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June 1985

Prepared for the U.S. Department of Energy
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Pacific Northwest Laboratory
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Richland, Washington 99352

(a) Global Competitiveness Council

PREFACE

This study was completed for the Office of Energy Systems Research (ESR) in the U.S. Department of Energy (DOE). The primary goal of ESR research programs is to provide a solid technology base in areas related to energy storage, energy conversion, energy end use, and the transmission and distribution of electrical energy. These programs serve as the foundation for the energy end-use offices in the DOE Conservation and Renewable Energy Program as well as for those in private industry. The specific objectives of ESR are:

1. to develop the technology base required to achieve improvements in the efficiency and fuel flexibility of future energy conversion, storage, transmission, distribution, and utilization in all end-use sectors.

2. to improve the energy efficiency of technologies having application in a variety of industries.

4. to provide technology options that will enhance the reliability of the nation's future electric network under normal and emergency situations.

To aid in achieving these objectives, in 1982 the ESR staff established the Technology Analysis and Evaluation Project, which is conducted from the Pacific Northwest Laboratory.[a] This project assists ESR in planning and managing its research program by conducting technical program evaluations, program information management, technology characterization and assessments, and international technology monitoring.

This document contains the details of a study performed to build the groundwork for ESR international monitoring efforts. The study explores the status of research and technology developments in Japan and the ability of U.S. researchers to keep abreast of Japanese technical advances. Ten technology

(a) Pacific Northwest Laboratory (PNL) is operated for the U.S. Department of Energy by Battelle Memorial Institute.

areas that can be applied to improving the efficiency of energy use and that are relevant to ESR research programs were examined. A brief overview of this investigation is published in an executive summary.[a]

(a) Hane, G. J. et al. 1984. Assessment of Technical Strengths and Information Flow of Energy Conservation Research in Japan: Executive Summary. PNL-5244, Vol. 1, Pacific Northwest Laboratory, Richland, Washington.

SUMMARY

The purpose of this study is to explore the status of research and technology developments in Japan and the ability of U.S. researchers to keep abreast of Japanese technical advances. To obtain this information, U.S. researchers familiar with R&D activities in Japan were interviewed. These researchers were chosen to represent ten fields that are relevant to the more efficient use of energy: amorphous metals, biotechnology, ceramics, combustion, electrochemical energy storage, heat engines, heat transfer, high-temperature sensors, thermal and chemical energy storage, and tribology. The researchers were questioned about their perceptions of the strengths of R&D in Japan, comparative aspects of U.S. work, and the quality of available information sources describing R&D in Japan.

Overall, the researchers interviewed sensed an increasing commitment to longer-term R&D in Japan and frequently commented that, although current U.S. work may be superior, the "momentum" behind the work in Japan indicates that significant competitive challenges will certainly be forthcoming.

Of the ten related fields, the researchers expressed a strong perception that significant R&D is under way in amorphous metals, biotechnology, and ceramics, and that the U.S. competitive position in these technologies will be significantly challenged. Researchers also identified alternative emphases in Japanese R&D programs in these areas that provide Japan with stronger technical capabilities. For example, in biotechnology, researchers noted the significant Japanese emphasis on industrial-scale bioprocess engineering, which contrasts with a more meager effort in the U.S. In tribology, researchers also noted the strength of the chemical tribology research in Japan and commented on the effective mix of chemical and mechanical tribology research. This approach contrasts with the emphasis on mechanical tribology in the U.S.

Researchers' evaluations of information transfer varied from good in some areas to poor in others. The most consistently noted shortcomings in the current ability to keep abreast of work in Japan were the poor interaction with and the infrequent opportunity to visit Japanese laboratories. Scientific exchanges to Japan and binational technical workshops were frequently recommended as ways to improve information exchange.

ACKNOWLEDGMENTS

The research staff would like to thank Terry Levinson of the Office of Energy Systems Research for her conceptual guidance and support of this project. We also thank Dr. W. Bradford Ashton for his managerial support of this effort. Finally, we extend our appreciation to Ken Burke for his valuable clerical support throughout the project.

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1.0 INTRODUCTION

In recent years, the U.S. has become increasingly aware of advances in international technology development. As a result of these advances, U.S. technology is faced with increasing levels of competition. Commercial developments since the 1970s have shown that a significant part of this technological challenge is coming from Japan. The challenge of Japanese technology developments has already been witnessed in major U.S. industries such as the iron and steel industry, the automobile industry, and consumer electronics. Currently, significant attention in the U.S. is being directed toward Japanese commercial developments in semiconductors and industrial robotics. Announcements of new technology developments are also expected in a number of diverse fields, as described below:

- In photovoltaics, Sanyo, TDK and Komatsu have all announced the development of amorphous silicon solar cells with efficiencies greater than 10%.
- In amorphous alloys, Japanese companies such as Hitachi and Sony have been the first to manufacture recording heads with a double-roller quenching method.
- In high-power semiconductors, Japanese companies have announced the development of thyristors with current and voltage capacities that are an order of magnitude greater than any made in the U.S.

Technology development in Japan has been notable for its remarkable effectiveness in combining national expertise with international developments and research results. Japan's significant advances in technology have caused concern about the ability of the U.S. technical community to keep abreast of those activities. Problems of language, culture, and interaction have aggravated the lack of U.S. understanding and made this deficiency in our ability to monitor Japanese R&D increasingly apparent.

This study was performed by Pacific Northwest Laboratory (PNL) for the Office of Energy Systems Research (ESR) in the U.S. Department of Energy (DOE). The objective was to explore the status of energy-related research and technology developments in Japan and evaluate the ability of U.S. researchers to keep abreast of technical advances in Japan. The study was conducted by interviewing U.S. researchers who are familiar with technology development in Japan to discuss their perceptions of the strengths and comparative status of Japanese work, and their perceptions of the quality of information transfer to the U.S. technical community. Researchers in ten technology areas were identified and interviewed:

- Amorphous Metals
- Biotechnology
- Ceramics
- Combustion
- Electrochemical Energy Storage
- Heat Engines
- High-Temperature Sensors
- Heat Transfer
- Thermal and Chemical Energy Storage
- Tribology.

These technology areas were selected because they can be generally applied in promoting the more efficient use of energy and because they are relevant to programs within the ESR in the U.S. DOE. Longer-term basic and applied research was given particular emphasis. Basic research typically involves investigating the fundamental behavior of processes, and applied research typically addresses particular applications or technologies and improvements in their performance.

Although the researchers' perceptions described in this study are generally qualitative, they nonetheless provide technically based assessments of overseas technical progress at the earliest stages of development. The researchers' comments on the quality of information transfer provide indications of the ability of U.S. researchers to benefit from research results and developments in Japan, as well as the ability of U.S. research managers to develop their plans with an international perspective.

A comprehensive analysis of the issues of comparative advantage and information transfer would require a far more extensive effort than was possible in this study. Instead, this study is intended to 1) provide preliminary indications of significant work in Japan through the perspectives of researchers, 2) develop a sense of the quality of technical information researchers have available, and 3) identify researchers and resources that could be used to conduct a more complete review of any single technical area.

This chapter provides background information on technology development in Japan, particularly R&D related to energy conservation, and on the specific issues addressed in this study.

1.1 OVERVIEW: TECHNOLOGY DEVELOPMENT IN JAPAN

This section provides historical information on Japanese technology development and summarizes current energy conservation related R&D in Japan.

1.1.1 Research and Technology Development in Japan

During the 1960s and 1970s Japanese R&D efforts were often characterized as "improvement R&D," which takes a technology typically developed in another country and improves its performance and cost. Peck (1976) notes that one Japanese company had determined that their commercial success rate for projects that improved on foreign technology was one in five, whereas their success rate for projects based on their own research was less than one in ten. As a result of this emphasis on improvement R&D and the commercial orientation of R&D efforts, there was little evident interest in performing longer-term basic or applied research. However, Peck (1976) also notes that by 1970 Japan had caught up to the international community in several technologies, and thus industries and the government were faced with the need to initiate and pursue their own research concepts.

A significant increase in R&D commitment has clearly been evident in Japan since 1970. In 1970 the investment in R&D as a fraction of the gross national product (GNP) was ~1.8% in Japan, compared with 2.6% in the U.S. By 1981 this commitment to R&D in Japan had increased to ~2.4%, approximately equal to the U.S. investment. R&D spending as a percentage of GNP from 1970 to 1983 is shown in Figure 1.1 for Japan, the U.S., West Germany, Great Britain, and France.

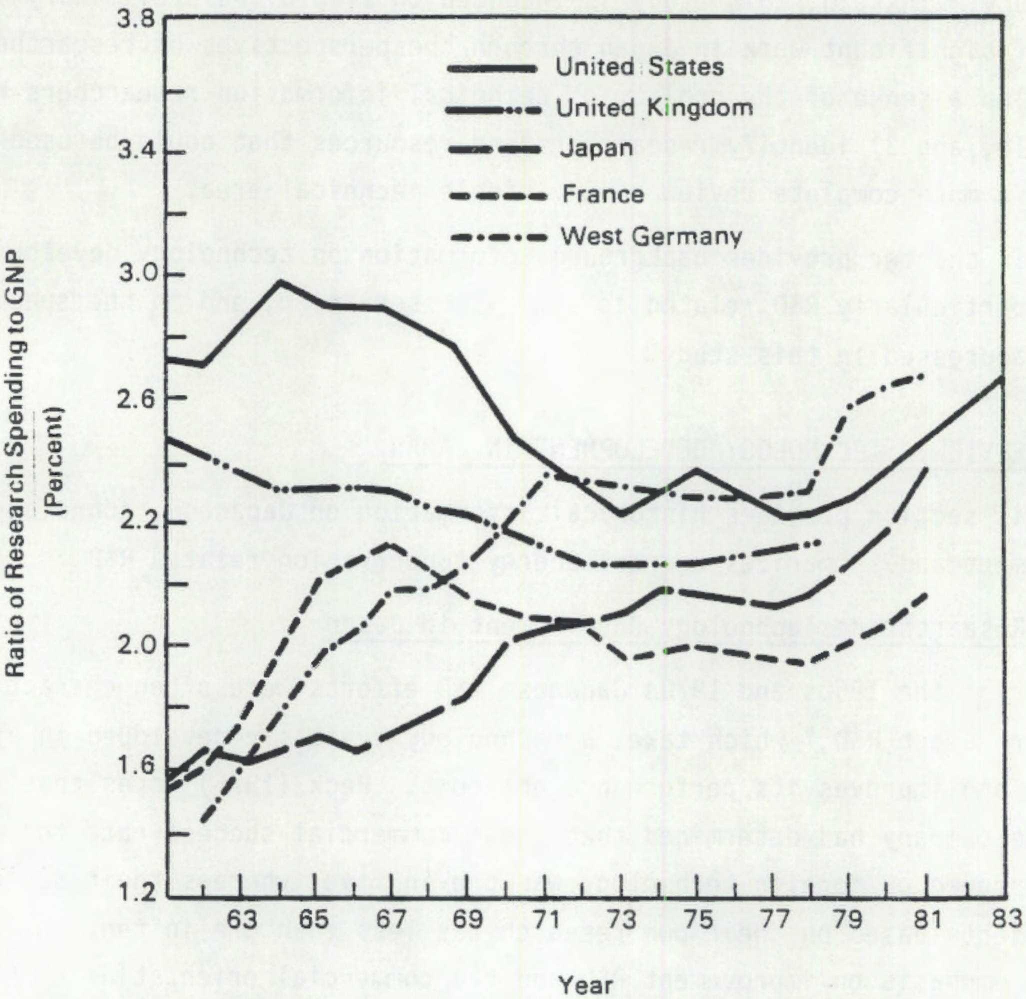

FIGURE 1.1. Ratio of Total National Research Investment to GNP (NSF 1983)

Although R&D directed toward defense and space technologies has produced spin-off products that are useful to the general economy, this is becoming less true as the needs of these fields become more specialized. Excluding defense and space R&D spending thus provides a more direct measure of efforts relevant to economic growth and social goals (National Science Foundation 1983). The ratio of this nondefense, nonspace R&D spending to GNP is shown in Figure 1.2. This figure shows that Japan has significantly outpaced the U.S. since the late 1960s. In 1981, the ratio was 2.2% in Japan and 1.7% in the U.S.

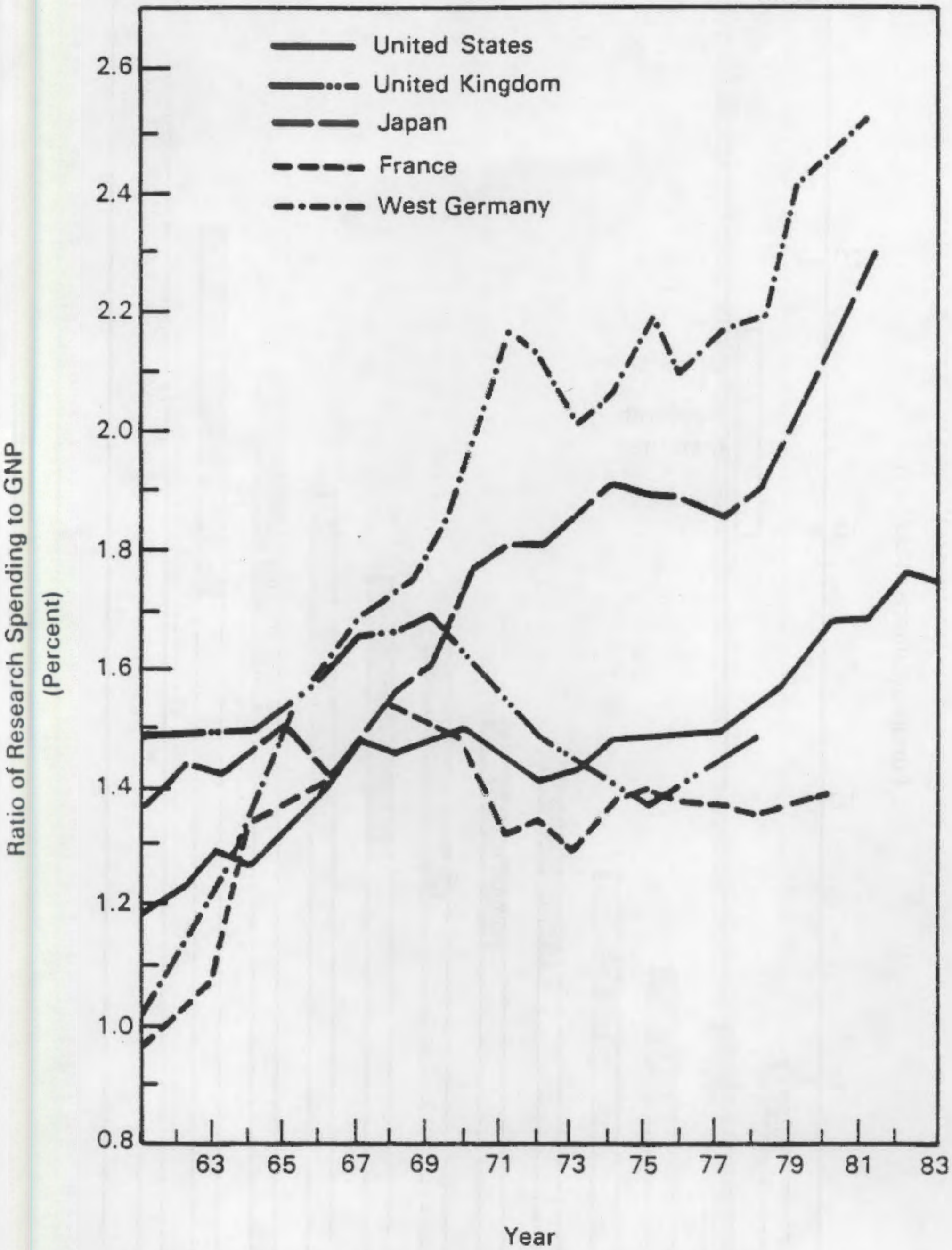

FIGURE 1.2. Ratio of Research Investment, Excluding Defense and Space Research, to GNP (NSF 1983)

The growth in Japanese R&D spending is attributed to increased activity in both the private and government sectors, as shown in Figure 1.3. Private sector R&D grew from 82 trillion yen (3.6 billion dollars)[a] in 1970 to 363

(a) $1 equals 225 yen.

