a list of subjects of particular interest. Based on this and the areas of interest to individual team members, the team prepared questions to ask during the site visits. These questions were distributed in advance to all of the participating organizations (see Appendix B).

The tour was timed to coincide with the Third International Scientific Workshop on Biodegradable Plastics and Polymers, held at the Senri Life Science Center in Osaka from November 9-11, 1993. The team attended the workshop, which featured talks on biodegradable plastics and polymers, presented by industry, government, and university R&D personnel from around the world. Conference topics included biodegradation of polymers and plastics; environmental degradation of plastics; synthesis and properties of new biodegradable plastic materials; biodegradation and morphologies of polymer blends; development of biodegradation test methods; and governmental policy, regulations, and standards. The workshop included contributions on properties, applications, testing, and future directions of biodegradables.

Visitation reports were prepared by the team members. Each member was assigned a company or organization to report on. Each evening, the team members met. The member responsible for the site (or sites) visited that day gave an oral presentation of what he would include in his report. When the team returned to the United States, the members wrote their reports and submitted them to Professor Lenz for editing and compiling. The final draft of each report was sent to the Japanese host organization for review. Each organization responded with comments or changes.

A day-long workshop was presented at the NSF building in Arlington, Virginia on February 28, 1994. All of the sponsoring companies and several government agencies sent representatives. Each team member presented his report(s) with transparencies.

ANALYSIS AND CONCLUSION

Japan's national program on biodegradable polymers and plastics, initiated by MITI in 1989, is thriving as it enters the last five of ten years originally allocated to assess opportunities for Japanese industry. The multifaceted program evaluates new technologies, testing methods, and potential markets for biodegradables. The program is coordinated by the Biodegradable Plastics Society, an open membership organization composed predominantly of industrial representatives. For the first time in Japan, MITI permitted foreign membership in this national program (others have subsequently been opened to foreigners). Several overseas companies, including Zeneca and Rohm & Haas, took advantage of the opportunity to join. Total membership currently stands at over seventy. The stated goals of the program are as follows:

- to achieve world leadership in biodegradable polymer technology
- to identify commercial opportunities for exploitation of biodegradable polymer technology at home and overseas

To achieve these goals, the BPS works with other organizations, including academia and government laboratories in Japan, as well as organizations throughout the world.

The program is based on the respect that exists in Japan for the environment, as well as concern that every option be considered for improving the environment and preventing further decline. Biodegradables, only one option under consideration, will compete with recycling, incineration, pyrolysis, and burial. Biodegradables may never develop into a major commercial opportunity in Japan. But even if the Japanese focus on the incineration option for the disposal of waste plastics, the possibility of choosing other disposal methods will remain. Indeed, biodegradable polymers and plastics may provide greater opportunities in export markets than within Japan itself.

The approach taken in Japan is a national collaboration directed at understanding the opportunities and technologies that may be successful. Competition will come later, once Japan decides to move ahead with the technologies and the various markets. It is currently anticipated that biodegradables will satisfy only certain special market segments. Biodegradable plastics could satisfy such niche markets as fast-food wrappers, agricultural films, personal hygiene products, and marine and freshwater applications. Water-soluble polymers could achieve much broader acceptance as expectations rise that the biodegradability of these water-soluble polymers, which are disposed of into the environment, will be mandated in a few years.

The team saw no major new technology breakthroughs. As is the case for U.S. researchers, Japanese scientists and engineers are focusing on the use of natural renewable resources, synthetic polymers, and bacterially-produced polymers such as polyhydroxyalkanoates, poly(amino acids), and polysaccharides. The major polymers receiving attention are the Zeneca PHBV Biopol®, poly(lactic acid) or PLA from several sources, polycaprolactone, and the new synthetic polyester Bionolle®, from Showa High Polymer. Each of these has one or more major deficiencies that inhibit their acceptance for large-scale applications. These deficiencies include high price (with little expectation of a substantial decrease in the near future), low melting temperature, poor tensile properties at elevated temperatures, poor solvent resistance, hydrolytic instability, insufficient mechanical properties of films and molded plastics, and various combinations of these factors, all of which affect acceptance of the polymers in specific applications.

A major conclusion of the team is that biodegradable polymer technology is materials limited. That is, the technological development of biodegradable polymers is restricted presently by the range of these polymers that can fulfill processing and property requirements for many applications in which biodegradability would be an important materials property.

The level of testing and test protocol development is not as advanced in Japan as in the United States. This observation is not surprising since Japan has only recently focused attention on this area. The country is now moving rapidly to develop its own tests; recently a modification of the MITI biodegradation test for organic materials was accepted as an International Organization for Standardization (ISO) standard. The test, although similar to one developed at the American Society for Testing and Materials (ASTM), is only for screening. Nevertheless, this is a beginning.

Acceptance of biodegradable polymers will depend on four unknowns: (1) customer response to costs that are considerably higher than conventional polymers; (2) possible legislation (particularly in water-soluble polymers); (3) the achievement of total biodegradability; and (4) the development of an infrastructure to collect, accept, and process biodegradable polymers as a generally available option for waste disposal. From the team's discussions, a reasonable estimate of achievable or needed selling costs would be two to four times the cost of the polymer or plastic being replaced. This range represents the perceived value of the application plus hidden factors such as savings on recovery, which could be included in the estimate of the selling cost acceptability. Legislation is considered likely in water-solubles and possible in disposable plastics, depending on the source. Total biodegradation, clearly demonstrated in one or more environments, is generally the only acceptable situation in Japan.

Until now, the concept of an infrastructure for disposal of biodegradable plastics and polymers has received minimal attention in Japan. The major thrust has been in the area of polymer development. This lack of infrastructure is probably a practical matter rather than an oversight: attention to disposal problems will follow successful polymer developments. The option of composting is beginning to receive some attention, particularly outside the large cities, where there always has been farm waste composting. Whether this will lead to accepting plastic waste for composting is far from clear. However, a few entrepreneurs are building and selling home composters to capitalize on the sentiments of composting proponents.

Although Japan is very active in biodegradable polymer and plastic research, the country has not yet decided to move ahead with the technology at home or abroad. The decision to do so probably will not be made until late in this decade.

At this time, the team believes that there is no major gap between the United States and Japan in the research aspects of biodegradable polymers. But if Japan begins to exploit the technology commercially, the country will have a better national program in place to promote its acceptance.