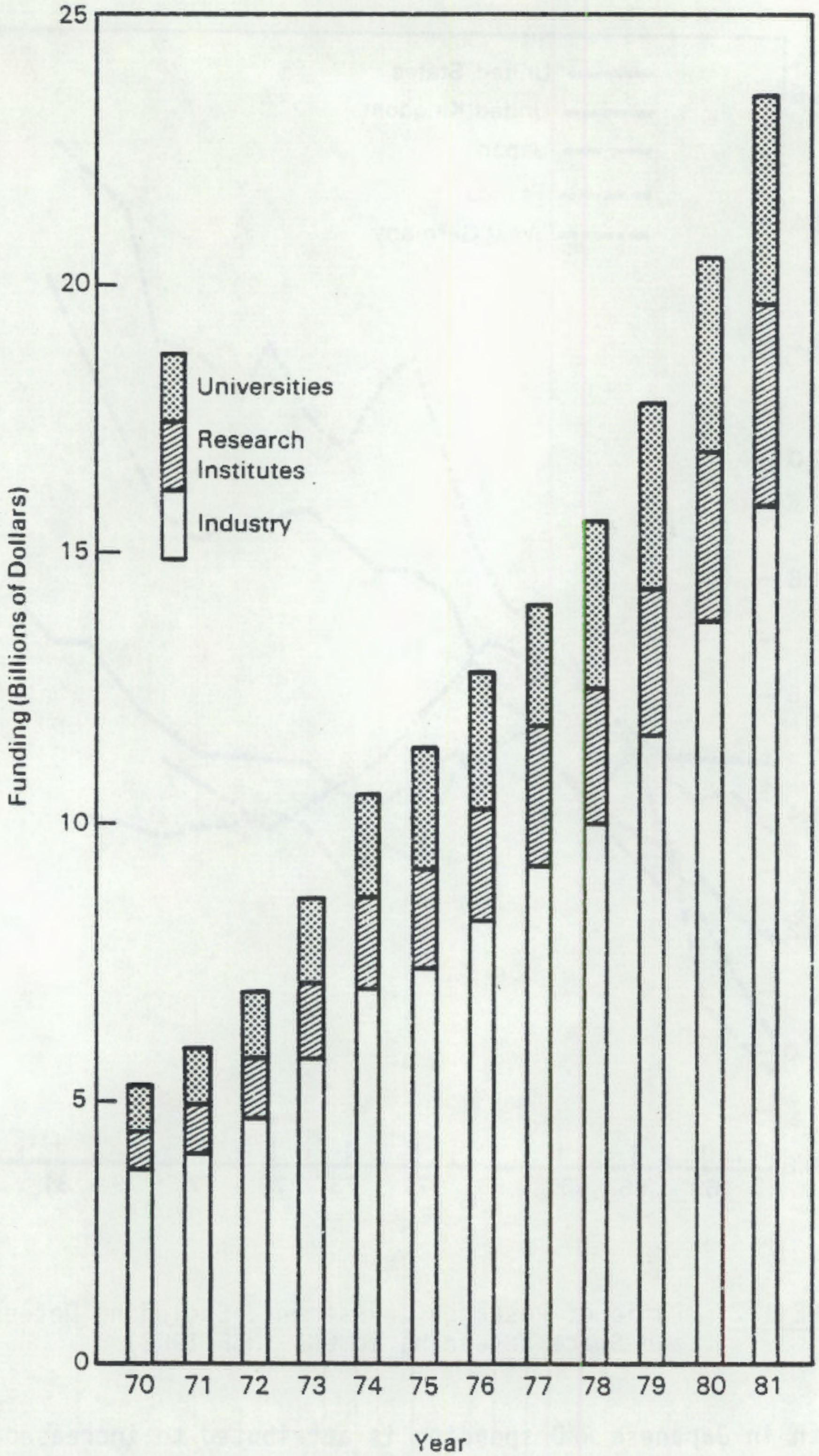

FIGURE 1.3. Composition of Research Funding in Japan, 1977-1981

trillion yen (16.1 billion dollars) in 1981. Government spending (national research institutes and universities) increased from 37 trillion yen (1.65 billion dollars) in 1970 to 174 trillion yen (7.8 billion dollars) in 1981. It should be noted, however, that faculty salaries are usually included as part of university research expenditure in Japan; U.S. statistics usually do not include those salaries. Thus, the actual spending on research in universities is likely to be overstated when compared with U.S. spending.

Statistical data indicate that most of the overall increase in Japan's R&D spending has been directed toward developmental projects. Between 1977 and 1981, research classified as basic increased modestly in funding, from $2.4 billion to $3.4 billion, with applied research showing an increase from $3.6 billion to $6.2 billion. The increases in basic, applied and developmental research funding are shown in Figure 1.4.

During this period of significant growth in R&D activity, Japanese technology developments have caught up with, and in several cases surpassed, developments in other countries. As this has occurred, Japan has been increasingly forced to turn to its own creative resources and long-term R&D capabilities. This study provides some perspectives on the extent and status of this shift toward longer-term R&D in the ten fields reviewed.

1.1.2 Review of Energy Conservation-Related Research Programs in Japan

Government-sponsored research in Japan and the U.S. has structural differences that reflect their somewhat different philosophies regarding publicly sponsored technology development. These differences are reflected, for example, in the coordination of energy conservation-related research. In Japan, several programs and organizations participate in sponsoring energy conservation-related work, unlike the U.S., where DOE has the principal role.

Government-sponsored research in the U.S. is assigned to topical needs that include defense, space, energy, agriculture, health, and NSF-funded basic research. Notably absent is an agency responsible for industry-related research. Consequently, long-term research related to industry, when performed, is performed under one of the other topical agencies.

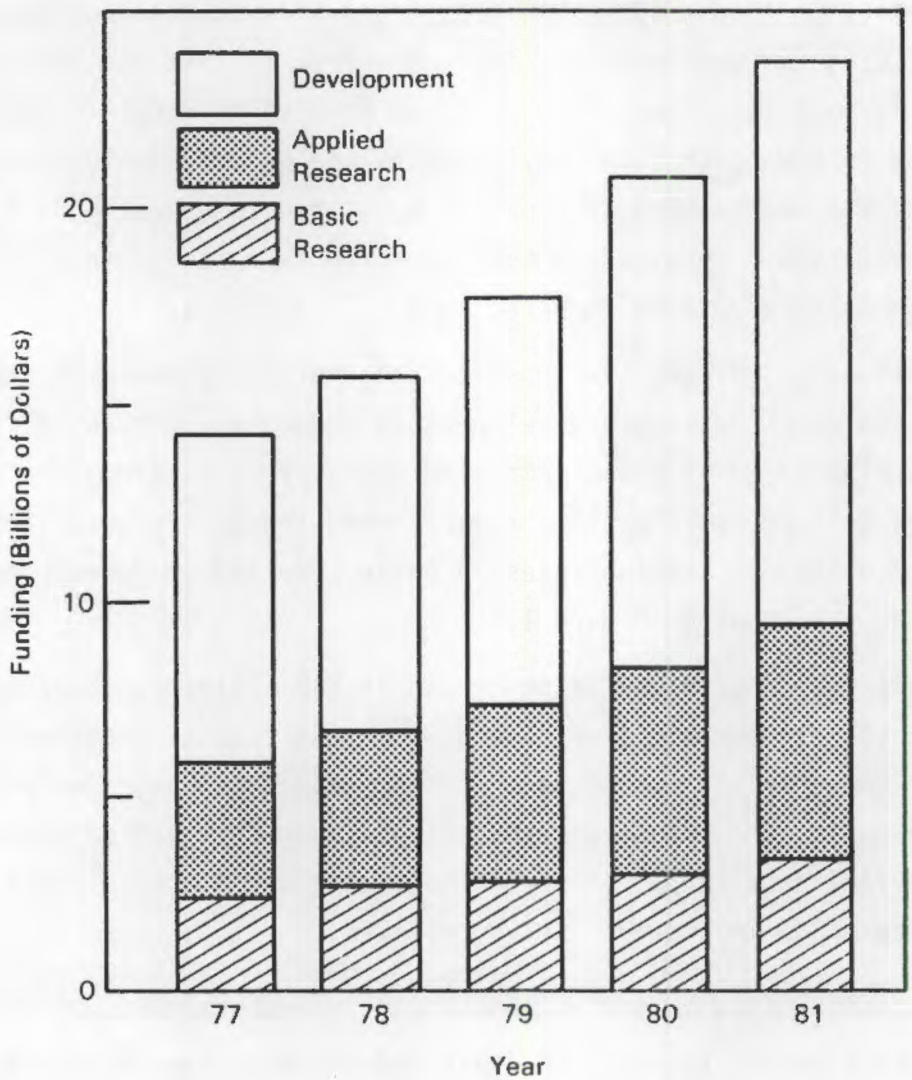

FIGURE 1.4. Distribution of Developmental, Applied, and Basic Research Between 1977 and 1981

In contrast, Japan has a governmental branch that has principal responsibility for coordinating activities affecting industrial development. This arm is the Ministry of International Trade and Industry, or MITI. The activities of MITI have received substantial publicity in the U.S. as the object of both passionate international praise and scorn.

One of MITI's responsibilities is coordinating energy-related research. For example, solar energy-related activities are coordinated within the "Sunshine Program," first organized in 1974. In 1978, an energy conservation technology development program was organized and named the "Moonlight Project." The responsibilities of this project centered on the near-term development of conservation-related technologies such as heat pumps, electric vehicles, waste heat recovery, electrochemical energy storage, and advanced heat engines. When most Americans think of conservation-related research in Japan, attention focuses on this project. In 1980, the Moonlight Project was merged into the New Energy Development Organization, which was established to coordinate all of the near-term energy-related developments. Table 1.1 lists projects sponsored through the Moonlight Project.

In addition to the work performed under the Moonlight Project, significant research is performed in conservation-related technologies in other branches of MITI and the government. For example, ceramics and industrial biotechnology are being promoted in the New Technologies for Basic Industries Program. This program includes several technology areas that are considered to be key in Japan's industrial future. The government is promoting development in these technologies through the long-term coordination of selected research activities.

Most fundamental research is not carried out within MITI but is largely supported by the Ministry of Education (MOE). The MOE performs a role filled by several of the agencies in the U.S., such as the National Science Foundation (NSF), the National Institutes of Health, and the Office of Basic Energy Sciences in DOE. The Science and Technology Agency (STA) is also a major contributor toward long-term research on energy conservation-related technologies in Japan. These three organizations share administrative responsibilities for the country's government research institutes. Therefore, in considering the government-supported research in energy conservation-related technologies, a web of agencies and programs must be included. Figure 1.5 shows the administrative relationships of the organizations sponsoring work most directly related to energy conservation and their associated advisory councils and national laboratories.

In addition to the government-funded efforts, significant interaction among the government, industry, and universities also must be considered in the overall picture of technology development. The role of the Japanese government

TABLE 1.1. Research and Development Sponsored Through the Moonlight Project (AIST 1982)

Primary Projects
Advanced Gas Turbine
Waste Heat Utilization Technology Systems
Magnetohydrodynamic Power Generation
Advanced Battery Energy Storage System
Fuel Cell Power Generation Technology
Stirling Engines for Small-Scale Use

Additional Projects
Research on the Potassium Turbine
Research on Advanced EHD Power Generation
Research Relating to the Conversion and Transmission of Electrical Energy
Research Concerning Very Low Temperature Technology
Research Relating to Energy-Saving Magnetic Materials
The Development of New Aluminum Refining Techniques Using a Smelting Furnace
The Development of Low Temperature Dyeing Techniques
Research Relating to Energy Conservation in Glass Smelting Furnaces
Studies on Energy Conservation Technology Relating to Infrared Radiation and Ceramic Materials
Studies on Utilization of Waste Heat from Industrial Plants in Agricultural and Stock Farming Applications
Research Concerning Techniques for the Measurement of Heat Flux
Research on Advanced Combustion Technology

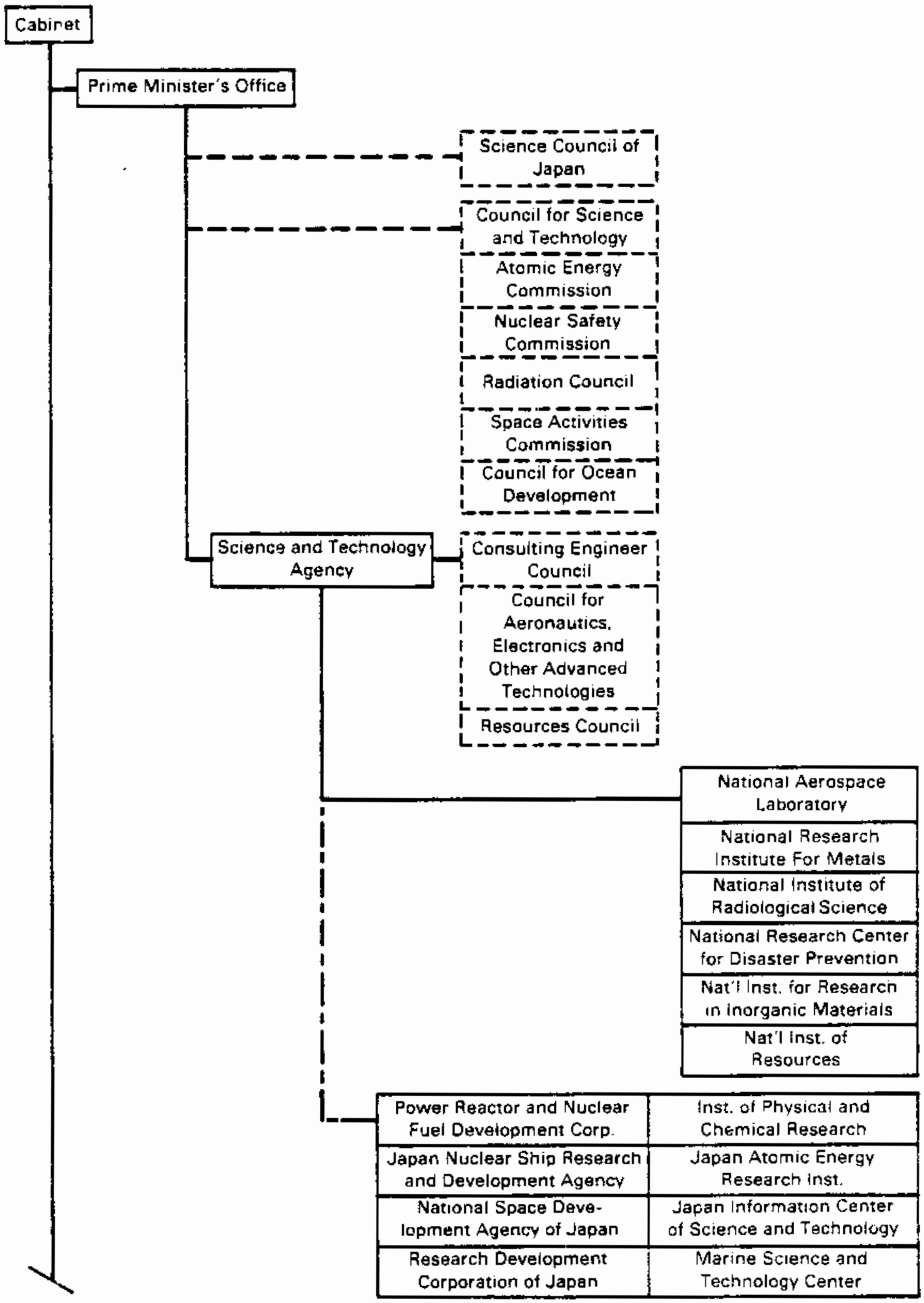

FIGURE 1.5. Japanese Governmental Agencies Sponsoring Work Most Directly Relevant to Energy Conservation

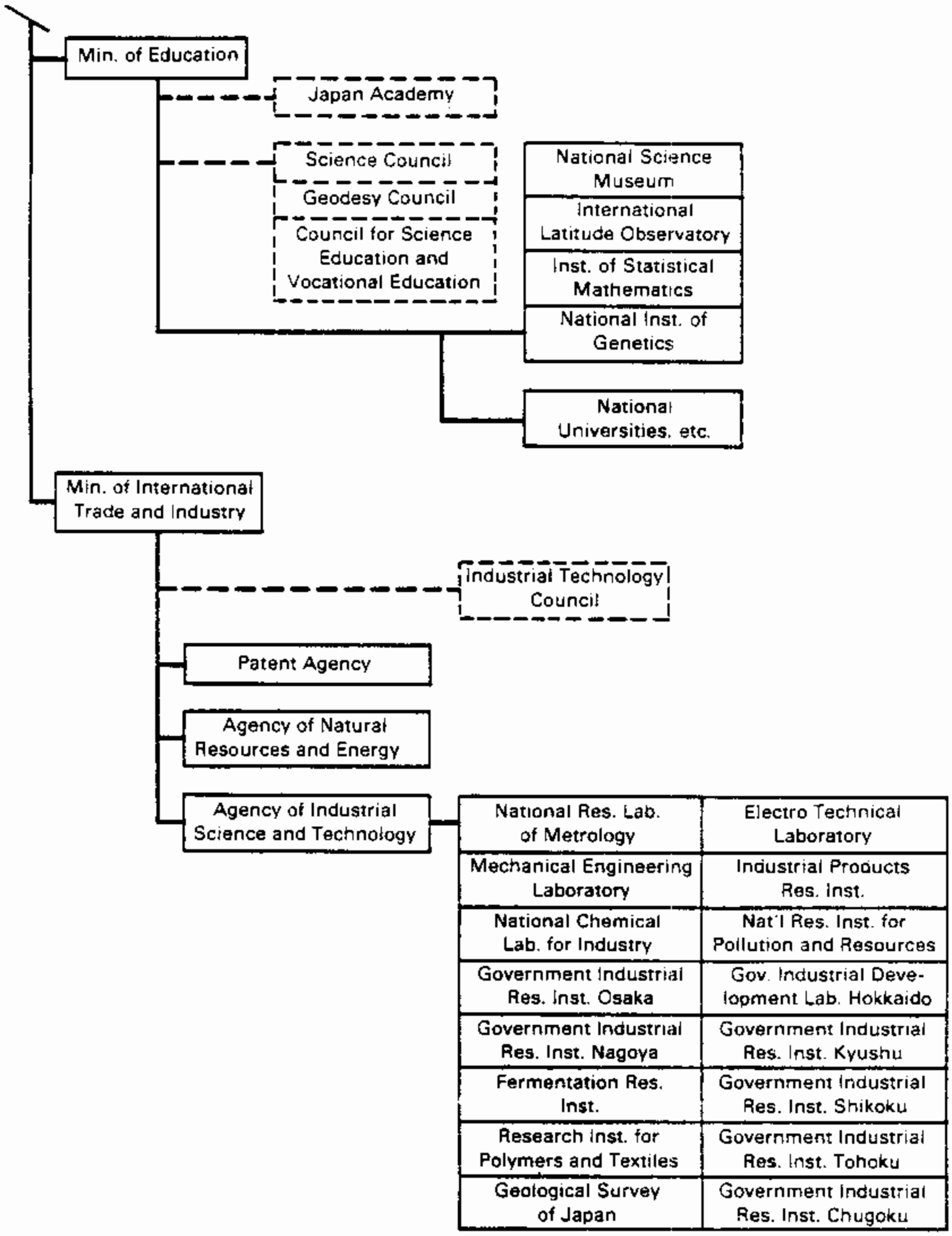

FIGURE 1.5. (contd)

in the long-term advancement of technology is significant and takes a variety of forms. In some cases the support is direct funding, as is common in the U.S. Loans also may be issued for developing a technology; those loans typically are not repaid if the project is unsuccessful. In other cases the effect is much more subtle, involving minimal funding but substantial benefits from the government's coordination of research efforts. Examples of this coordination include government encouragement of intercompany working groups in biotechnology, and a recent series of meetings co-sponsored by the STA and MOE on the fundamental development of amorphous materials. Both mechanisms of direct funding and facilitating coordination have proved to be effective in promoting technology development in Japan.

1.2 COMPETITION AND INFORMATION TRANSFER

This section discusses the two major issues addressed in this study: 1) the relative competitive positions of U.S. and Japanese technology development, and 2) information transfer.

1.2.1 Comparative Technological Positions

The comparative status of technology development in the U.S. and Japan is an important issue in analyzing technology developments in Japan. A variety of direct measures can be used to assess the comparative technical position of commercial technology in the two countries. A technology's performance, maintenance, materials, and fuel and capital requirements can be measured directly. At the earlier stages of technology development, however, the ability to define comparative technical status becomes increasingly difficult. At the level of long-term, directed, basic research, prototype equipment is often not even available to use as a measure of technical status. Assessing comparative position therefore becomes a qualitative judgment of technical experts considering the following issues:

- Fundamental insight - Does the work add significantly to the level of understanding of the process or technology? Does the research advance the insight into the process that would lead to its more effective use?

- Fundamental data base - Does the research add significantly to the prediction of material behavior?
- Facilities - Do the facilities allow researchers access to state-of-the-art research tools? How many significant research centers exist?
- Researchers - Are there many researchers of international caliber? Are labs well staffed?

Patents may also provide an indication of the type and level of activity underway in different technology areas.

The researchers interviewed used measures such as these to evaluate strengths of Japan's technical effort. It should be emphasized, however, that the researchers were only requested to provide qualitative perceptions; technical documentation to support their perceptions was not pursued. An in-depth analysis of comparative position would require comprehensive information on all significant U.S. and Japanese activities in the field; such an assessment was not attempted.

In addition to the status of technology development, another important characteristic is the rate of growth or decline of research interest. This acceleration or deceleration indicates the status and pace of future research developments in the field. This characteristic was frequently mentioned in the interviews with researchers and will be referred to as the "momentum" of the activity. Components of momentum include investment in facilities, investment in research staff and research training, and the rise of significant research work as seen in publications or patents. In many fields Japan began development later than the U.S. but has made a significant and directed commitment that seriously challenges U.S. technical leads.

1.2.2 Information Transfer

The second issue addressed in this report is the quality of the information available to U.S. researchers on Japanese technical developments. In the near term, poor information transfer can cause commercial technology gaps. In the longer term, continued deficiencies in our understanding of overseas work may result in knowledge gaps that are more fundamental and lasting.

As technical progress in Japan continues to accelerate and broaden, the penalties of poor information flow to the U.S. will become increasingly severe. While Japan has a well-known, extensive information gathering capability, the analogous mechanisms in the U.S. are very dubious.

Researchers have a variety of ways available to keep current on domestic and international developments in their fields:

- journals and magazines
- conferences
- seminars
- trip reports
- professional contacts
- information services.

The quality of these avenues was commented upon by the researchers interviewed in this study. In evaluating the quality of technical information flow, researchers considered several elements:

- timeliness
- technical detail
- comprehensiveness.

The first element, timeliness, is particularly important in rapidly advancing fields such as ceramics, biotechnology, and amorphous materials. For example, Japanese publications in the international, English language literature typically lag the work by two years. In some cases these two years can represent the difference between the laboratory work and commercialization. In other cases this two-year lag can represent a substantial gap in the actual status of research. However, basic research typically advances slowly and two-year-old material can often be quite relevant. As a development enters the more applied phases, rapid changes can occur, with the actual status of work significantly ahead of that reported in the literature. The significance of the problems with this timeliness, along with the concerns over the useful technical detail and comprehensiveness, will be explored in each field covered in this study.

Concern over this timeliness issue has been recently expressed in Congressional hearings of the Subcommittee on Science, Research and Technology in the House Committee on Science and Technology. These hearings, held March 6 and 7, 1984, focused on the availability of Japanese technical information to U.S. researchers. The objectives of this subcommittee hearing were to:

- identify science and engineering fields that could benefit from increased knowledge of Japanese scientific activities
- determine if the private sector and government are providing adequate access to Japanese technical literature
- assess the role of the federal government in facilitating access to this literature
- assess the current status of collection and translation efforts.

At the hearings witnesses raised several points that indicate the current status of monitoring technical work in Japan:

- Only a few Japanese technical publications are currently available to U.S. researchers. Of the roughly 10,000 Japanese scientific and technical periodicals, 4,000 are considered to cover applied science. Of these applied science periodicals, only 14%, or about 600, are covered by Western indexing services. Further, only 19% of Japanese applied science journals are available in English translations.
- Japan is more active than the U.S. in translating their important work into English. Although there appear to be no unusual attempts to hide scientific and technical achievements in Japan, cultural barriers and the extremely competitive nature of Japanese industry often present this impression.
- Language is by far the greatest barrier to improved access to Japanese technical literature. Japanese is a difficult language to master and technical Japanese requires an additional level of

comprehension and sophistication. Several witnesses stated that there are no more than a handful of competent technical Japanese translators in the U.S.

- The cost and difficulty of translating Japanese technical articles and journals are prohibitive for most private firms and libraries. When translation services are used, the process is costly and the translations generally are poor. Witnesses stated that on several occasions articles were returned to them from these services because the articles were too difficult to translate. Translation cost estimates cited included $7500 for translations of three issues of a photography journal and $20 to $250 per 1000 words, depending on the difficulty.

Members of academia, representatives of information services, and policy analysts were invited to these hearings. While these participants made a valuable contribution by answering questions, the researchers and research managers who would most benefit from improved information transfer were noticeably absent. This study provides preliminary views on this issue from researchers familiar with Japanese technical developments, with some suggestions for improving the availability of quality technical information.

1.3 REPORT OVERVIEW

The following ten chapters describe the comments offered by researchers in each of the technical areas covered. Several researchers were willing to discuss their perceptions but asked not to be identified. Each of the following ten chapters contains three sections:

- a discussion of the perceptions of notable features of Japanese R&D in that particular field
- a discussion of the quality of technical information available
- a listing of the researchers interviewed and their methods for following work in Japan.

Following these chapters is a summary of the information services identified that can provide information on technology developments in Japan. The appendix contains address and phone listings of the researchers interviewed.

2.0 AMORPHOUS METALS

The development of amorphous metals in Japan began accelerating approximately ten years ago as the promise of unique magnetic, electronic, and structural properties was increasingly recognized. In 1980 and 1981 the development of amorphous metals became more visible when the MITI, the MOE and the Research and Development Corporation of Japan (RDCJ) announced the initiation of programs to promote the development of this technology. These government-sponsored and coordinated programs covered the range of R&D from basic research of the atomic structure to production techniques that emphasized power transformer applications. In the late 1970s and early 1980s the number of Japanese publications in this field also increased substantially . At the triennial International Conference on Rapidly Quenched Metals held in 1981 in Sendai, Japan, almost half the papers presented were by authors from Japan.

In 1983 and early 1984 the MOE and the STA sponsored a series of workshops on fundamental research issues concerning amorphous materials. Also in 1983, significant Japanese developments began to reach the marketplace. Hitachi, Sony, and others commercialized an amorphous tape recording head produced by double-roller quenching, an advanced technique not developed commercially in the U.S. In the related field of amorphous silicon, Sanyo announced plans to commercialize an amorphous silicon solar cell with an electrical conversion efficiency greater than 10%. Late in 1983, Komatsu announced an amorphous solar cell that achieved an efficiency of 10.7%, the highest thus far achieved.

Considering these announcements of national programs to develop amorphous metals and the recent, significant commercial developments in amorphous materials, the U.S. would be wise to consider the current status of amorphous metals research in Japan. This chapter will thus explore the perceptions of U.S. researchers on the status of long-term research in this field. Because a major potential application of this technology is in power transformers, Japanese research in the soft magnetic properties of amorphous metals will be emphasized. Researchers who offered their time to discuss their perceptions of this work in Japan include those listed below:

Takeshi Egami	University of Pennsylvania
William Geissen	Northeastern University
Chad Graham	University of Pennsylvania
Ryusuke Hasegawa	Allied Corporation
Lyman Johnson	General Electric Corporate R&D
William Johnson	California Institute of Technology (Cal Tech)
Carl Koch	North Carolina State University
Don Kroeger	Oak Ridge National Laboratory (ORNL)
Fred Luborsky	General Electric Corporate R&D
Robert Maringer	Battelle-Columbus Laboratories (BCL)
Joe Mort	Xerox Corporate R&D
Tom Thomas	Pacific Northwest Laboratory (PNL)

The following section will summarize comments offered by these researchers on notable aspects of long-term research in amorphous metals in Japan. This will be followed by a discussion of the quality of technical information transfer between U.S. and Japanese researchers.

2.1 NOTABLE ASPECTS OF AMORPHOUS METALS RESEARCH IN JAPAN

Interviews with researchers revealed that a wide variety of active research is under way in Japan, ranging from the near-term development of amorphous metals to fundamental research. Because this report focuses on the basic and applied research activities in each technical area, comments from researchers on this aspect of amorphous materials development will be presented first. However, the researchers' overwhelming consensus was that the strength of Japanese efforts in this area lies in the near-term development and commercialization of the technology. Comments on these issues will follow the discussion of basic and applied research.

2.1.1 Basic and Applied Research

Although the researchers interviewed generally acknowledged that there is a significant level of fundamental research under way in Japan, opinions about the quality of the research were mixed. Researchers such as Egami of the University of Pennsylvania, Hasegawa of Allied Corporation, L. Johnson of General Electric, Kroeger of ORNL, and W. Johnson of Cal Tech felt that the more creative and insightful work is still produced by researchers in the U.S. In particular, in the area of the magnetic properties of amorphous metals, L. Johnson and Hasegawa noted the work of Egami and Graham and their staff at the University of Pennsylvania. L. Johnson and Hasegawa also felt that their respective staffs at General Electric and Allied include several researchers who have performed more insightful work in magnetic properties than any research they have witnessed from Japan. While this was a general consensus, it was not unanimous, as Luborsky at General Electric commented that the amorphous magnetism research in Japan is comparable with work in the U.S.

Geissen of Northeastern University, Koch of North Carolina State University and Maringer of BCL expressed the opinion that the overall effort in fundamental research is comparable in the U.S. and Japan. Geissen further noted that research in corrosion processes in amorphous metals is particularly advanced and appears to be a stronger effort than that of the U.S. Thomas of PNL added to this observation by noting that surface science was applied to the study of amorphous materials in Japan several years before it was applied in the U.S. This included the use of tools such as Auger electron spectroscopy, x-ray photoelectron spectroscopy, and secondary ion mass spectroscopy.