The advantages of the Japanese system for developing technology have been discussed many times in recent years. Development of biodegradable polymer technology in Japan over the past five years is typical of the country's approach. Before 1988, only two Japanese laboratories were involved in biodegradable polymers at the international level. These were the laboratories of Professor Yoshito Ikeda (in biomedical polymers) at Kyoto University and Dr. Yutaka Tokiwa at the National Institute of Bioscience and Human Technology, Tsukuba.

After 1988, when the Biochemical Industry Division became a separate unit in the Basic Industries Bureau of MITI, a national policy was established to:

- accelerate research and development
- provide facilities for creative research

- develop basic systems
- promote regional development and exchange
- improve safety measures and information exchange activity
- promote international exchange

As a result, the Japan Bioindustry Association and the Biodegradable Plastics Society were established to make policy, distribute funds, promote information exchange, and coordinate testing. Through various channels, a group of eight- to ten-year projects were funded.

Key factors in the Japanese approach to technology development are: (1) intellectual property generally belongs to the industry as a result of cooperative research efforts, in which researchers carry out work at academic and government institutes; (2) information is shared more freely among academic, governmental, and industrial laboratories; (3) the scientists concentrate on carefully selected and sometimes narrowly-defined research topics; and (4) the project coordinators redefine goals during annual reviews, but they do not reduce funding prematurely. The advantages that Japanese scientists and engineers have over their U.S. counterparts are: (1) they work together to determine the value of solving a problem, and (2) they share information more readily, if not totally.

Academic and governmental institutes are mainly funded by ministries. Professors, once established, do not have to spend time seeking funds, and students and researchers are supported by universities and institutes. In that respect, they are much more efficient in devoting their energies to research, despite the fact that facilities at many of these universities are not up to date. Typically, basic research starts at university and governmental laboratories, and development and processing are carried out at industry laboratories, which eventually produce new products. Tax incentives, grants, and low-interest loans encourage the development of new technology.

Industrial incentives seem to come from consumer products industries, which feel pressure from the public. Japan is a more environmentally sensitive country than most of the developed nations. For this reason, although incineration for energy is and continues to be a primary means of waste management for Japan, biodegradation is considered to be a very desirable future option.

ACKNOWLEDGMENTS

The twelve companies that responded favorably to the request for funds to supplement the NSF grant were:

Eastman Chemical Co.
Ecochem
Cargill
Gillette Co.
International Specialty Products
Johnson & Johnson
Kimberly Clark Corp.
Rohm & Haas Co.
3M
Tambrands Inc.
United States Surgical Corp.
Zeneca BioProducts

The members of the fact-finding mission are also especially grateful to two of their Japanese hosts, Kazuhiko Fukuda of the Biodegradable Plastics Society (Dowa Building 7F, 5-10-5 Shimbashi Minato-ku, Tokyo 105), and Dr. Kyugo Tanaka of Rohm & Haas, Japan, K.K. Mr. Fukuda organized the team's schedule and made all of the arrangements for the site visits. Dr. Tanaka met with the team members each morning of the tour to provide directions and other information needed for the site visits. Without the exceptional dedication and commitment of these two men, the tour would have been very difficult to carry out and much less effective. Since the visit, Dr. Tanaka has retired from Rohm & Haas, Japan, and has established a consulting company, EMS Consultants Co. (Midori-ku, Yokohama, 227 Japan, FAX: 011081-45-961-9508, E-mail: 722061.435@compuserve. com; also see Reports of Organizations), which offers services and a newsletter in the field of biodegradable polymers and plastics.

REPORTS ON ORGANIZATIONS, COMPANIES, AND MINISTRIES

This section contains condensed reports on the government ministries and institutes, universities, companies, and societies visited. (More extensive reports were prepared that contain background information and brief descriptions of each organization's current interests and research programs on biodegradable polymers. Information on cooperative programs and names and addresses of contact persons, where appropriate and available, also were included. These full reports may be published by the Department of Commerce in the future.) See the Table of Contents for a full listing of these sites.

AICELLO CHEMICAL CO., LTD.

Summary

Aicello is a private company founded in 1933 as a cellophane manufacturer with current major products in high performance packagings for pharmaceuticals, fine chemicals, electronics, agriculture, and consumer goods. Annual sales in 1992 were $130 million. Among its 460 employees is a permanent research and development staff of 50 individuals. The company is adding 40 people per year, while losing 10 per year to retirement, resulting in a net gain of 30 people per year. Research and development accounts for ~4% of total annual sales.

Highlights

- Aicello is one of the original members of both the Biodegradable Plastics Society and the PVOH associations. It uses soil burial and MITI slurry tests for biodegradation.
- The company will not claim biodegradability until it is satisfied with the testing results.

AJINOMOTO CO., INC.

Summary

Ajinomoto has decided not to actively pursue internal research and development on biodegradable packaging materials. However, the company has joined the Biodegradable Plastics Society to monitor developments in this area. The company is closely monitoring changes in society, government, and consumers to be in a position to move into biodegradable packaging when the situation warrants. The company also suggested that petroleum-based polymers may be preferable to renewable resource-based polymers because the price of petroleum-based products may be more stable and the quality of the

products more consistent. It was thought that poly(lactic acid) might be a good compromise in this regard.

Highlights

- Ajinomoto is not actively pursuing internal research and development into biodegradable packaging.
- The company is closely monitoring developments in this area, and will test biodegradable packaging materials as they become commercially available.

BIODEGRADABLE PLASTICS SOCIETY

Summary

The meeting with the Biodegradable Plastics Society of Japan was attended by every team member and many of the BPS member companies' representatives. This informal “welcome to Japan” meeting contained only a few discussion points. Professor Lenz thanked the BPS for its help in organizing the NSF team's visit and establishing its itinerary in Japan.

The major accomplishments at the meeting were: an update from Dr. Hideo Sawada of the Technology Committee of the BPS (Dowa Building 7F, 5-10-5 Shimbashi Minato-ku, Tokyo 105); open discussions on composting and anticipated market growth for biodegradable polymers; and information on the relationships between all major committees and government- supported organizations involved in funding research into biodegradables in Japan.