Although there was some disagreement about the overall status of fundamental amorphous metals research in Japan vis-a-vis the U.S., there was a general consensus that individual researchers and programs are producing notable work. L. Johnson and Egami note that the research group at Tohoku University at Sendai is probably the most extensively staffed and well-equipped facility in the world for amorphous metals research. The Tohoku group is led by Dr. Masumoto, who chaired the Fourth International Conference on Rapidly Quenched Metals and who has an international reputation in the field. Several other researchers on his staff also possess international reputations, including Fukamichi for his work in magnetics and the Invar properties of amorphous metals, Fujimori for his work in soft magnetic properties, Suzuki for his work in atomic structures, and Hashimoto for his work in corrosion.

Tohoku University is also the site of the first accelerator used as a source of neutrons for scattering experiments with amorphous alloys. This accelerator is a 300-MeV electron LINAC, which was constructed in the early

1970s. In 1980, a second accelerator, a 500-MeV proton booster synchrotron, began operation at the Laboratory for High Energy Physics at the Tsukuba Science Center.

Research into the physics of amorphous materials is also being conducted at many of the national universities. Active fundamental research is under way at the Universities of Tokyo, Nagoya, Kyushu, Osaka, Hiroshima and Hokkaido. Professors Kaneyoshi and Mizutani at Nagoya University, for example, are known internationally for their work in the magnetic properties of amorphous materials. The research at the universities is a mixture of research into materials with soft magnetic properties and research into the solid state physics of a disordered or random system. The research tools and techniques being used include a range of advanced methods, including x-ray, neutron, and electron diffraction, small angle x-ray scattering (SAXS), nuclear magnetic resonance (NMR), scanning electron microscopy (SEM), transmission electron microscopy (TEM), Mossbauer spectroscopy, field ion microscopy (FIM), Auger electron spectroscopy (AES), and electron spin resonance (ESR). There also are innovative applications of these techniques and laboratory-developed equipment such as the electron holograph developed at Hitachi. Fundamental research projects under way at selected laboratories in Japan are more completely described in the report Long-Term Research in Japan: Amorphous Metals (Hane et al. 1985).

Researchers noted that university researchers in Japan seem able to rely on funding over a longer term than those in the U.S., thus allowing more effective program planning.

Although researchers generally noted that amorphous metals work in Japan has emphasized the near-term development and commercialization of the technology in the past, several researchers noted that this situation appears to be changing. Egami noted that the government has recently initiated a program that appears to be directed toward understanding some of the basic aspects of the behavior of amorphous metals. Although the details have yet to be publicly announced, initial indications are that the focus is different from the RDCJ-MITI sponsored project in amorphous metals, which focused on preparation methods for power transformer core materials. Luborsky and Maringer have also noted a general trend toward a greater amount of work addressing the basic physics of the behavior of amorphous metals.

This shift in emphasis is reflected in the activities of the MOE and the STA. These organizations have recently coordinated several workshops focusing on the fundamental study of amorphous materials. These workshops involve approximately 35 companies and 20 universities. Themes addressed by these workshops have included the following:

- structural control of amorphous metals (October 1983)
- thermodynamics and dynamics of supercooling metal to the amorphous state (December 1983)
- chemical short-range order and the magnetic thermal stability of amorphous materials (February 1984).

As of this writing only these general themes have been released as public information.

Several researchers also noted that in the larger private sector laboratories, fundamental research and near-term development work are often mixed together. Because the researchers in many companies do not make an effort to separate the fundamental work from the developmental efforts, it is difficult to gauge the status of private sector research. At times this work can be overshadowed by the developmental aspects, because the Japanese researchers seem to excel in this aspect of technology development.

2.1.2 Developmental Research

The consensus of the researchers interviewed was that developmental research in amorphous metals has been the stronger aspect of Japanese efforts. Japanese researchers have been particularly active in pursuing compositional studies. Egami, L. Johnson, Geissen, and Maringer noted that this compositional work is typically performed very thoroughly. They noted the willingness of Japanese researchers to test literally hundreds of different compositions to find one with the desired properties. Because of this, Geissen noted, some of their discoveries appear almost serendipitous. It was mentioned that it was not uncommon to see researchers at adjacent stations working on compositions that were only incrementally different. This, it was noted, is unlike the U.S. system in which researchers are concerned about maintaining an air of uniqueness and independence in their work. This experimental approach in Japan also enables the researchers to derive general rules about the effects of composition changes upon the properties of the materials.

Egami, L. Johnson, Mort, Koch, and Geissen also noted that technology seems to pass from the laboratory to the commercial market much more effectively in Japan than in the U.S. Part of this is attributed to the closer coordination and cooperation among industry, universities, and national laboratories. Not only do professors such as Masumoto and Hashimoto act as consultants for industry, but their associates and students frequently participate in joint research projects with industrial partners. This intermingling of organizations is evidenced in the reports published. For example, at the last International Conference on Rapidly Quenched Metals, a large percentage of the papers presented by Japanese researchers involved collaboration among different organizations, including many joint projects between industry and universities or national laboratories.

The primary applications for amorphous metals developments in Japan are in power distribution transformer cores and magnetic recording heads; however, the development of superconducting amorphous materials also seems to be increasing. Hasegawa and L. Johnson stated that the U.S. currently has superior technology to produce amorphous metal ribbons for power transformers (although some have indicated that Nippon Steel makes the same claim). However, the RDCJ is sponsoring a five-year project, which began in 1981, to develop preparation methods for amorphous metals for transformer cores. Nippon Steel and Tohoku University are the primary participants. The ultimate objective is to produce a 30-kVA transformer using thin bands of amorphous material 150 mm wide. The project is supported by a grant of 1,688 billion yen (approximately $7.5 million) from the RDCJ and by internal funds from Nippon Steel, placing the overall level of support at 2,500 billion yen ($11.1 million). The program is addressing production problems such as the cutting of amorphous ribbons as well as increasing the heat resistance of the material and reducing the magnetostriction.

Researchers including Egami, W. Johnson, Hasegawa and Luborsky note that Japanese industry is developing amorphous magnetic materials for a wider range of applications than the U.S. A notable area of application is consumer electronics. Several Japanese companies have recently commercialized amorphous alloy recording heads with superior responsiveness produced by a double-roller quenching method. This method allows for smoother surfaces and more uniform thicknesses than can be achieved through the current single roller method. Hitachi, Sony, and TDK are among the companies pursuing this technique, which is not used anywhere else in the world.

Japanese development in amorphous materials also provides general indications of the relative focus of Japanese research when compared with U.S. research. An example can be taken from the 1982 joint International Magnetics Conference (INTERMAG) and Magnetism and Magnetic Materials Conference (MMM). Of the 275 papers presented, 20 were by Japanese authors and 15 of those dealt with amorphous magnetism applicable to transformers or recording heads. In most of the other magnetics sections of this conference, such as spin glasses, mixed-valence compounds, critical phenomena, phase transitions and critical phenomena, statistical mechanics, one-dimensional magnetism, metallic superlattices, etc. (topics that are more pure basic research and less directed basic research), there were no papers presented by authors from Japan. A similar pattern has been evident at previous meetings of INTERMAG and MMM, which indicates that a few specialized areas of directed basic magnetics research are being emphasized.

In amorphous silicon, a related branch of amorphous materials, Mort of Xerox noted that applying this technology to photovoltaics is probably the greatest area of amorphous materials activity in Japan. Although the possibility of using amorphous materials in photovoltaic cells has been understood in the U.S. for several years, Japanese companies appear to have been the first to commercialize this technology for consumer use. Sanyo has a factory that is producing cells that have efficiencies in excess of 10%. In November of 1983, Komatsu announced that it had designed an amorphous silicon cell that achieved an efficiency of 10.7%. Mort noted that Japanese developments in this area are very significant and a substantial challenge for U.S. industries in this field.

2.2 THE QUALITY OF INFORMATION TRANSFER

Although there are neither a large number of journals or conferences that report the progress of Japanese research in amorphous materials, most of the researchers interviewed felt that the information available is adequate. The English language publications that most researchers rely upon for information on work in Japan include the Journal of Applied Physics, the Japanese Journal of Applied Physics, and the IEEE Transactions on Magnetics. There is also a new journal that began publication in January, 1984 called the International Journal of Rapid Solidification by ABA Publishers. This journal is expected to be useful in following international work.

In addition to these journal publications, several researchers noted the usefulness of the Science Reports from the Research Institutes of Tohoku University: Amorphous Materials, Series A. Since June, 1976, six reports on amorphous metals research have been published at irregular intervals. The latest volume was published in March, 1983. Table 2.1 lists publications that contain information on amorphous metals research and categorizes them as either primary or secondary sources.

Conferences provide an equally valuable forum for the exchange of technical information in this field. The most significart international conference cited by researchers is the International Conference on Rapidly Quenched Metals (RQM), which is held every three years. The Japanese were very well represented at the RQM conference held in 1981 in Sendai, Japan. Of the 407 papers presented, 189, or about 46% of the papers, were by authors from Japan.

Other conferences include the INTERMAG Conference, the Conference on Magnetism and Magnetic Materials, the meeting of the American Physics Society, the meeting of the American Metallurgical Society and the meeting of the Materials Research Society. Table 2.2 lists conferences at which papers describing amorphous metals research were presented.

TABLE 2.1. Publications Containing Information on Amorphous Metals Research in Japan

Publication	Primary	Secondary
IEEE Transactions on Magnetics		x
International Journal of Rapid Solidification		x
Japanese Journal of Applied Physics	x	
Journal of Applied Physics		x
Journal of the Physical Society of Japan		x
Science Reports of the Research Institutes of Tohoku University: Amorphous Materials-Series A	x	

TABLE 2.2. Conferences with Papers Describing Amorphous Metals Research in Japan

Conference	Primary	Secondary
Conference on Liquid and Amorphous Metals		x
Conference on Magnetism and and Magnetic Materials (MMM)		x
International Conference on Rapidly Quenched Metals (RQM)	x	
International Magnetics INTERMAG Conference	x	

Egami noted that although many articles are written by Japanese researchers in English, this literature lacks good peer review, which obscures the true meaning of the more significant efforts under way. Because critical peer review is viewed as constituting personal rather than professional criticism in Japan, it is seldom done, resulting in a mix of excellent and very poor papers being published. Obtaining the real meaning of the research being conducted can be more effectively achieved through personal discussions in a small workshop setting. This view is supported by Mort, who added that topically well-focused workshops seem to be very effective. He noted the success of a binational workshop that he organized, with NSF funding, that focused on amorphous tetrahedral solids.

L. Johnson and Luborsky noted that many articles appear to be published first or only in Japanese. For example, the Journal of the Magnetics Society of Japan is only available in Japanese, although abstracts in English are available.

Several suggestions were offered for overcoming some of the shortcomings in information transfer. These include creating more opportunities for personal interaction in a workshop setting and meeting the need for the more timely translation of information. The IEEE Magnetics Society has planned to translate some articles from the Journal of the Magnetics Society of Japan beginning in April, 1985. A need was also identified to support more study in Japan for U.S. researchers and graduate students.

2.3 SUMMARY OF PERSPECTIVES ON AMORPHOUS METALS RESEARCH IN JAPAN

In the past few years there has been a significant level of Japanese activity in the development of amorphous metals and amorphous materials. This activity is evidenced by 1) the recent initiation of two government programs to promote amorphous metals development, 2) by the large volume of research papers submitted to international conferences and journals by Japanese authors, and 3) by recent commercial developments. The researchers were interviewed to investigate the technical basis for long-term development of fundamental research in amorphous metals. In particular, the discussion focused on research into the magnetic properties of amorphous metals. This limitation on the scope of the investigation is important to bear in mind. Although other notable aspects of amorphous metals development in Japan did surface in discussions with researchers, their perspectives concerning broad developments in the area were not sought. Comprehensive comments about the overall development of amorphous metals or amorphous materials would require further investigation.

Although there is significant activity in Japan in the research and development of amorphous metals, the researchers interviewed generally agreed that U.S. researchers still possess a greater understanding of the fundamental aspects of the magnetic properties of the metals. Researchers singled out the work of Egami and Graham at the University of Pennsylvania as an example. Several researchers commented that the work by Egami and Graham has offered substantially more insight into the fundamental magnetic properties of the materials than any of the published work from Japan. Dr. Johnson at General Electric and Dr. Hasegawa at Allied Corporation also commented that the research staffs at their companies have produced more insightful work than the work they have witnessed in Japan. The researchers interviewed expressed the general opinion that the fundamental research into magnetic properties of these materials is currently stronger in the U.S.

The researchers interviewed emphasized, however, that this overall evaluation should not imply that the fundamental work under way in Japan is insignificant. To the contrary, researchers noted that some of the world's best research in the corrosion and formability areas is being conducted in Japan. This is a particular strength of the research group at Tohoku University in Sendai. This group is led by the internationally known Dr. Masumoto and includes several excellent research professors and highly competent graduate students. Several researchers commented that this group, overall, is possibly the strongest single research group in amorphous metals in the world. In addition, the emphasis on the fundamental aspects of the materials by the second MITI-sponsored program in amorphous alloys is regarded as a significant shift in focus. Although few details are currently available, this work has strong potential for producing very significant results because it combines the capabilities of several industrial and university groups. This may also signal a shift in emphasis in government programs from the developmental work of the past few years to more fundamental research.

The researchers noted that the technological strengths of Japanese development in this area are still being developed, particularly in processing techniques. In addition to the high level of activity directed toward power transformer materials, researchers noted a strong interest in using the unique magnetic characteristics of amorphous alloys for consumer electronics. For example, several companies are currently using a unique double-roller quenching method for producing superior recording heads. This method is not being used anywhere else in the world.

In commenting about the general strengths of research in Japan, researchers in the U.S. consistently pointed to two factors: 1) a greater willingness to conduct repeated empirical tests to derive general rules about material characteristics, and 2) a better coordination of research nationwide. The most noted feature of Japanese research was the willingness of Japanese researchers to test hundreds, perhaps thousands, of related materials to deduce general rules of material behavior. U.S. researchers were also impressed by the willingness of individual researchers to conduct work that varied only slightly from that of their colleagues. In the U.S., it was noted, there is generally a strong desire among researchers to pioneer new territory significantly different from the research of one's colleagues. It was also commented that the research in Japan appears much better coordinated between universities and government institutions, and that the cooperation among universities, industry and the government allows the overall research effort to be used far more effectively.

Researchers seemed to agree that information transfer in the field worldwide is generally adequate. The major shortcoming identified is the lack of interaction among researchers of the two countries on an individual basis. It was commented that the most effective settings for such interaction are small workshops in which introductions and informal discussions can easily take place.

Although some delay occurs in translating from Japanese to English, most researchers felt that much of the significant (as well as trivial) Japanese research in this field has been published. A second major area of information transfer is international conferences. It was noted that at the 1981 Rapidly Quenched Metals conference, over half of the papers were written by researchers from Japan.

2.4 RESEARCHERS CONTACTED REGARDING AMORPHOUS METALS RESEARCH IN JAPAN

The following researchers offered comments on this field.

Takeshi Egami - University of Pennsylvania

Dr. Egami is a Professor of Materials Science and is well known for his research into the structure and magnetic properties of amorphous materials. Other U.S. researchers place Dr. Egami at the forefront of this research internationally. Dr. Egami has regular interaction with several of the primary amorphous materials researchers in Japan, and he can read and write Japanese. Dr. Egami is one of the most knowledgeable researchers identified regarding amorphous metals research in Japan.