Dr. Sawada gave an update on the soil burial of plastics to assess how soil condition affects biodegradation. Although the study has almost been completed, no clear conclusions have been established. However, it is apparent that biodegradable plastics will break down at rates dependent on soil conditions. The control in the series, polyethylene, shows no tendency to biodegrade under any of the soil conditions. On the subject of biodegradation testing protocols, Japan has proposed and ISO has accepted the MITI test for biodegradation as an international standard. There will be a meeting of ISO in Tokyo in September 1994 hosted by the Japan Plastics Industry Federation. BPS has developed a definition for biodegradability consistent with that of the American Society for Testing and Materials.

Compost was discussed from the perspective of the disposal of biodegradable polymers in Japan. The BPS members acknowledged that composting has long been used by farmers for agricultural waste, but were not sure how the disposal of plastics would occur. However, BPS members indicated that at the 1994 Winter Olympic Games in Norway, all food containers and implements would be manufactured from biodegradable plastic and then composted to assess the effectiveness of this disposal method.

There was no expectation on the part of BPS members that biodegradables would represent anything but a niche market in the plastics area. They see only a market of 15 X 10(9) yen by the end of the century, an amount which is about equivalent to $150 million at the current rate of exchange.

Highlights

- The Biodegradable Plastics Society is the industrial hub of biodegradable plastics research in Japan, integrating and coordinating most of the research in academia, industry, and government research centers.
- BPS is developing standards and anticipates that the modified MITI test for biodegradation will be accepted by ISO.
- The organization is assessing technology and market opportunities so that Japan will be in a position to dominate world markets when the technology is adopted.
- BPS is placing strong emphasis on niche markets, such as fishing nets, fishing line, agricultural film, and disposable packaging.
- The organization currently sees no way to effectively dispose of biodegradables, but is encouraging the development of a composting infrastructure in Japan.

DAI NIPPON PRINTING CO., LTD.

Summary

Dai Nippon Printing Co., Ltd. has a Central Research Institute (CRI), six divisional laboratories, an engineering laboratory, and an Image and Information Research Laboratory. The company also has a software division and a division in Denmark for the manufacture of TV projection screens. The division laboratories are concerned with the development of new processes, new materials, and new machines for: (1) packaging materials, (2) information media, (3) business forms, (4) materials development, and (5) microprocessing. New research and development programs are initiated on the basis of market needs that can be supplied by technologies available in one of the company's divisions.

The Central Research Institute has approximately 200 people, and is responsible for initiating and developing technologies for new products. CRI has R&D programs on: (1) electronic display devices; (2) optoelectronics; (3) information imaging; (4) biochemistry (blood test strips for sugar and proteins); (5) functional materials and process innovation; and (6) analysis.

Highlights

- Dai Nippon has two national programs on biodegradable plastics. The first, conducted in conjunction with the Biodegradable Plastics Society, is for developing standard methods for measuring biodegradation. The second is with the ECOPACK Association, and is for the development of biodegradable packing materials for snack foods, frozen foods, and dairy products.
- The company has several other internal projects on the evaluation of melt processable biodegradable polymers and polymer blends for consumer products.
- At the time of the site visit, because of price/property considerations, the company believed that only Bionolle and polycaprolactone were viable candidates for applications requiring melt processable materials.

EMS CONSULTANTS COMPANY

Eco-Materials and Systems Consultants Company (EMS) is a newly formed consultancy in Japan that offers services in the field of biodegradable polymers and plastics. The founder, Dr. Kyugo Tanaka, is a recently-retired research manager from Rohm & Haas, Japan, and has wide experience in this field. Dr. Tanaka has participated in symposia in Japan and throughout the world, and is very familiar with all aspects of this emerging technology. He recently assisted in organizing an NSF-sponsored visit of a group of American scientists to Japan. Services provided by EMS include a biweekly newsletter, *Japan Eco-Science and Technology News*; detailed reviews on special topics; technology assessments; legislative issues in Japan; technology searches; academic introductions; translations; and assistance with travel arrangements in Japan.

References are available on request. For further information, please contact Dr. Kyugo Tanaka at 1-5-51 Tachibanadai, Midori-ku, Yokohama, 227 Japan, FAX: 011-81-45-961-9508, E-mail: 72061.435@compuserve.com.

INSTITUTE OF PHYSICAL AND CHEMICAL RESEARCH (RIKEN)

Summary

The Institute of Physical and Chemical Research or RIKEN is the central laboratory of Japan and collaborates with the Imperial University System. RIKEN is a nonprofit research institute that is supported by the government's Science and Technology Agency. The annual budget is $200 million, of which 90.3% comes from the government. The on-campus staff consists of 1,300 researchers, including 300 scientists and 200 engineers and technicians. The 1,600 visiting scientists include 100 foreign postdoctoral fellows, 100 Japanese postdoctoral fellows, 140 researchers from Japanese companies, and 400

graduate students. Companies pay 30% overhead to support their visiting scientists, and the government pays 10% overhead to support their visiting scientists.

Highlights

- No commercial products from the food packaging project are on the horizon.
- No large-scale testing of biodegradable materials for packaging is underway in Japan.
- No standardized waste management policy has been developed at the national level by the Ministry of Health and Welfare.
- Dr. Yoshiharu Doi, who is associated with almost every biodegradable polymer project in Japan, has the best-equipped laboratory for the study of biodegradable polymers in the world.
- RIKEN has foreign scientists managing laboratories.

JAPAN CORN STARCH CO., LTD.

Summary

Japan Corn Starch Co., Ltd. (JCS) is a family-owned business that has been in operation since 1867. Headquartered in Nagoya, JCS currently has a current staff of about 500 persons. In Kimura, the company maintains the most advanced wet milling plant in Japan.

The plant processes 500,000 metric tons of corn starch per year. In addition, JCS operates a starch modification plant. The company is a major supplier of sweeteners for the food industry; its corn starch, corn oil, and by-products are used in the production of paper, textiles, adhesives, building materials, and consumer products.

Highlights

- Japan Corn Starch is the primary supplier of corn starch in Japan.
- JCS has a very active collaboration with Michigan Biotechnology Institute to develop starch derivatives.
- The company's philosophy in the biodegradable polymer field is motivated by the development of new materials with starch, and is not based on replacing existing materials with biodegradable polymers.
- JCS wants to be well-positioned if government regulations provide incentives for using biodegradable polymers. Otherwise, the company feels that the current customer demand for these types of materials is short term.