William Geissen - Northeastern University

Dr. Geissen is a professor of Materials Engineering and specializes in research of the composition and manufacturing of amorphous metals. Dr. Geissen presented a paper at the Rapidly Quenched Metals conference in Sendai and visited the facility at that time.

Chad Graham - University of Pennsylvania

Dr. Graham was the Chairman of the Department of Materials Science and Engineering and is known internationally for his research of the magnetic properties of materials. Dr. Graham was chairman of the 1983 INTERMAG Conference. He is spending six months of 1985 working on amorphous magnetic materials in Japan.

Ryusuke Hasegawa - Allied Corporation

Dr. Hasegawa specializes in research of the magnetic properties of amorphous metals, particularly as applied to power transformers. Dr. Hasegawa serves on the board of Nippon Amorphous Metals, a joint venture of Allied and Mitsui Corporation. Through his work Dr. Hasegawa has developed extensive contacts in the private sector in Japan. He reads and writes Japanese. Dr. Hasegawa is one of the most knowledgeable researchers identified regarding amorphous metals research in Japan.

Lyman Johnson - General Electric Corporate R&D

Dr. Johnson specializes in the research of materials science and is manager of the amorphous metals development at the R&D center. Through his years in the field, he has developed a network of research contacts in Japan and he monitors developments there. Dr. Johnson also follows the patents submitted both in the U.S. and in Japan in the area of amorphous metals.

William Johnson - California Institute of Technology

Dr. Johnson is well known for his research on amorphous super conductors and he specializes in the research of solid state diffusion reactions to produce amorphous materials. Dr. Johnson co-organized the 1980 Panel Report on Amorphous Materials, which described fundamental research needs in this technology for DOE. He has presented papers at several of the Rapidly Quenched Metals and LAM conference and generally monitors developments in Japan through interaction at conferences and visits by Japanese colleagues.

Carl Koch - North Carolina State University

Dr. Koch is a professor of Materials Science and has specialized in the research of non-equilibrium crystalline materials. For the past five years his research has dealt with amorphous materials. Dr. Koch presented a paper at the Rapidly Quenched Metals Metals conference in Sendai and corresponds periodically with researchers at various institutions in Japan.

Don Kroeger - Oak Ridge National Laboratory

Dr. Kroeger is a principal researcher in the amorphous materials program at Oak Ridge and is currently performing amorphous metals research for the Electric Energy Systems Division of DOE. Dr. Kroeger follows the Japanese research through conferences and English language literature.

Fred Luborsky - General Electric Corporate R&D

Dr. Luborsky is internationally known for his research in amorphous materials. He has recently edited a book titled Amorphous Metallic Alloys, which was published in 1983. Dr. Luborsky presented a paper at the Rapidly Quenched Metals conference in Sendai and generally follows work in Japan through correspondence with researchers there or through the English language literature.

Robert Maringer - Battelle-Columbus Laboratories

Dr. Maringer specializes in the research of rapid solidification. He presented a paper at the Rapidly Quenched Metals conference in Sendai and has regular contact with Japanese technology needs through his research.

Joe Mort - Xerox Webster Research Center

Dr. Mort specializes in the research of amorphous silicon, particularly as applied to photovoltaic cells. He organized a U.S.-Japan seminar on Amorphous Tetrahedral Solids funded by the National Science Foundation. Dr. Mort keeps abreast of developments in Japan through his contacts in the Japanese industry.

Tom Thomas - Pacific Northwest Laboratory

Dr. Thomas is internationally known for his surface science research. He attended the Rapidly Quenched Metals conference in Sendai. Dr. Thomas keeps abreast of the surface science research of amorphous materials in Japan through English language journals.

3.0 BIOTECHNOLOGY

Biotechnology is rapidly emerging as one of the major high technology industries of the future. A notable increase in the rate of technological development in this field was noted in a recent report published by the Office of Technology Assessment (OTA 1984). The report noted that Japan is one of the countries with a high level of activity in biotechnology R&D.

This OTA study has been interpreted by some as documenting America's vast superiority in the field. A recent commentary in Science magazine focused on the impressive financial investment of the U.S. when compared with other countries: "The private sector in the U.S. invested more than $1 billion in 1983 to commercialize new biological techniques" (Norman 1984). This investment was made possible by the availability of venture capital, which is not very well developed in Europe or Japan. Further, it was noted that "the U.S. government spends more than $500 million a year on biotechnology while the Japanese government spends only about $60 million."

Those who argue against this view claim that the focus should be on the technical work that the money supports rather than the quantity of money spent. Evaluating the work supported by the more meager funding of the Japanese government may reveal that these efforts may result in significant technological advantages for Japan. This debate is explored further in this chapter.

Researchers in the U.S. who monitor work in Japan were contacted and interviewed for their perceptions of notable aspects of Japanese research and the quality of information flow in biotechnology. These interviews primarily focused on research in the processing of industrial (non-pharmaceutical) materials. The potential use of biotechnology in biocatalytic processes to reduce energy use in materials processing is of primary interest to DOE's ESR Office, which sponsored this work.

Unlike most of the other fields covered in this report, some work has been conducted to investigate the extent of biotechnology research in Japan. As part of the OTA study mentioned above, Professor Gary Saxonhouse was commissioned to study government programs in Japan as well as in Japanese industry. The primary purpose of this work was to support policy analyses; therefore, the work was not technically detailed. However, general budgets and general plans of Japanese government work were provided, as well as a qualitative overview of activity in the private sector. This level of detail does provide a sense of the general trends in the Japanese programs.

Areas of R&D activity in biotechnology range from the creation of pharmaceuticals, to the accelerated fermentation of food stuffs, to the synthesis of industrial chemicals, to fundamental investigations of microbes and enzymes. Several of these areas, including the synthesis of industrial chemicals, are still nascent fields; hence, the community of specialists, especially international specialists, is far from an established group. Researchers in this area have typically come from other disciplines in microbiology or chemical engineering. Consequently, comments about developments in the new field of industrial biocatalysis were general. The comments of these researchers nonetheless provide insight into the strengths of the technical effort in Japan and the quality of U.S. understanding of that work.

Researchers who provided their insights into biotechnology development in Japan are listed below:

Oskar Zaborsky	OMEC, International Inc.
Charles Scott	Oak Ridge National Laboratory (ORNL)
Yoriko Kishimoto	Japan Pacific Associates
Boyd Woodruff	Soil Microbiology Associates, Inc.
Eric Dunlop	Washington University, St. Louis
Charles Cooney	Massachusetts Institute of Technology
Gary Saxonhouse	University of Michigan, Ann Arbor.

The following sections will summarize comments offered on notable aspects of research in Japan and the quality of technical information available.

3.1 NOTABLE ASPECTS OF BIOTECHNOLOGY RESEARCH IN JAPAN

Distinct differences were identified between R&D in Japan and in the U.S. regarding the basic versus applied research efforts. Researchers unanimously agreed that fundamental science such as microbiology and genetic engineering is substantially more advanced in the U.S. Researchers in Japan are still drawing information from the tradition of fundamental studies in this country. In contrast, Japan has had a long tradition of developing fermentation technology for producing foodstuffs. Consequently, Japanese industry excels in the scale-up and process control skills that are critical to producing commercial industrial products. The researchers expressed a strong sense that Japanese technical development exceeded that of the U.S. in this aspect of the field.

Fermentation technology in Japan has been widely used for centuries in producing foods such as soy sauce, bean curd, and sake. This knowledge is reflected in a strong understanding of the engineering aspects of industrial fermentation. The ability to scale-up technologies to industrial demands was cited by several researchers as a superior aspect of the work in Japan. These researchers pointed out that as a consequence, Japan has a superior capability to produce industrial products from certain biotechnology processes.

Two factors that contribute to this level of commercial development are 1) greater emphasis on fermentation engineering in the universities and 2) the willingness of the scientists to test hundreds of organisms to find one with the desired characteristics. It was noted that Japanese college training for chemical engineers has a much stronger emphasis on fermentation engineering than U.S. colleges. Thus, Japan continues to develop the skills to advance their engineering knowledge of production processes. It was also noted that rather than trying to design enzymes or organisms that would produce a certain set of characteristics, the approach more commonly used in Japan is to find an organism through extensive screening. Such an approach allows for the deduction of rules about behavior from empirical data. Such an approach is also typically shunned as uncreative by the U.S. research community.

A second theme echoed by several U.S. researchers was that the work in Japan appears to be much better coordinated. Thus, even though the equipment in the laboratories may be no more advanced than that available in U.S. laboratories, the coordination among laboratories in the government, industry, and universities helps to make the development of the technology effective.

Because of the newness of this field and the variety of actors, processes, and end uses to which biotechnology can be applied, researchers found it difficult to evaluate the comparative position of technology development in the U.S. and Japan. Several areas with significant Japanese research were mentioned, however:

- Thermophilic enzymes - Zaborsky noted that Japanese researchers are submitting more patents in this area than researchers from any other country. These patents include oxidation-reduction enzymes and carbohydrate enzymes. A recent project to develop thermophilic microbes that would also survive in highly acidic and highly basic environments has recently been announced by the Japan Research and Development Corporation. This effort, which is part of the Creative Science and Technology Promotion Project, will involve 20 scientists and is scheduled to run through 1988. It was noted that U.S. awareness of the significance of this field has increased in the past 6 months.
- Enzyme sensors - Zaborsky noted that this is an area of combined university-industry development in Japan that has very effective interdisciplinary teams of scientists and engineers.
- Solid phase enzyme systems (immobilization) - Japanese development here is not only significant in the large-scale fermentation areas but also in applying this technology to small systems. Such an application provides useful data for the design of other, perhaps larger, systems. This has not been the pattern in the U.S.
- Ethanol production - Here, again, the significance is the development of immobilized host cells.
- Cellulose hydrolysis - and the associated enzyme development.
- Advanced bioreactors - R&D in this technology is being supported by several government agencies, including MITI, the STA, and the Ministry of Agriculture, Forestry and Fisheries. These programs will be described in a later section.

3.2 QUALITY OF INFORMATION TRANSFER

The opinions on the quality of the information transfer from Japan varied much more than opinions about comparative technical skills. This difference was particularly noticeable in the comments on the literature. One group felt that information transfer via journals was already timely and comprehensive, while another group felt that the U.S. is still only receiving fragments of the R&D under way in Japan. There was, however, general agreement that the interaction between researchers in the two countries was insufficient.

Because of the limited sample of researchers, it is difficult to determine if the differing perceptions of the literature are due to differences in research specialities and hence a difference in relevant journals. Researchers who feel that the literature is adequate pointed to several publications with articles describing work in Japan. These are included in the publications listed in Table 3.1. These researchers also commented that the English language publications from Japan tend to be of a high quality.

In addition to journals and magazines, there is also the Biotechnology in Japan Newsservice. This newsletter is published monthly and summarizes aspects of biotechnology work in Japan such as recent commercial developments, joint

TABLE 3.1. Publications Containing Information on Industrial Biotechnology Research in Japan

Publication	Primary	Secondary
Journal of the Agricultural Society of Japan (in English)		X
Journal of Antibiotics (from Japan in English)		X
Journal of Fermentation Technology (from Japan in English)	X	
Journal of Agricultural Chemistry (from Japan in English)		X
Journal of Biotechnology and Bioengineering		X
Applied Microbiology		X
Microbial Technology		X
Biotechnology Patent Digest		X
Enzyme and Microbial Technology Journal		X
Journal of Chemical Technology and Biotechnology		X
Biotechnology in Japan Newsservice		X

ventures, and public and private development plans. The newsletter has only begun publication recently and is published by Japan Pacific Associates, an organization that specializes in market research in the field.

Researchers who feel that the literature does not adequately provide a full understanding of the research in Japan asserted that the information received in the U.S. is still very fragmentary and that significant Japanese publications exist that are not translated. For example, although the Biotechnology Patent Digest reviews Japanese patents, it is limited to those patents submitted in the U.S. It was also noted that the University of Tokyo and the University of Osaka have biannual publications that comprehensively survey the industry (including information on research, funding, and patents) but that the documents are only available in Japanese. This second group of researchers therefore felt that additional selected translations, as well as additional, comprehensive study of the research with technical detail, would be very enlightening.

In contrast, the researchers interviewed generally concurred on the insufficiency of interaction between researchers in Japan and the U.S. Two particular needs were identified: the need for more one-to-one interaction and the need for U.S. researchers to visit Japan. Several researchers noted that visits by large groups often result in information that is too general and lacks the technical specificity to be useful. This issue was also identified as a problem at larger conferences in the U.S., where mingling between Japanese and U.S. scientists is typically poor. To remedy this situation, it was recommended that smaller workshops or symposia to society meetings be organized to create a relaxed atmosphere for introductions and individual discussions. Several scientists also expressed quite strongly that the U.S. needs to internationalize its research perspectives. Although Japanese researchers constantly visit the U.S. for conferences and other business trips, few U.S. researchers can afford the opportunity to visit Japan, and even fewer can do so repeatedly. By visiting Japanese facilities, U.S. researchers can view the technical facilities first hand and can meet researchers who cannot easily arrange international travel to the U.S.

Again, there are those who felt that this need was less pressing, who noted that their organizations are frequently visited by Japanese researchers, and that many U.S. conferences are well attended by Japanese. This group felt that even if one were to visit Japan, Japanese researchers might not be as open about their work as U.S. scientists. One researcher who recently visited Japan as part as a study group felt that both the government and the private sector were very guarded about the information that they would reveal. However, all researchers interviewed acknowledged the importance of personal interaction and all agreed that the best discussions were those held in one-to-one settings.

3.3 SUMMARY OF PERCEPTIONS ON BIOTECHNOLOGY RESEARCH IN JAPAN

The researchers interviewed generally agreed that the U.S. continues to excel in the fundamental study of microbiology and recombinant DNA, but that Japan possesses a comparable if not superior ability in applying biotechnology to production. The more end-use oriented approach in Japan is clearly reflected in both the government research programs as well as those in the private sector. To support these applied efforts, there is a general sense that Japan still relies heavily upon the basic research being conducted overseas, particularly in the U.S.

Japanese government programs in industrial applications of biotechnological processes are supported by several agencies, including the MITI, the STA, the Ministry of Agriculture, Forestry, and Fisheries, and the MOE. In addition, the private sector has several cooperative councils.

The strengths of the Japanese effort in biotechnology are reflected in several differences in their research approach compared with the U.S. These differences include the following:

- Japanese R&D is clearly more end-use oriented
- Japanese R&D emphasizes processing engineering
- Japan draws upon its extensive fermentation industry experience and the resource of engineers trained with this experience
- Japan's research approach is heavily empirical.

Researchers' evaluations of the current information transfer from Japan varied from ratings of good to significantly inadequate. Several Japanese journals published in the English language were identified; however, these tended to focus on agricultural and pharmaceutical topics. The publication that is potentially most relevant to industrial biotechnology is the Journal of Fermentation Technology. Also noted were significant publications in Japan that are not translated to English, including the biannual publications of the Universities of Tokyo and Osaka. The OTA study on international development in biotechnology provides a useful overview of government and private sector activities. However, this study focuses upon policy concerns and program directions and does not explore the technical detail of the work under way.

To improve the quality of technical information transfer from Japan, the following actions were recommended:

- Translate selected materials that provide unique technical or programmatic insight.
- Perform a technical overview of R&D in Japan as a followup to the OTA study.
- Provide a forum (workshops, symposia) for the informal interaction of scientists from the two countries.
- Encourage rather than impede the visits of U.S. scientists to research facilities in Japan.

3.4 GOVERNMENT AND SELECTED PRIVATE SECTOR ACTIVITIES IN JAPAN

Before 1980, the involvement of the Japanese government in biotechnology research only existed at a very low level. The only agency with any notable involvement was the STA, which began supporting research in this field in 1971. As late as 1979 the government had banned genetic engineering research in universities and severely restricted it in the private sector. However, since 1980, the government has dramatically shifted its position, designating biotechnology as a major industry of the future. The discussion below will review direct government activity in the promotion of biotechnology research. This will be followed by a brief discussion of selected private sector activities.

3.4.1 Government Programs in Japan

In 1983, government funds supported 20 to 25% of all of the biotechnology R&D work performed by private sector firms, universities, and public and private research institutes. Six different branches of the Japanese government are responsible for most of the support for biotechnology R&D: MITI; the STA; the Ministry of Agriculture, Forestry, and Fisheries; the MOE; the Ministry of Welfare; and the Environmental Protection Agency. The biotechnology R&D programs that were supported by each of these organizations in 1982 and 1983 are shown in Table 3.2. The relationships of government ministries to research institutions active in biotechnology are shown in Figure 3.1.

Biotechnology research at the government laboratories spans a wide range of applications, from waste water treatment to the synthesis of new materials to pharmaceuticals. The time frame of the research also extends from long-term fundamental work to near-term, applications-oriented projects. Selected projects being conducted at government laboratories are described in Table 3.3. This table lists the project title, the sponsoring agency or agencies, the organization(s) doing the research, the research period, and the funding level.

The table also shows that MITI, STA and MAFF are the largest supporters of biotechnology R&D. These activities as well as the general principles guiding MOE research will be discussed below.

Ministry of International Trade and Industry (MITI)

MITI entered biotechnology in 1981 with the establishment of a biotechnology study group. This group, called the Biotechnology Industry Long-Term Vision Study Group, established the Office of Biotechnology Promotion and three projects within the Next Generation Basic Industrial Technology program. This program is administered by MITI's Next Generation Research Coordination Bureau. In addition to these research programs, MITI also created the Office of Venture Enterprise Promotion in 1982.

The MITI program in biotechnology development involves a combination of government laboratory and private sector participation. The five active government laboratories include the Fermentation Research Institute, National Chemical Laboratory for Industry, Research Institute for Polymers and Textiles,

TABLE 3.2. Major Biotechnology Related Products in 1982 and 1983 (million yen)

Ministry/ Agency	Topic/Project	1982	1983
MITI	1. Next Generation Basic Industrial Technologies	1043	1191
	- recombinant ONA technology	324	364
	- bioreactor	385	452
	- mass cell culture	334	376
	(10-year plan with total budget of 20 billion yen, began 1981)		
	2. New Fuel Technology R&D Subsidies (biomass portion)	1116	918
	- development of conversion and utilization technologies		
	- cooperation with less developed countries		
	- information exchange		
	(7 year plan with total bucget of 35 billion yen, began 1981)		
	3. Comprehensive Feasibility Study	218	180
	- conceptual framework for the mass production and use of biomass		
	4. Fuel Alcohol Technology R&D	--	203
	- subsidies		
	5. Bioindustry Promotion	4	11
	Subtotal	2381	2503
Science and Technology Agency (STA)	1. Life Science Promotion Projects	1098	1050
	- development of bioreactors		
	- research on enzyme production		
	- development of new medicines		
	- screening and breeding of new microorganisms with recombinant DNA methods		
	- construction of P4 facility at Tsukuba		
	2. New Technology Promotion Fund	976	897

TABLE 3.2. (contd)

Ministry/ Agency	Topic/Project	1982	1983
	3. Creative Science and Technology Promotion Program - biotechnical functions (including biotopical information exchange)	98	391
	4. STA Coordination Fund	505	NA
	- extraction, analysis and synthesis technology for DNA	315	
	- safety of recombinant DNA technology		115
	- recombinant DNA technology for influenza and B-type hepatitis (5-year plan with 6 billion yen, began 1981)	55	
	Subtotal	2172	2338
Ministry of Agriculture, Forestry, and Fisheries	1. Green Energy (10-year program, began 1978)	NA	801
	2. Biomass Conversion (10-year program, began 1981)	311	391
	3. Cell Fusion (5-year program, began 1982)	226	228
	4. Promotion of New Artificial Insemination Techniques	NA	28
	5. Bioresources	79	208
	6. Crop Breeding, Crop Cultivation and Marine Ranching	NA	41
	7. Insect Extermination	NA	209
	8. Transplanting of Fertilized Eggs of Cattle	NA	110
	Subtotal	1874	2017
Ministry of Education (MOE)	Research on Recombinant DNA Experimental Techniques (3-year project, began 1980)	73	NA
	Subtotal	73	

TABLE 3.2. (contd)

Ministry/ Agency	Topic/Project	1982	1983
Ministry of Welfare	1. Bioresources	1014	1040
	2. Cancer Research Subsidies	48	NA
	3. Study Group for Application of DNA-related Technologies to Health Care and Medical Practice	31	NA
	Subtotal	1093	1040
Environmental Protection Agency	Environmental Impact of the Development of New Organisms	10	8
	Subtotal	10	8
	TOTAL	7603	7906

The MITI program in biotechnology development involves a combination of government laboratory and private sector participation. The five active government laboratories include the Fermentation Research Institute, National Chemical Laboratory for Industry, Research Institute for Polymers and Textiles, Government Industrial Research Institute, and the Institute of Physical and Chemical Research. These laboratories account for 10% of the bureau's research. In addition to the government laboratories, 14 private sector groups are receiving grants from the Next Generation project and have been organized into the Biotechnology Development Research Association. The current activities of the government laboratories and the private sector groups will be briefly discussed below.

The projects that appear to be most relevant to the use of biotechnology in industrial processes are the three projects under the Next Generation Basic Industrial Technologies program. These three projects are in the areas of 1) recombinant DNA techniques, 2) bioreactors, and 3) mass cell culture. R&D conducted in this program is part of a 10-year R&D plan that began in 1981 with a total budget of 20 billion yen (~88.9 million dollars).

The 10-year research plan for the MITI bioreactor project is outlined in Figure 3.2. Currently, the bioreactor project is composed of two subprojects:

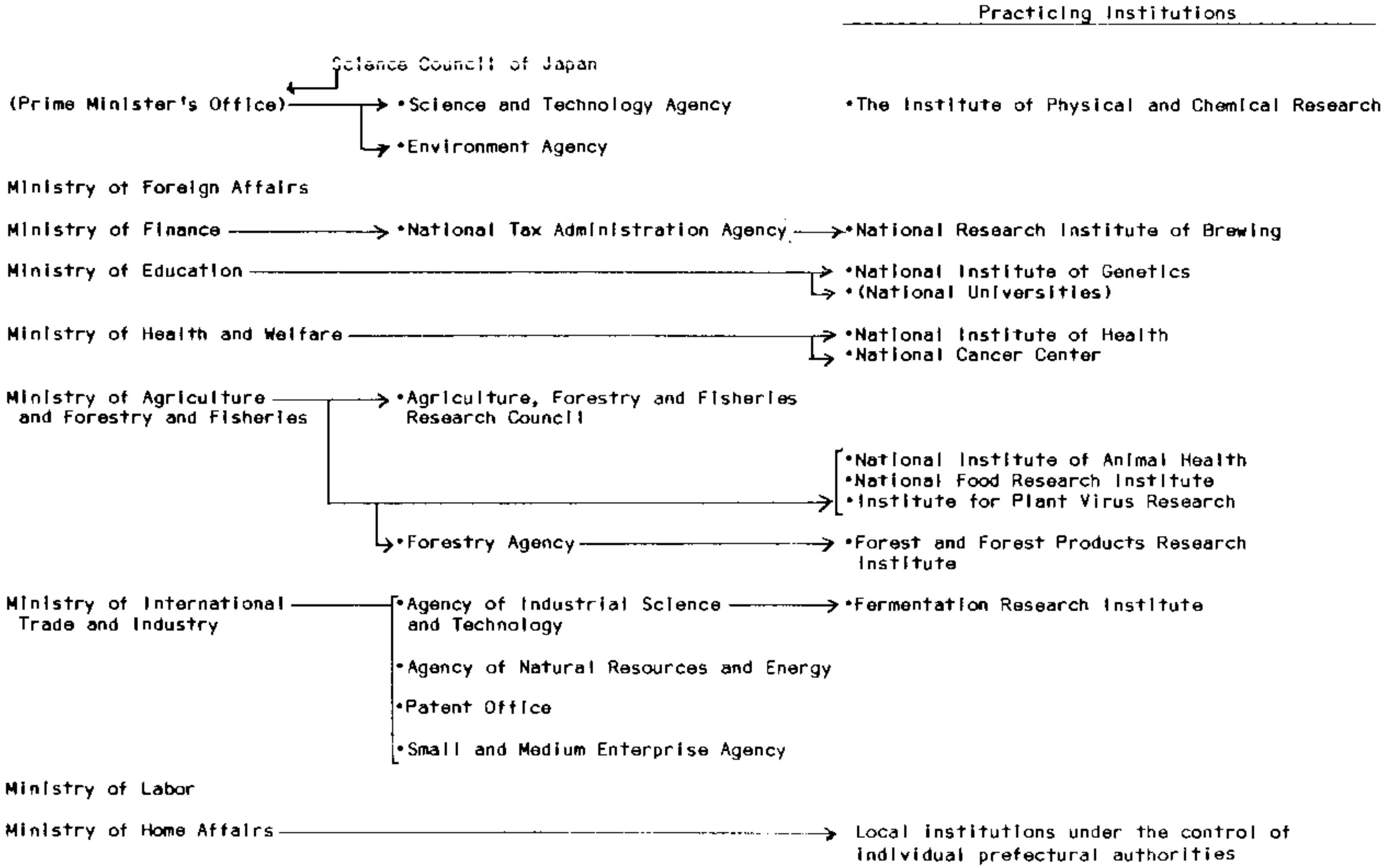

FIGURE 3.1. Government Organization and National Institutions of Japan in Relation to Advanced Biotechnology

TABLE 3.3. Selected R&D Projects in Life Sciences and Subsidies and Grants for Life Science R&D[a]

Format: Project Title
- a. Sponsoring Agency
- b. Research Organization
- c. Period of Performance
- d. Funding

1. Synthetic R&D on Technology to Efficiently Utilize Bioresources (The Biomass Transformation Plan)
   - a. MAFF
   - b. Business Office, Agriculture, Fishery and Forestry Technology Council
National Institute of Agricultural Sciences
Forestry Experiment Station
National Agricultural Experiment Station
National Research Institute of Agriculture
   - c. 1980 - 1990
   - d. 245,610

2. Chemical Synthesis of Nucleic Acids
   - a. MITI
   - b. National Chemical Laboratory for Industry, AIST
   - c. 1981 - 1986
   - d. 36,304 in 1981; 38,975 in 1982
40,000 in 1983; 64,721 in 1984 - 1986

3. R&D on Enzyme Reactors
   - a. MITI
   - b. National Chemical Laboratory for Industry, AIST
   - c. 1979 - 1983
   - d. 80,000

4. R&D on the Use of Nitrogen Fixing Ability of Microorganisms
   - a. MITI
   - b. Fermentation Research Institute, AIST
   - c. 1980 - 1984
   - d. 73,150

5. Research on Genetic-Biochemical Breeding of Microorganisms
   - a. MITI
   - b. Fermentation Research Institute, AIST
   - c. 1980 - 1985
   - d. 99,000

6. R&D on Production of Physiologically Active Agents, Utilizing Biological Functions
   - a. MITI
   - b. Fermentation Research Institute, AIST
   - c. 1980 - 1983
   - d. 103,837

TABLE 3.3. (contd)

7. R&D on Industrial Uses of Enzyme's Functions
   a. MITI
   b. Fermentation Research Institute, AIST
   c. 1980 - 1984
   d. 40,298

8. R&D on Physiologically Active Macromolecules and Their Production Process Technologies
   a. MITI
   b. Research Institute for Polymers and Textiles, AIST
   c. 1978 - 1982
   d. 93,449

9. R&D on Biochemical Pulp Technology
   a. MITI
   b. Government Industrial Research Institute, Shikoku
   c. 1980 - 1983
   d. 40,000

10. R&D on Utilizing Carbon Dioxide for Industrial Use
    a. MITI
    b. National Industrial Research Institute
    c. 1979 - 1981
    d. 9,325

11. R&D on the Safety of Recombinant DNA Techniques
    a. STA, MOW, MOF, MOAg, MOE
    b. Research Coordination Bureau
       National Institute of Health
       National Institute of Public Health
    c. 1980 - 1982
    d. 314,258

12. R&D on Chemical Synthesis of Nucleic Acids and Its Applications
    a. MITI
    b. Research Institute for Polymers and Textiles
    c. 1981 - 1986
    d. 12,072

(a) Abbreviations:
MAFF - Ministry of Agriculture, Forestry and Fisheries
AIST - Agency of Industrial Science and Technology
MOW - Ministry of Welfare
MOF - Ministry of Finance
MOAg - Ministry of Agriculture
MOE - Ministry of Education
STA - Science and Technology Agency
MITI - Ministry of International Trade and Industry.

Research Objective	Fiscal Year 81–84	Fiscal Year 85–90
1. Search for Micro-organism for Target enzyme	search for producer organism	breed and improve of micro-organism
2. Improve Productivity of Enzyme	examine stabilization methods for enzyme	improve productivity of enzyme
3. Immobilize Technology for Micro-organism and Enzyme	examine materials for immobilization methods	develop immobilization methods
4. Develop Optimal Reaction Methods		develop optimal reaction methods
5. Test, Assess		assess productivity of reactors

FIGURE 3.2. Long-Term Planning For the R&D of Bioreactors

researching the acid reaction bioreactor and researching the reactor based on reduction reactions. Research on these subprojects will be conducted simultaneously. The Mitsubishi Chemical company has overall responsibility for the project. The acid reaction bioreactor subproject is also led by Mitsubishi Chemicals with other companies participating, including Kao Soap, Daicel, and the Mitsubishi Gas Chemical Company. The reduction reaction bioreactor subproject is being led by Mitsubishi Petrochemicals, with Mitsubishi Petrochemicals and Denki Kagaku Kogyo also participating.

The recombinant DNA project is also composed of several tasks that span a 10-year planning period. The overall objective of the work is to discover new host-vector systems for B. Subtiles, yeast and other micro-organisms. The four primary tasks come under the following headings: 1) separation of target DNA, 2) development of new host-vector systems, 3) development of productivity improvement technology, and 4) empirical assessment. These tasks and their subtasks are outlined in the 10-year research plan shown in Figure 3.3. The Sumitomo Chemical company is the project leader, with Mitsui Toatsu and Mitsubishi Kasei Institute of Life Sciences also participating.

Research Objective	Fiscal Year 81 82 83 84 85	86 87 88 89 90
1. Separation of Target DNA	search of target DNA separation, structure	
2. New Host-Vector	synthetic and related enzymes	
3. Development of Productivity Improvement Technology	thermophilic bacteria	anaerobic organisms
4. Empirical Assessment	improving efficiency of host-vector system	technology to improve productivity of DNA recombinant cells

FIGURE 3.3. Long-Term R&D Planning for Utilization Technology for Recombinant DNA

The overall objective of the mass cell culture project is to develop a substitute cultivation medium for animal tissue cultures. Of particular interest are mediums for diagnostic pharmaceuticals and artificial organs. The project leader is Kyowa Hakko with Asahi Chemical, Ajinomoto, Takeda Chemical and Toyo Jozo also participating.