KAO CORPORATION

Summary

With more than 550 products, Kao Corporation is the largest manufacturer of household products in Japan. Founded in 1887, the consumer-oriented company has established a reputation as a quality producer of chemicals, including fatty chemicals, edible oils, detergents, household products, cosmetics, aural products, sanitary products, and food additives. Kao is also a leader in the manufacture of floppy disks and other communication/information technologies. The corporation, which is committed to bringing quality products to consumers around the world, has operations in twenty-five countries in Asia, North America, and Europe.

Kao Corporation maintains a commitment to service, quality, and consumer satisfaction through the implementation of three fundamental principles:

> Commitment to consumers, who are Kao's most valued asset, and their satisfaction is Kao's primary goal. A commitment to providing consumers with useful innovative products that answer actual needs guides all of Kao's corporate decisions.
>
> Equality and inherent dignity of all people is Kao's stressed corporate philosophy. The company emphasizes open communication and the sharing of ideas to improve performance to better serve the consumer.
>
> Wisdom is gained through experience and maintained through continuing effort. Kao pays close attention to the increasingly diverse market to gain a clearer understanding of consumer needs and how to satisfy them.

Kao is consumer-oriented and environmentally conscious (the company is well-versed in the requirements for the environmental biodegradation of detergent ingredients). The corporation has thoroughly researched the impact of the environmental issues surrounding its large-volume packaging use and consumer products. Regarding its near-term goals in the area of the waste-management of plastic and polymers, Kao has concluded the following:

- Kao does not anticipate introducing biodegradable packaging in the near term because of deficiencies in properties and costs relative to currently used plastics.

- The company's standards are high for accepting biodegradable polymers, that is, total biodegradability at costs very close to current plastics and polymers. Until this is achieved, Kao will use alternative approaches to lighten the environmental load, such as recycling, smaller and reusable containers, lighter bottles, and so forth.

Highlights

- Kao does not anticipate the introduction of biodegradable polymers, water-solubles or plastics, in the near future based on cost and performance deficiencies.
- Total, accountable biodegradation is the only acceptable position to Kao.
- The company does not have and will not have research programs on biodegradable polymers because it believes that no cost-effective solution is apparent. However, the company would readily adopt a material meeting its requirements, which are performance equivalence at cost similar to current polymers.

KEIO UNIVERSITY

Summary

Keio University is one of the largest private universities in Japan. Professor Shuichi Matsumura of the Applied Chemistry Department is an expert on water-soluble polymers. There are six graduate students and six undergraduate students in his laboratory. Total research funds are ~$80,000 per year. He does not pay for salary and overhead, an amount equivalent to $400,000 at an American institution. The laboratory is extremely well equipped. In addition to standard polymer and organic chemistry research equipment, it also has BOD, total oxygen demand (TOD), and other equipment for fermentation and biodegradation studies.

Highlights

- Keio University produces very basic and elegant work in water-soluble biodegradable polymers.
- Dr. Matsumura's laboratory studies the mechanisms of biodegradation of water soluble polymers.
- Dr. Matsumura uses elegant synthesis to prepare materials for studying the effects of molecular weight, tacticity, and functional groups.
- The laboratory uses UCED, gas permeation chromatography.
- weight loss, and CO_2 production by gas chromatography to follow biodegradation.

KIRIN BREWERY CO., LTD.

Summary

Kirin Brewery carries out biodegradable testing both on site and in collaboration with suppliers. On-site facilities include CO_2 production from soil microcosms. Kirin is also

hoping to get Bionolle from Showa High Polymer for testing, but has not received any material to date. The company, which is heavily involved in primary and secondary food packaging, would like to use a renewable resource rather than a petroleum-based source for the production of packaging materials.

Highlights

- Kirin expects poly(lactic acid) to be the same price as poly(ethylene terephthalate), or PET. The company will replace PET with PLA if it has the required material properties.
- The company appears to be committed to using recyclable or biodegradable materials for packaging. Kirin has stopped development work with new materials because the company believes that it is too far behind. However, the company continues to work closely with potential suppliers.

KYOTO UNIVERSITY, CENTER FOR BIOMEDICAL ENGINEERING

Summary

The Center for Biomedical Engineering at Kyoto University is the largest research center on materials for biomedical uses in Japan. Of the eight faculty members who are professors, there are two in polymer science, two in biomechanics, three in surgery/dentistry, and one in engineering. One associate professor and one assistant professor work with Professor Y. Ikeda, who is the former head of the center. There are forty graduate students, postdoctoral fellows, and researchers at the center. Funding, which is funneled through the university, comes from the Ministry of Education and various industries. The center is capable of carrying out basic materials research, processing, *in vitro* and *in vivo* testing (with 100 dogs), and human clinical testing at the university hospital. The center can carry out vertical research through testing in a manner few institutes in the world can match.

Highlights

- Professor Ikeda's group covers fundamental polymer synthesis, material processing, biocompatibility evaluation, and *in vitro* as well as *in vivo* testing of implants and drug formulation.
- It is the most comprehensive and efficient group for biomaterials in Japan and in the world.
- Professor Ikeda is the most important researcher and educator in the biomaterials field in Japan.

- Professor Ikeda's group carries out both *in vitro* and *in vivo* biocompatibility and degradation studies with quantitative techniques such as weight loss, isotopic labeling, changes in physical properties, and microscopy.

KYOTO UNIVERSITY, FACULTY OF AGRICULTURE

Summary

Although the laboratory at the Faculty of Agriculture tests the biodegradability of materials, it appears that most of its products are prepared with an emphasis on incineration as the final disposal method. The laboratory's focus seems to be on the reduction of ash through the use of natural materials.

Highlights

- Kyoto University is studying novel applications for wood derivative and cellulose derivative products.
- The university has an interest in biodegradation, but its emphasis is on ash reduction during incineration.
- Kyoto University is studying biodegradable polymers from renewable resources used in blends with synthetic polymers to reduce incineration residues.

KYOTO INSTITUTE OF TECHNOLOGY (KIT)

Summary

The Department of Polymer Science and Engineering at Kyoto Institute of Technology has 17 professors. Each professor's research group has one associate and one assistant professor. The department accepts approximately 150 undergraduate students and 50 to 60 graduate students per year. Professor Yoshiharu Kimura usually has 7 graduate students (5 in MS degree programs and 2 in Ph.D. programs) and 11 undergraduates in his research group. The MS and Ph.D. programs are separate academic programs with separate curricula. The MS is a two-year program; the Ph.D. is a three-year program. The department usually graduates 5 to 10 Ph.D.s, 50 MS students, and 100 undergraduates per year. All receive offers for positions in industry.

The Department of Chemistry and Materials Technology accepts 145 undergraduates, 50 MS students, and 8 to 10 Ph.D. students per year. Professor Nariyoshi Kawabata has 9 undergraduates, 9 MS students, and 3 Ph.D. students in his research group.

Highlights

- The Polymer Science and Engineering Department graduates the largest number of students in that field in Japan at all levels (BS, MS, and Ph.D.). It must also be one of the largest academic programs in the world in the polymer field.
- Professor Kimura's laboratory has been able to prepare high molecular weight poly(lactic acid) by the direct polyesterification of L-lactic acid.

MINISTRY OF AGRICULTURE, FORESTRY AND FISHERIES (MAFF)

Summary

The Ministry of Agriculture, Forestry and Fisheries (MAFF) funds programs on biodegradable polymers, including a feasibility study entitled “Research for Development of Fishing Gear Utilizing Biodegradable Plastics.” This research program is in its first year of a five-year effort. The program supports work at Hyogo Prefectural Fisheries Lab (a government laboratory established by the regional Prefecture Office) and at Dr. Y. Doi’s RIKEN laboratory. Dr. Doi serves primarily as a consultant to this program.

The goals of the program are to explore products for sports fishing line and fishing nets (for cultivation of seaweed and off-shore fishing). Total funding for the program is about $110 thousand per year. In addition, the ministry funds a project entitled “R&D for Food Packaging Friendly to the Environment.” This effort supports nine projects at a total of about $2 million per year. Dr. Doi is also an advisor to this project.

Highlights

- MAFF programs focus on commercial products for the marine industry.
- MAFF has a five-year feasibility study in progress for marine applications, but has no legal authority to implement regulations for fishing gear.
- While cost is a major issue for commercial use, this may not be the case for fishing line. Consequently, this area could provide a good niche for the use of biodegradable polymers.
- No established position on biodegradation testing was discussed by the staff. Currently, only tensile strength is used to assess material performance.
- Legislation has been passed to comply with MARPOL so that all plastics are returned to shore and not disposed of overboard.

MINISTRY OF INTERNATIONAL TRADE AND INDUSTRY (MITI)

Summary

MITI has approximately 300 divisions and 10 bureaus. It has been described as an organization with many pyramids in its structure. The division administrators do not closely oversee ongoing programs. Instead, they seem more concerned with future directions for their programs. In most cases MITI provides five to ten years of assured funding for their active programs, and makes low-interest loans available for the commercial development of the products from those programs.

Highlights

- Programs funded by MITI are assured funding for five to ten years in general.
- MITI assigned the administration, management, and evaluation of the program on their specific projects to nonprofit organizations such as Japan Biotechnology Association and NEDO. MITI discusses basic policies on the technical aspects of the program with those organizations.

MITSUBISHI PETROCHEMICAL CO., LTD., YOKKAICHI DIVISION

Summary

The Mitsubishi Petrochemical Co. (MPC) has principal research centers at Yokkaichi and at Tsukuba. The former is devoted to market-oriented research and the latter to long-term basic research, including biotechnology. The company had sales of approximately $3.7 billion dollars in 1992 in five major areas: (1) industrial chemicals (45%); (2) plastics (45%); (3) fine chemicals (e.g., components of consumer products); (4) electronic components; and (5) bio-related products (especially L-aspartic acid, fungicides, and amino acids). Their plastic products are of three principal types: (1) polyolefins, especially polypropylene; low-density, linear low-density, and high-density polyethylene; and ethylene-vinyl acetate copolymers; (2) specialty polymers, including propylene-based thermoplastic elastomers, poly(acrylic acid), polymers for adhesives, and conducting polymers; and (3) engineering plastics, especially fiber-reinforced PET and poly(phenylene ether)-nylon blends.

The major market area for MPC plastics is in the company's polyolefins films (more than 50% of MPC's polyethylenes are sold as films). MPC has a particularly strong capability for producing cast films and oriented films. A large market for the company's PE films is in greenhouse covers. The company also has substantial sales in Japan of PE films for nondegradable, mulch film applications. Japanese farms are relatively small, so it is not too inconvenient for them to remove the mulch films after the growth season and dispose of them in landfills or by incineration. MPC has evaluated photodegradable films for that purpose. However, such materials were found to be unsuitable because pieces of the

disintegrated film remained in the soil and were considered to be an environmental hazard. The company takes the same view of PE films, which have prooxidants designed to degrade by oxidation. MPC agrees that biodegradable mulch films would be very desirable if they had acceptable mechanical properties and did not cost substantially more than normal PE films. The company estimates that a product that was up to 50% more in price than current nondegradable mulch films would be acceptable to the farmers because of the saving on labor costs.

Highlights

- There has been a steady and substantial increase in the use of biodegradable polymers over the past several years, ever since this area was recognized as one of national importance. Mitsubishi Petrochemical Co. is very optimistic about future development of commercial products based on biodegradable polymers.
- MPC primarily produces polymers. The company takes the position that, to protect its customer relationships and future markets, it must become proficient in processing and converting biodegradable polymers for consumer products, whether or not it produces such polymers.

MITSUI TOATSU

Summary

Mitsui Toatsu is a chemical company with $4.3 billion in sales in 1993. Polypropylene (PP), polystyrene (PS), and poly(vinyl chlorine) (or PVC) are the company's major products in the commodity sector. The team visited the company's Life Sciences Department. The six groups in the Life Sciences Department are pharmaceuticals, agrochemicals, plant biotechnology, biotechnology, amino acids, and biodegradable polymers. The task group was introduced to the company through the company's brochures and descriptions of the products and research.

Highlights

- Mitsui Toatsu is a large chemical company that plans to become a raw materials supplier in biodegradable polymers. The company currently manufactures two types of biodegradable polymers for medical applications: polyglycolic acid and glycolic-lactic acid copolymers.
- Mitsui Toatsu has patented a novel process to polymerize lactic acid through direct condensation polymerization to obtain high molecular weight poly(lactic acid).
- The company plans to build a plant between 1995 and 1998 to produce 1,000 to 10,000 tons per year of poly(lactic acid).

- Mitsui Toatsu believes that the introduction of legislation to mandate the use of biodegradable polymers would be a key factor for expanding the market.