Science and Technology Agency (STA)

As shown in Table 3.2, the STA is also supporting a significant effort in biotechnology R&D. The programs supported by this agency include the Science and Technology Coordination Fund, the Life Science Promotion Project, the Creative Science and Technology Program, and the New Technology Promotion Fund. The first two programs contain projects that most likely will affect biocatalysis.

Within the Science and Technology Coordination Fund, basic research is under way to investigate the extraction of DNA and the development of DNA synthesis techniques. Participants in the program include Ajinomoto, Wakinaga, Yakuhin, Yamasa Shoyu, Yuki Gosei Yakuhin Kogyo, and Toyo Soda Manufacturing Co. Ltd.

Within the Life Science Promotion Project, R&D is being conducted jointly with MITI in two areas: bioreactors and enzyme production techniques. The objective of the bioreactor project is to develop amino acid synthesis reactors and automatic diagnosis systems that make use of enzymes of medical significance. The enzyme production project is directed toward the effective use of immobilized enzymes.

Ministry of Agriculture, Fisheries and Forestry (MAFF)

The MAFF is also initiating an ambitious program to promote biotechnology. While their primary interests are in plant cell improvement and raising the seed growing efficiency of organisms, they are also interested in introducing bioreactors into the food industry. The MAFF has approximately 200 of its own researchers engaged in biotechnology research and is also inviting private sector researchers to work in their labs.

The MAFF is anticipating a 512 million yen (~2.3 million dollars) budget in fiscal 1984 to begin 5-year joint research projects in five areas: 1) bioreactor system development, primarily for the food industry, 2) cell fusion technique development with the chemical industry for new agricultural chemicals, 3) micro-organism and plant cell improvement by cell fusion routes with both the food and chemical industries, 4) simple diagnosis of animal diseases by immunology, and 5) seed productivity improvement by tissue culture (JEI 1984).

Ministry of Education

The Ministry of Education is supporting research on biotechnology under eight general themes:

- biological containment with new host-vector systems
- recombinant DNA research using chemically synthesized and biosynthesized DNA
- screening of various enzymes related to recombinant DNA experiments and their applications
- transformation of techniques
- techniques for determining the structure of recombinant DNA molecules

- reproduction of recombinant organisms
- structural changes of recombinant DNA
- expression of the genes in recombinant organisms.

In addition to research projects conducted under these themes, the Research Grants Section of the Technology Council routinely screens and allocates funds among the yearly research grant applications.

3.4.2 Private Sector Activities

In addition to this government-sponsored research in the private sector, many companies are investing private funds in biotechnology R&D in Japan. Table 3.4 summarizes the number of companies in the Tokyo Stock Exchange that were engaged in Biotechnology R&D in 1982, along with their levels of expenditure on biotechnology R&D. As might be expected, the primary interest is in developing pharmaceutical products. The chemical and food processing industries follow at a far lower level of activity.

It is interesting to note that 90% of the food processing firms in biotechnology plan to enter pharmaceuticals through biotechnology. The textiles industry is also targeting pharmaceuticals as a potential market for its biotechnology research. However, activity is also under way in the basic materials processing industries. Companies in the pulp and paper industry are interested in securing their supply of pulp and wood and in improving the quality of their products. The chemical industry is also moving toward expanding its product line by using biotechnology as a lever. One avenue of high interest is applying enzyme technology to R&D on bioreactors. In a recent survey of 132 company executives conducted by the newspaper Nikkei Sangyo Shimbum, 10% of the executives thought that biotechnology would begin to replace energy-using chemical processes in the next 10 years. Fifty-three percent thought that the replacement would increase to 10 to 30% in the next 20 years (54% of the executives interviewed directly affiliated with the chemical industry.)

Two of the leading private sector organizations in biotechnology research are the Mitsubishi Chemical Industries (MCI) and Kyowa Hakko. The president of MCI, Eiji Suzuki, is also the president of the 14-member Biotechnology Research

TABLE 3.4. Number of Companies Conducting R&D in Biotechnology and R&D Expenditures by Industry in Japan, 1982

Industries	No. of Companies Registered on TSE (Column I)	No. of Companies Engaged in Bio-technology and R&D (Column II)	Columns (II)/(I)	Total Expenditures for Biotechnology and R&D (in millions of Yen) (Column III)	Columns (III)/(II)	Expenditures for Recombinant DNA (in millions of Yen) (Column IV)	Columns (IV)/(III) x 100
Industry Total	1,621	305	18.8%	¥255,816 mil.	¥839 mil.	¥5,826 mil.	2.3%
Agriculture, Forestry and Fishery	9	2	22.2	X		--	
Mining	24	1	4.2	X		--	
Construction	152	21	13.8	1,963	93	--	--
Manufacturing Industry	1,318	277	21.0	53,072	914	5,826	2.3
Food Processing	104	39	37.5	18,224	467	1,795	9.8
Textile and Natural Fiber	89	6	6.7	4,531	755	120	2.6
Pulp and Paper	41	3	7.3	113	38	--	--
Chemical Industry	201	162	80.6	216,071	1,334	3,833	1.8
Chemical Fiber	10	32	100.0	38,291	1,197	1,596	4.2
Oil, Fat, and Paint	26	8	30.8	1,349	169	104	7.7
Pharmaceutical	40	113	100.0	172,735	1,529	2,076	1.2
Other Chemicals	125	9	7.2	3,695	411	58	1.6
Petroleum and Coal Products	13	3	23.1	606	202	9	1.5
Rubber	25	1	4.0	7	7	--	--
Ceramics	76	8	10.5	1,413	177	8	0.6
Iron and Steel	69	4	5.8	612	153	--	--
Non-Iron Metals	44	3	6.8	511	170	--	--
Machinery	219	14	6.4	3,221	230	--	--
Electronics Machinery	175	12	6.9	3,757	313	56	1.5
Electric Wares	36	7	19.4	2,008	287	56	2.8
Electronics	139	5	3.6	1,748	350	--	--
Transportation Vehicles	91	5	5.5	184	37	--	--
Motorcar	60	1	1.7	5	5	--	--
Others	31	4	12.9	179	45	--	--
Fine Mechanicals	40	3	7.5	3,049	1,016	5	0.2
Other Industries	49	14	28.6	773	55	--	--
Transport, Telecommunication and Other Services	118	4	3.4	242	61	--	--

Source: Prime Minister's Office '82

Association. MCI has a strong basic research orientation, and the company is currently managing the bioreactor project for the Biotechnology Research Association. The bioreactor project is directed toward energy-saving chemical reactions, new materials, refining rare metals, new energy, and new protein sources. Kyowa Hakko is also involved in a bioreactor R&D project, this one being part of the MITI Biomass Project. The bioreactor research at Kyowa Hakko has already resulted in developing the immobilized yeast technology discovered by Nippon Oil (a pilot plant is ready) and developing a bioreactor to immobilize thermophile enzymes to provide a production yield of 90%.

One feature that should be noted about private sector cooperative organizations (such as the Biotechnology Research Association) is that companies at the leading edge of the technology tend to avoid joining associations because of competitive concerns. For example, Tanabe is considered a leader in bioreactor R&D but has avoided participating in the BRA project.

3.5 RESEARCHERS CONTACTED REGARDING BIOTECHNOLOGY RESEARCH IN JAPAN

The following researchers offered comments on this field.

Charles Cooney - Massachusetts Institute of Technology (MIT)

Dr. Cooney specializes in biochemical engineering, including fermentation technology, enzyme catalysis, and separations. Dr. Cooney relies upon Japanese journals published in English and on visitors from Japan to MIT for his information about research in Japan. Although he has visited Japan several times, he notes that the many visitors from Japan to MIT provide ample opportunities to discuss their work.

Eric Dunlop - Washington University, St. Louis

A professor of Chemical Engineering, Dr. Dunlop heads the biotechnology center at Washington University. He is particularly interested in Japanese developments in biocatalytic process technology. Dr. Dunlop has recently visited Japan to survey activities in industrial biotechnology in both the public and private sectors. He also monitors work in Japan through Japanese publications in English journals.

Yoriko Kishimoto - Japan Pacific Associates

Ms. Kishimoto currently manages the Japan Pacific Associates, which publishes the Biotechnology in Japan Newsservice, a monthly newsletter that describes industrial and government activity in this field. Ms. Kishimoto is fluent in Japanese and participated in the OTA stucy of biotechnology in Japan. She relies on visits to Japan and the company's Japan affiliate to monitor the developments.

Gary Saxonhouse - University of Michigan, Ann Arbor

Dr. Saxonhouse is an economist well known for his study of Japan. He was the project leader in the study of biotechnology in Japan sponsored by the OTA. Dr. Saxonhouse is fluent in Japanese and conducted the OTA study with many Japan source documents.

Charles Scott - Oak Ridge National Laboratory

Dr. Scott is the leader of a biotechnology group at ORNL and a research fellow with Union Carbide. As a chemical engineer, he specializes in bioengineering and the industrial biotechnology processes with an emphasis on advanced bioreactor systems. Japanese research in biotechnology is discussed with frequent Japanese visitors to ORNL as well as with Japanese participants in the annual symposium series in this area that is organized by Dr. Scott. Although he has not visited Japan for several years, two of Scott's staff have recently had significant interactions with their Japanese colleagues via NSF-supported conferences. Dr. Scott and his staff read articles from Japan published in English language journals.

Boyd Woodruff - Soil Microbiology Associates, Inc.

Dr. Woodruff recently retired from Merk, Sharp and Dome where he was in charge of the laboratory in Japan. His work has been in antibiotics and pharmaceuticals, and he is most familiar with developments in these areas in Japan. He has some experience with the Japanese development of large-scale fermenters. Through his work with the laboratory in Japan, Dr. Woodruff has extensive first-hand exposure to Japanese research and has published in U.S. journals.

Oscar Zaborsky - OMEC, Inc.

Formerly with the National Science Foundation, Dr. Zaborsky is currently the editor of Biotechnology Patent Digest and the Microbial Enzyme Digest. Through this work, as well as through other English language publications, Dr. Zaborsky monitors Japanese patent applications in the U.S. and Japanese submissions to U.S. journals.

4.0 CERAMICS

Since the late 1970s, ceramics development in Japan has received a high degree of attention from both government and industry. This push was highlighted in 1980 when the Japanese government announced a ten-year program to develop high-technology ceramics into a major industry of the future in Japan. As a result of this impetus by the government, a large effort appears to be under way in developing and commercializing ceramics products in a very wide range of end uses. These end uses include high-temperature applications, heat engine components, electronic equipment, and non-energy-related uses such as medical applications.

Advanced ceramic technologies are commonly referred to in Japan as fine ceramics. Fine ceramics are distinguished from traditional ceramics, used in pottery, glass, and refractory brick. Whereas traditional ceramics are produced from natural raw materials such as clay, fine ceramics are produced from synthetic materials with tightly controlled physical compositions and properties.

Because fine ceramics is likely to become a major international industry in the future, it is becoming increasingly important for technology planners and researchers in the U.S. to understand the status of work in the international community. This chapter explores the perceptions of U.S. researchers regarding the strengths and comparative position of ceramics R&D in Japan and the quality and timeliness of the technical information available.

This investigation relied upon the observations offered by researchers in the ceramics field who have monitored developments in Japan. The researchers who offered their comments include the following:

Charles Bersch	National Aeronautics and Space Administration (NASA) Headquarters
Richard Bradt	University of Washington
Robert Gottschall	U.S. Department of Energy, Office of Basic Energy Sciences
Henry Graham	Air Force, Wright Aeronautical Laboratories
Robert Katz	Army Materials and Mechanics Research Center

Roy Kamo	Adiabatic, Inc.
Dave Kotchiz	Garrett AiResearch Corporation
Frederick Lange	Rockwell International Research Center
Joseph Pask	University of California, Berkeley
Arvid Pasto	GTE Research Laboratories
Roy Rice	Naval Research Laboratories
David Richerson	Garrett Turbine Company
Richard Sprigs	National Research Counseling
Maurice Torti	Norton Company
Shelly Wiederhorn	National Bureau of Standards
David Wirth	Coors Porcelain Division

4.1 NOTABLE ASPECTS OF CERAMICS RESEARCH IN JAPAN

The researchers interviewed agreed that a very high level of activity is occurring in ceramics research in Japan. Because of the potential for widespread applications of ceramic devices, there is a particularly high interest in applied research activities. This focus on applied research is reflected in the comments offered by U.S. researchers about activities in Japan; most of the observations offered dealt with applied R&D activities, with few comments on long-term or fundamental research.

Comments were mixed regarding the comparative status of research and technology development in Japan and the U.S. Several researchers felt that U.S. work still appears to be more innovative and advanced, particularly in the fundamentals, whereas others felt that a rough parity exists, with Japan being superior in some areas and the U.S. in others. It was encouraging to note that none of the researchers placed U.S. technical development at an overall disadvantage, at least currently. Several researchers noted, however, that the level of effort in Japan is generally perceived to be increasing. Many noted that momentum was a significant component favoring technology development in Japan. As a result, although the current levels of development might be comparable between the two countries, the future is likely to pose significant challenges to the technological leadership of the U.S. in these areas.

Researchers offered comments about a broad range of aspects of R&D in Japan, including processing technology, microstructure, fracture, life, material development and characterization, structural ceramics, electrical ceramics, other end-use specific ceramics, and manufacturing technology. These aspects will be discussed further below, along with general observations about factors contributing to Japan's ability to perform effective research.

The aspect of Japanese R&D most frequently identified as having high levels of activity is ceramic processing technology. Several researchers, including Bradt, Katz, Kotchiz, Lange, Rice and Wirth, felt that Japanese technology development is ahead of development in the U.S. Wirth noted that particularly good work is being conducted in coupling the processing techniques developed to the manufacturing process. Bradt noted that, in the development of processing substrates, the work at Kyocera is unparalleled. Rice and Richerson noted Japan's particular interest in investigating the behavior of materials during processes to enhance reproducibility.

While Richerson did not assert that Japanese processing technology is superior to that of the U.S., he noted that there does appear to be a push in Japan to develop more sophisticated processing technology. He further commented that with the new generation of processing technology and the already superior edge in research manpower, Japan is certain to be in the lead in this area.

The research of processing technology is closely related to the use of processing technology in manufacturing, and several researchers commented on the high level of Japanese work in product development. Components from Japan were noted as being more uniform and reliable. Kamo, Kotchiz and Rice noted the strong effort in the development of fabrication technology. For example, it was noted that ceramic regenerator cores produced in Japan possess superior performance characteristics. It was also noted that the manufacture of starting powders seems to be superior in Japan. Wirth and Graham noted that Japan is beginning to gain an edge in manufacturing experience and the commercialization of ceramic technologies. Specific technologies will be discussed later in this section.

Researchers offered a wide variety of perceptions about the strengths of applied research on the various forms and properties of ceramic materials. Bersch, Bradt, Kotchiz, Pask, Pasto, Rice and Torti all noted the high level of activity directed toward developments in composition and characterization. The ceramic compositions include all of the major forms including silicon-carbide, silicon-nitride, zirconia, and alumina. The developments in Japan in these areas can again be evidenced in products. For example, Torti noted that the toughened zirconia produced in Japan is superior to compositions in the U.S. Kamo added that there seems to be a push in transformation-toughened materials in general.