NAGOYA UNIVERSITY

Summary

The focus in the School of Agricultural Sciences of Nagoya University is on the study of the utilization of natural products. Dr. Masahiko Okada's group consists of one associate professor, two assistant professors, one secretary, one doctoral student, ten master's degree students, and five undergraduate students. Dr. Okada obtains funding from the Ministry of Education through the university, and an equivalent amount from companies. Some funding also comes from the Japan Society for the Promotion of Science (JSPS) and private organizations and foundations to which proposals for grants are submitted. In the case of funding support from companies, the company obtains patent rights to inventions. The major focus of Dr. Okada's research is on synthetic polymer chemistry approaches to novel polymers for medical applications.

Dr. H. Kimura's group consists of an associate professor, one assistant professor, one doctoral student, seven master's degree students, seven undergraduate students, and four foreign research associates or doctoral students (one from France, two from China, and one from Korea). His funding comes from four main sources: (1) the Ministry of Education, which provides core government funding to the university (no proposals are required); (2) proposals submitted to the Ministry of Education; (3) private foundations to which proposals are submitted; and (4) the Biodegradable Polymer Society and related associations and companies.

Highlights

- Extensive synthetic chemistry programs for the preparation of new biodegradable/hydrolyzable polymers are underway.
- Microbial ecology assessments of biodegradable polymers are in process.
- Some studies are carried out in activated sludge and soils, some with recovery of carbon dioxide, and others with hydrolysis.
- The analysis of field samples is based on film exposures in active natural environments.

NIPPON GOHSEI

Summary

Nippon Gohsei, founded in 1927, is a producer of a variety of synthetic chemicals, including poly(vinyl alcohol) (or PVA) and ethylene-vinyl acetate copolymers. The company's PVA manufacturing capacity is the second largest in the world at approximately 6,000 tons per month, and includes a 30% share of the Japanese market. The company employs approximately 1,100 people, 130 of whom are at the R&D laboratory in Osaka. Nippon Gohsei maintains three production facilities in Japan. PVA is used in textiles, paper processing, emulsifiers, sizing, and adhesives.

Highlights

- Nippon Gohsei is involved in a joint effort with Novamont to develop and market starch blends.
- The company is a major producer of PVA for biodegradable materials.
- PVA used in textile sizing and other applications is currently treated in an activated sludge system. The company believes that it is completely biodegradable under these conditions.
- Nippon Gohsei has already succeeded in isolating specific microorganisms and enzymes involved in this process,[*] while they use the MITI method as a novel one to assess biodegradation (activated sludge and BOD).

NIPPON SHOKUBAI, K.K.

Summary

Research spending at Nippon Shokubai (NS) is about 6% of sales, that is, approximately $80 million per year. Over 600 employees, comprising 25% of the total company employment, are engaged in research work.

The company's credo is "to create technology for better lives." This is embodied in a concept called TechnoAmenity, which is aimed at making peoples lives healthier and happier through technological innovation by solving environmental problems such as acid rain, ozone depletion, rain forest losses, desertification, and global warming.

Interest in biodegradable polymers is related to the pressure that the company is feeling from its customers in the water-soluble and super-absorbent polymers. The company expects that those polymers will eventually have to be biodegradable, and that legislation will be introduced in Japan mandating the biodegradability of some water-soluble

[*] Nishikawa, H., and Fujita, Y. Chem. Econ. Eng. Rev., 7 (4),33 (1975).

polymers. Nippon Shokubai bases this position on the April 1994 joint statement in Tokyo from MITI and the Organization for Economic Cooperation and Development (OECD) that water-soluble polymers represent a potential environmental problem. The joint statement is considered a strong indication of impending MITI requirements and control.

In addition to programs in the chemical synthesis of biodegradable water-soluble polymers, the company is also embracing biotechnology to clean waste streams before release into the environment.

Highlights

- Nippon Shokubai expects legislation mandating biodegradable water-soluble polymers to be initiated by MITI in the future.
- The company has twenty or more people working in biodegradable polymers, with outside contributions.
- Total biodegradability is the company's stated goal.
- The company does not expect the standard vinyl polymerization to form water-soluble polymers, that is, acrylics to meet the requirements for biodegradation. Nippon Shokubai is moving toward new approaches to explore synthetic polymers that have a natural-type structure, either wholly or in part.

OSAKA NATIONAL RESEARCH INSTITUTE, AGENCY OF INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

Summary

The Osaka National Research Institute receives its budget from MITI and accepts no funds from industry. The institute's 1993 operating budget was $29.2 million. There are 207 permanent staff, of whom 159 are researchers. Fifty-nine percent of the budget is allocated to salaries and 41% to research expenses. The institute has received 1,000 patents, of which 70 have been used in commercial applications. Approximately 70 students are sent from universities to receive training at the institute.

Highlights

- Osaka National Research Institute participates in large-scale national projects with long-term funding (e.g., Energy Conservation Technology, Moonlight project; New Energy Technology, Sunshine project; and Global Environment Technology).
- More than 40% of the institute's budget goes directly to research expenses.

PLASTICS WASTE MANAGEMENT INSTITUTE (PWMI)

Summary

The Plastics Waste Management Institute (PWMI) was founded in 1971 as the plastics industry's response to local governments' claims that the increase of plastics was a cause of trouble. PWMI currently receives $5 million per year from thirty petrochemical companies and $400,000 per year from MITI. PWMI employs twenty-one staff engineers who provide research and development in plastics waste recycling, pyrolysis, and incineration, and also provide surveys and public relations.

Highlights

- PWMI is supported by thirty petrochemical companies and MITI, which encourage R&D efforts that enable adequate disposal and recycling of waste plastics. As such, the institute's efforts are primarily focused on the recycling and incineration of waste plastics.
- The biodegradation position of PWMI was very negative. The company favors recycling and thermal recycling.

SHIMADZU

Summary

Shimadzu, founded in 1875, employs approximately 4,300 persons. The company had 1992 sales of approximately $1.3 billion. Shimadzu's headquarters are in Kyoto. The company also has two factories in Kyoto; sales and marketing branch offices throughout Japan; overseas offices in Egypt, China, and Russia; and overseas subsidiaries in the United States, Germany, England, Austria, Italy, Singapore, Australia, and Brazil. The Bio-Applications Center is located in Tokyo. There are four main divisions in the company: Analytical Instruments, Medical Equipment, Aircraft Equipment, and Industrial Machinery. Virtually all of the company's focus is on analytical equipment and related test and evaluation systems. Shimadzu exports approximately 22-25% of its total sales.

Highlights

- Production of poly(lactic acid) is a new direction for the company; commercial production is planned for 1994.
- Shimadzu has developed a lactic acid fermentation process and is collaborating with Mitsubishi Plastics Ltd. to develop poly-L-lactic acid.
- The company has begun construction of a pilot plant in Ohtsu City with a 100 ton per year capacity. Shimadzu anticipates that the plant will be fully operational by next

summer. If the pilot scale plant is successful and if the markets are favorable, the company has further plans to scale up to 1,000 tons per year in two to three years.

- The company plans to make and sell resin. Customers will generate the products.

SHOWA HIGH POLYMER CO., LTD.

Summary

Showa is a major Japanese producer of unsaturated polyesters, emulsions, and phenolics, with 1993 sales in excess of $261 million. The company is a member of the Showa Denko group, which also owns Showa Denko, K.K., a multiline chemical company. It is producing Bionolle® polyesters chains extended with diisocyanate.

Highlights

- Bionolle is one of the most developed biodegradable synthetic polymers since polycaprolactone (PCL).
- Showa tested Bionolle in Japan and Belgium with soil, active sludge, and suspended soil in water.
- Showa representatives think Bionolle is better than PE for incineration since it has lower BTUs.

TAISEI CORPORATION

Summary

Taisei Corporation, primarily a building construction and engineering company, had $13.2 billion in sales in 1993. The biotechnology team of Taisei was formed seven years ago and is divided into two groups: plants and bioreactors. The plant group is currently working on turf grass and salt tolerance of rice for sea water irrigation. The bioreactor group is currently working on developing bioreactors for wastewater treatment/purification.

Highlights

- The Taisei Corporation, which is a building construction and engineering company, is working on a recovery system for production of microbially-produced polyester from wastewater treatment facilities. Poly(ß-hydroxybutyrate), or PHB, was accumulated in amounts up to 27% by weight by batch culture under anaerobic conditions utilizing thermochemically liquefied sludge.
- Taisei's system is being scaled up to a semibatch culture to produce PHB using activated sludge and excess sludge as carbon sources at wastewater treatment facilities.

TOKYO INSTITUTE OF TECHNOLOGY

Summary

Tokyo Institute of Technology is primarily a graduate school with no postdoctoral program. The Research Laboratory of Resources Utilization is headed by Professor Takeshi Endo. The laboratory consists of thirteen divisions, each with an associate professor and two research associates. The research areas in the laboratory include biochemistry, polymer chemistry, organic-metal complexes, catalysts, polymer processing, and other topics. The primary topics covered in the team's discussions included the synthesis of biodegradable polymers, recycling of organic wastes into useful materials, and chemical recycling of polymeric materials. The institute's representatives discussed mechanisms available to obtain research support at the institute. They said that in general, funding was considered difficult to obtain. Some companies send research staff to the institute. However, most of these types of exchange occur based on personnel contacts between the companies and the professor. The company obtains all rights to patents that may derive from the joint research.

Highlights

- The Tokyo Institute of Technology is evaluating novel synthetic chemistry approaches to the preparation of new biodegradable polymers.
- Enzyme hydrolysis is the primary research tool used to assess biodegradability.

TOPPAN PRINTING

Summary

The Toppan Printing Company is a large manufacturer of food packaging. Founded in 1990, this publicly-traded company had 1993 net sales of $10 billion. Its main divisions are General Printing and Electronics (48%), Packaging (27%), Publications and Printing (20%), and Scientific Printing (4%). The current products that the Packaging Division manufactures are 65% for food uses, 20% for medical and cosmetics uses, and 15% for other uses. The products range from PET bottles to milk cartons to chip bags and snack packaging. Except for the PET bottles, the company wants to make all of its packaging biodegradable.

Highlights

- Toppan is developing food packaging using the currently available biodegradable materials.
- Toppan Printing Company has developed a coextrusion process for coating paperboard (such as containers and cups) by using Biopol®, which consists of a series of

poly(3-hydroxybutyrate-co-3-hydroxyvalerate) copolymers that are biodegradable polyesters.

- Toppan wants to convert all of its plastics packaging, except PET bottles, to biodegradable materials. However, since Toppan Printing is not a manufacturing company, it depends on other companies to provide those materials.
- Within the next ten years, the company's research goal is to find a material that performs as well as the current packaging material for less than $2.50/lb.
- Toppan takes the view that the price is more important than whether the material is based on renewable resources or petrochemicals.
- The application areas projected for biodegradable polymers are for all of the packaging that Toppan produces, with the exception of PET soda bottles.

TSUKUBA RESEARCH CENTER: NATIONAL INSTITUTE OF BIOSCIENCE AND HUMAN TECHNOLOGY NATIONAL INSTITUTE OF MATERIALS AND CHEMICAL RESEARCH

Summary

The National Institute of Bioscience and Human Technology (NIBHT) has an annual budget of approximately $13.7 million. The institute has a permanent staff of 220, of whom 185 are involved in research. The National Institute of Materials and Chemical Research has an annual budget of $59 million. Of the permanent staff of 419, 349 are engaged in research. The biodegradation research includes poly(ß-hydroxybutyrate) production and microbial degradation, production of derivatized starches, and blend yarns of PCL and conventional plastics, with emphasis on biodisintegration after biodegradation.

Highlights

- NIBHT has one of the principal microbiology programs involved with biodegradables in Japan.
- The Tsukuba Research Center is well positioned to become a focus for creative technologies with the advent of Tsukuba Science City.
- Dr. Yutaka Tokiwa is a recognized authority and pioneer in the development of biodegradable polymer blends.
- Several RITE researchers are working in Dr. Tokiwa's laboratory.

UNITIKA

Summary

Unitika is just over twenty years old. The company was formed in 1970 through the merging of Nichibo, a fiber producer founded in 1889, and Nippon Rayo, a fiber and plastics producer founded in 1926. The current research and development center in Uji was opened in 1939 (Nichibo). Current business in Unitika is divided into eleven divisional lines:

Technical Development
New Business Development
Fibers and Textile #1
Fibers and Textile #2
Plastics
Spunbonded
Glass Fibers
Engineering
Construction and Real Estate
International
Synthetic Spun Textile

The research philosophy at Unitika is to maintain current business and extend into new areas that are considered viable long-term opportunities. Biodegradable polymers, particularly for fibers, are seen as such an opportunity. This opportunity is being exploited in the Fine Chemicals, Nonwovens, Plastics, and Synthetic Fibers divisions.

Highlights

- The company has well thought-out goals developed through understanding its available options.
- Unitika is open to new ideas and has very active collaborations outside the company.
- The company projects that biodegradable plastics will probably only comprise a niche market.
- Unitika has a serious concern about costs, and believes this to be very limiting for the market.
- Company representatives express honest doubt, and are reserving decisions and commitment to biodegradables to a later date.
- The company considers biodegradability to be total removability from the environment.

ZENECA, K.K.

Summary

Zeneca, K.K. is a 100% wholly-owned subsidiary of Zeneca Ltd. (U.K.). On June 1, 1993, Zeneca became a separate company from ICI, its former owner. The task force, consisting of Drs. McCarthy, Lenz, and Kaplan, met with Yoshinobu Muta, Manager of BioProducts; Makoto Yamashita, Biopol Commercial Manager; and Katsuhiko Tsuchikura, Biopol Technical Manager, at the Zeneca Office located in Chiyoda-ku, Tokyo. The entire staff of Zeneca, K.K. consists of ten people in both the Tokyo office and in the research and development laboratory in Tsukuba at Japan Technical Center.

The biodegradation position of Zeneca is to impose strict guidelines on converters to use, ideally, biodegradable or inert food grade colorants and additives, and insure complete biodegradation of any product using Biopol, or poly (3-hydroxybutyrate-co-3-hydroxyvalerate). Currently there are no industry or government standards. Zeneca stated that incinerators are difficult to site. Also, large city composting facilities are a problem due to the lack of farmers near large cities and fear of contamination. The company stated that home composting is popular, and that there are sophisticated composting devices that can be installed inside the home; 3,000 of these very popular devices have been sold. In addition, the consumer feels somewhat better when purchasing a biodegradable product since, in the worst case, if the waste is dumped into the ocean or ends up as litter, it will biodegrade.

Highlights

- Zeneca, K.K. is a supplier of Biopol, which is produced at the company's United Kingdom plant. Approximately 50% of its sales, from a capacity of 300 tons in 1992 and 600 tons in 1993, were sold in Japan.
- Large-volume commercial and developmental products include a disposable razor, shampoo bottles, golf tees, combs, utensils, dishes, cups, and toiletry products.
- All research on Biopol is done in the United Kingdom. However, the company has facilities for applications and technical service at the Technical Center of ICI Japan Ltd. in Tsukuba.

APPENDICES

APPENDIX A. MEMBERS OF THE VISITING TEAM

Group A:

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Professor Stephen P. McCarthy
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APPENDIX B. SCHEDULE OF VISITS

The following schedule was arranged by the Biodegradable Plastics Society:

TOUR DAY	GROUP	MORNING	AFTERNOON
1	A and B	MITI* , MAFF*	PWMI*
2	A	RIKEN*	Toppan Printing
	B	RIKEN	Dai Nippon Printing
3	A	Showa high Polymer	Kao Corp., BPS*
	B	Zeneca	Mitsui Toatsu Chemicals, BPS
4	A	Kirin Brewery	TIT*
	B	Keio Univ.	Taisei Corp.
5	A	Kyoto Univ.	Unitika
	B	Nippon Gohsei	KIT*
6	A and B	Japan Corn Starch	
7	A and B	Osaka National Research Institute	Shimadzu
8	A	Aicello Chem. Co	Toyohashi Univ. of Tech.
	B	Nagoya Univ.	Mitsubishi Petrochem. Co.
9	A and B	----------	Nippon Shokubai
10	A and B	Government Institutes in Tsukuba	

* Abbreviations:

MITI	Ministry of International Trade and Industry
MAFF	Ministry of Agriculture, Farming and Fisheries
PWMI	Plastics Waste Management Institute
RIKEN	Research Institute of Physical and Chemical Research
BPS	Biodegradable Plastics Society
TIT	Tokyo Institute of Technology
KIT	Kyoto Institute of Technology

APPENDIX C. QUESTIONS POSED TO JAPANESE HOSTS

A. Questions on financial support for research and development and on policy matters:

- What are the sources of support from industry, government, university and /or institute?
- What is the duration of support -- are the funds given for long or short periods of time?
- Are there any restrictions on publications, and is the choice of research investigations and directions given to scientists in the use of the funds?
- Who owns the patents and how are royalties of licenses arranged?
- Do some of the funds given to universities or institutes go to the support of students or post-doctoral fellows?
- Is a distinction made between basic and applied research for project selection and financial purposes?
- What are the national priorities for short and long-term solutions to plastic waste disposal. What is the relative importance of recycling, incineration, landfills, ocean disposal, and biodegradation? Is plastic pollution on land (litter) and at sea given a high priority? How much effort is being placed on composting?
- Are there specific initiatives and funding programs for these subjects? If so, what is the percentage of distribution of effort in each? Are these programs coordinated by various agencies, i.e., by government, industry, and institutions?
- Do government, industry or academic programs and institutes set policies and control priorities for research? If so, at what level in these funding agencies are programs initiated? How does the coordination between these various levels and agencies work?
- Is there any possibility that legislation will be passed in Japan requiring the use of biodegradable polymers and/or plastics for specific applications? If so, will the government provide a tax incentive for that purpose?

B. Questions about research and development projects and programs:

- What polymers and related materials are being studied?
- What are the primary goals of the research?
- What polymer processing issues are being studied? Is recycling considered important?
- What types of products are being targeted?
- How is biodegradation assessed (including definitions, acceptability, and test methods)?

- Who funds the work and at what level of effort (number of research workers involved)?
- How long has it been funded?
- When do you expect to have a product for evaluation and for sale in quantity?
- What are the expected consumer and/or industrial markets for your product?
- What is the expected price of the materials; which raw materials will be used in its Production?
- How important is it to derive the technology from renewable resources rather than use petrochemicals as the raw materials?
- How does this effort fit within other approaches to the problem of waste disposal (e.g., recycling, incineration, etc.)?
- Does the research and development involve cooperation and exchanges between industry, universities, and government? If so, how is that arranged and funded?

C. We would be pleased to receive from each organization:

- Material that will help us write our report, including copies of publications, patents, and summaries of activities, and reference listings.
- Suggestions on how to foster the exchange of information and collaborations between the United States and Japan.
- Perceptions of strengths and weaknesses of the United States and of Japan in this field.

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