It was also noted that the Japanese experiments in characterization and composition have been aided by high-quality instrumentation, sensors, and a greater use of computers in conjunction with the experiments. Bradt, Gottschall and Kamo commented that the use of high-quality instrumentation is very widespread in Japan. Bradt also noted the sophisticated use of sensors and he pointed out that widespread use of computers in conjunction with experiments allows researchers to process and analyze data in many experiments.

The processing investigations are also aided by the fundamental research tools that provide insight into the ceramic's structure. Bersch noted that researchers in Japan are very interested in investigating improvements in the microstructure of ceramics for greater quality assurance. Bradt noted the widespread use of high-quality electron microscopes in Japanese labs. He noted, for example, that while the U.S. has a first-class facility at the Lawrence Berkeley Laboratory, Japan has ten facilities that are merely a degree below the Berkeley facility. Gottschall also noted Japanese industrial laboratories use equipment that does not appear to be used in U.S. laboratories.

Several researchers commented that one strength of the ceramics development work in Japan is in the breadth of applications being addressed. These categories of ceramics include those being developed for their electrical, magnetic, optical, chemical, thermal, structural, biological, and nuclear properties. Two areas frequently mentioned were structural ceramics and electrical ceramics. The push in structural ceramics was noted by Bradt, Gottschall, Pask, Pasto and Rice. Although some disagreed on the comparative status of development, the consensus was that this has become a highly active area of work in Japan. Bradt commented that 10 years ago Japanese work in structural ceramics was very weak. Since then, however, a tremendous effort has been made in this technology. In 1983 structural ceramics accounted for 21% of the monetary value of all ceramics produced in Japan (STJ 1983). Gottschall also commented that the push in structural ceramics seems to occur across the board. Rice noted in particular the development of structural elements in large machine tools.

A major aspect of structural ceramics is cutting tool ceramics. Katz and Rice noted that significant work is under way in this area. Katz commented that the Japanese are looking at ceramics as machine tool beds for greater dimensional stability and higher stiffness, adding to the machine's precision.

The second area mentioned frequently was electrical ceramics. In 1983 electrical and magnetic ceramics accounted for 67% of the capital value of all ceramics produced in Japan (STJ 1983). Bradt noted that this has been an area of strength of Japanese technology development for several years. Pasto also noted that Japan appears to be significantly outpacing the U.S. in the financial and manpower support devoted to R&D in this area. This, he foresees, is sure to yield a technological lead in this area for Japan in the near future. Other researchers pointed to specific advanced technologies: Katz noted the development of aluminum-nitride as a substrate material for use in microcircuitry to dissipate heat more effectively in the new super computers. Lange and Katz pointed to the development of multi-layered capacitors, and Pasto and Wirth noted the emphasis on developing packaging ceramics for electronic components.

Several researchers also noted that this emphasis in electrical ceramics can already be seen in the marketplace. Katz noted that the Japanese dominate in the substrate and chip-carrier markets through the products of companies such as Kyoto Ceramics. Pasto pointed to their dominant position in pizeoelectric ceramics.

Other technology areas noted by researchers include high-temperature and heat engine ceramics. In heat engine ceramics, Katz noted that the Japanese have developed a superior capability in relevant ceramic processing and design. Wirth noted that although heat engine ceramics are still a few years from commercialization, the work in Japan is highly innovative and directed toward a broad range of applications. Katz noted that Toshiba is pushing silicon nitride for use in ceramic engines and appears to be conducting work very comparable to that under way in the U.S. Graham and Rice added that this high-temperature ceramics work is mirrored in other applications, such as heat exchangers.

Through the Moonlight Project, MITI is sponsoring the development of high-temperature ceramics for use in gas turbine blades. Performance goals of this research include the following:

- Flexural strength - in 3-point bending
  over 100 kg/sq mm at room temperature
  over 60 kg/sq mm at 1500°C.
- High-temperature corrosion resistivity - room temperature flexural strength (3-point bending) of over 50 kg/sq mm after oxidation in air at 1500°C for 1000 hr.
- Creep rupture strength - creep rupture strength of over 25 kg/sq mm after exposure to 1500°C for 1,000 hr.

The one other technical area commented upon by the researchers interviewed concerned the design aspects of ceramic technology. Comments offered indicated that this is perhaps a weaker element of the effort in Japan. Lange noted that while Japanese researchers have made significant progress in design methods using finite element analysis as a standard design tool, there still appears to be a lower use of predictive techniques in design. Fracture mechanisms, for example, are typically determined empirically. Torti also noted the superior use of analytic tools and experience in the U.S.

As illustrated by this discussion, researchers indicated that a broad range of active work is under way in Japan in developing ceramics. The discussion also indicates that many researchers perceive this R&D activity in ceramics to be paying off in superior commercial products. Several researchers commented that the Japanese seem notably more effective at performing this transition from the laboratory to the market and at adapting general technology to specific applications. The reasons for this effectiveness were not explored in detail in the interviews, but researchers did speculate that it was a mixture of technical capability and organizational structure.

The advantage in technical capability is perceived to result from a significant commitment to manpower and equipment in Japan. Bradt, Kamo and Richerson noted that the level of research intensity is reflected in the greater investment in research manpower in Japan. The magnitude of this difference is illustrated by researchers' comments that for every five to ten researchers working in an area in Japan, there may be one similarly committed in the U.S.

Further aiding the effectiveness of the research is what U.S. researchers perceive to be more effective government participation and coordination among research efforts. Several government organizations are involved in developing advanced ceramics. The most highly publicized program is sponsored by the Agency for Industrial Science and Technology in MITI and is part of the Basic Technologies for Future Industries Program. The focus of this effort is on developing fine ceramics for use as structural materials. The goal is to develop desired characteristics of high strength, corrosion resistivity and wear resistivity in high-temperature applications. Research under this program is being conducted by four national research institutes and the Fine Ceramics Technology Research Association, which has 15 private corporations as members. Kamo pointed out that although the actual financial support received by the industrial participants is small (Toshiba receives about $200,000), the actual purpose of the cost sharing is to facilitate program coordination.

In addition to these MITI programs, the STA is pursuing ceramic dispersed composites for use at very high temperatures (1000 to 3000°C) (STJ 1983). The MOE is promoting the study of innovative ceramics, and the Ministry of Transportation is advancing ceramic developments applicable to marine engines. The government programs and participating labs are summarized in Table 4.1.

TABLE 4.1. R&D of Fine Ceramics by Government-Affiliated Laboratories and Institutes

Project System	R&D Project	Period (FY)	Participants
Science and Technology Agency			
Special R&D	Study on the development of ceramics dispersion and strengthened fine materials	1981-1985	National Research Institute for Metals
	R&D of ultra high-temperature heat-resistant ceramics	1980-1984 (1st phase)	National Institute for Research in Organic Materials
Ministry of International Trade and Industry			
Research and Development Project of Basic Technology for Future Industries	Fine ceramics (high-performance ceramics)	1981-1990	Government Industrial Research Institute, Nagoya (GIRI, Nagoya) Government Industrial Research Institute, Osaka (GIRI, Osaka) Mechanical Engineering Laboratory National Institute for Research in Inorganic Materials Engineering Research Association for High Performance Ceramics
R&D on Energy Conservation Technology (The Moonlight Project)	Advanced gas turbine	1978-1984	Government Industrial Research Institute, Kyushu GIRI, Osaka, GIRI, Nagoya Engineering, Research Associations for Advanced Gas Turbine
	Advanced battery energy and storage	1980-1990	Electrotechnical Laboratory GIRI, Osaka New Energy Development Organization (NEDO)
	Magnetohydrodynamics (MHD) generation technology	1976-1982 (2nd phase) 1966-1975 (1st phase)	Electrotechnical Laboratory GIRI, Nagoya GIRI, Osaka
Leading and Basic R&D on Energy Conservation Technology	Studies on energy conservation technology relating to infrared radiation and ceramic materials	1979-1982	GIRI, Nagoya
Special R&D	Research on application of the structure of ceramics	1980-1984	Mechanical Engineering Laboratory
	Research on generation and application of super high energy by high explosives (explosive treatment of ceramic powder)	1980-1984	National Chemical Laboratory for Industry
	Research relating to super refractories and thermal-insulating ceramics	1976-1982	GIRI, Nagoya
	Study on development of high-performance, high-melting inorganic material	1980-1984	GIRI, Nagoya
	Research on laser-related glass materials	1980-1983	GIRI, Osaka
	Research on production technology for new functional porous glass film	1981-1984	GIRI, Osaka
	Research relating to developing technology for high-strength reflecting devices for ultraviolet rays	1982-1984	GIRI, Osaka
	Research on new material for cutting tools	1979-1982	GIRI, Osaka
	Study on development of carbon-ceramic composite material	1981-1984	GIRI, Kyushu
Ministry of Education			
Grant-in-Aid for Special Research	New investigation into functional ceramics	1982-1984	Osaka University, Kyushu University, etc.
Ministry of Transport			
Special R&D	Research on advanced gas turbine for ships	1979-1983	Ship Research Institute

Coordination of research was also evident to some degree in the private sector in the meetings of the professional associations. Three ceramic associations were organized in the private sector in 1980. In addition to the ceramic technology research organization mentioned earlier, there are the Association for New Functional Elements Research and Development and the Association for New Metal and Compound Material Research and Development. The objectives of the Fine Ceramics Technology Research Association are as follows (Kenney and Bowen 1983):

- improve the reliability and reproducibility of ceramic components
- establish a high-temperature ceramic engine system
- promote basic research of fine ceramic materials.

Bradt noted that members make presentations at the monthly meetings of the Fine Ceramics Technology Research Association to reduce the duplication of research effort. Researchers also sensed that in the private sector there seems to be more stability in the R&D efforts, enabling the workers to plan for longer-term programs.

4.2 THE QUALITY OF INFORMATION TRANSFER

Interviews with researchers revealed that there is a large body of information related to the development of ceramics in Japan. The primary sources of this information available to U.S. researchers include the English language literature and international conferences. The literature sources, conferences and special studies identified in this study are listed in Table 4.2. There have also been more reviews of Japanese research in this field than in any of the other fields covered in this study. However, although several researchers noted the large amount of published information on research in Japan that is currently available, it was also noted that several definite shortcomings in the literature exist. Highlights of the current literature and a discussion of significant shortcomings will be provided below.

The literature on ceramics developments is quite broad, encompassing both fundamental research and applications-oriented endeavors. The literature

TABLE 4.2. Publications Containing Information on Ceramics Research in Japan

Publication	Primary	Secondary
Actametallurgic	x	
Asian Wall Street Journal		x
Bulletin of the American Ceramics Society	x	
Ceramic Abstracts	x	
Ceramic Forum International		x
Ceramic Industry		x
Ceramics Japan, Seramikkasu		x
Japan Chemist		x
Japanese Economic Journal		x
Japanese Journal of Applied Physics		x
Journal of the American Ceramics Society	x	
Journal of Applied Physics		x
Journal of the Electrochemical Society		x
Journal of Material Science	x	
Material Science and Engineering		x
Transactions of the AIME		x

includes specialized technical journals and magazines that address broader science and technology trends. The strength of the literature, in fact, lies in its abundance and broad coverage.

The primary English language literature containing technical papers submitted by researchers from Japan includes the Journal of the American Ceramic Society, the Bulletin of the American Ceramics Society, and Ceramic Industry. The Journal of the American Ceramic Society is one of the most prestigious publications in this field. It contains research reports on the arts and sciences of ceramic materials. The Bulletin of the American Ceramics Society contains news of the society and articles on applied ceramic research and engineering. Ceramic Industry is a magazine covering the fine ceramic industry and often includes new ceramic product announcements. It was also noted that the

Japan Economic Journal often contains news related to the Japanese ceramics industry. Typical articles might cover new product announcements, summaries of government policy papers, or corporate links.

These traditional journal and magazine sources are supplemented by other information services and publications. Ceramic Abstracts is a publication of the American Ceramic Society that contains reports on significant literature on ceramics and related fields worldwide. NASA Scan is a service that gathers abstracts of various articles dealing with ceramics internationally. The Foreign Science and Technology Center also scans literature relevant to ceramics research but its information is only available to personnel in the U.S. Department of Defense. The Defense Technical Information Center also collects some information on projects in Japan, but researchers find that the material is not very well screened and is consequently only marginally useful.

The other primary mechanism used by researchers to keep abreast of activities in Japan is the domestic and international conferences that draw papers from Japan. These conferences and meetings are listed in Table 4.3. Researchers identified the Annual Meeting of the American Ceramic Society and the Society of Automotive Engineers (SAE) Annual Meeting as the most significant meetings. The Ceramics Society meeting is perhaps the most important international meeting in the ceramics field. It typically attracts about 3,000 attendees, including many Japanese participants. The papers tend to encompass a

TABLE 4.3. Conferences with Papers Describing Ceramics Research in Japan

Conferences	Primary	Secondary
American Ceramics Society, Annual Meeting	x	
Conference on Fracture Mechanics of Ceramics		x
DOE Contractor Coordination Meetings		x
Gordon Research Conference		x
British Ceramics Society		x
SAE Annual Congress	x	
Zirconia, Annual Meeting		x

wide range of fundamental and applied research areas. The SAE Annual Meeting provides information on the status of development efforts in Japan related to ceramic components for advanced heat engines.

Although the researchers generally agreed that there is abundant information available in English regarding research activities in Japan, several researchers pointed to significant shortcomings. These shortcomings include the lack of detail in the published material, the spotty coverage of the papers, the age of the research presented in the literature, the overabundance of poorly screened material, and the misinformation propagated in the popular literature.

Researchers including Bradt, Kamo, Lange, Pasto, Rice, Richerson, Torti and Wirth all commented that the literature is not detailed enough to provide an understanding of the research. Comments varied from, "the research is just too general," to "the work seems to be sanitized to omit important technical detail." For example, it was noted that in papers relating to zirconia ceramics, information on composition or manufacturing temperature necessary to permit replication of the experiments is often omitted. It was also noted that papers describing component testing typically only discuss results and do not describe the experimental method.

A second major concern about the literature is that even though it is abundant, it is also spotty and incomplete. Several researchers, including Bradt, Katz, Pask and Wirth, have the sense that there are significant gaps in the information published in English. Bradt, Pask, Pasto and Katz noted that they have seen important Japanese publications that are not translated into English. For example, Bradt noted that each large company has a journal that is only issued in Japanese. Pask also noted that little is seen in the open English language literature that describes the activities of the industrial laboratories, and Pasto pointed to the general lack of literature describing research into processing. Bradt further commented that literature not available in English frequently appears as references in the international literature. Overall, he noted that there is a great deal of literature published in Japan that most academicians are not seeing, that contains many important papers, and that does not duplicate the material appearing in the prominent international periodicals. The quantity and quality of technical information that is not published in English needs to be examined.

One example noted of technical areas where information gaps exist was the evidence of significant work in injection molding, with little detail about what the work encompasses. Kamo commented that if U.S. firms could effectively follow what the Japanese are doing, the U.S. would have competitive ceramic powders.

Mixed opinions were expressed about the available information describing work in the Japanese government laboratories. Some felt that most of the publications from the government labs and universities are seen in the U.S. However, the opposite opinion, that the U.S. sees little of this work, was also expressed.

The age of the research presented in the journal literature was noted to be a definite drawback by several researchers, including Kamo, Katz, Lange, Richerson, Torti and Wirth. They noted that the typical delay between the actual work and publication is two years, which is a major delay in a field that is evolving so quickly. Richerson notes that this typical two-year delay is often equal to the period between the actual laboratory work and the emergence of the technology in the marketplace. This evaluation of the literature emphasizes the need for personal interaction and more timely information services.

Although researchers commented that an abundance of information is available in both English and Japanese, the quality and timeliness of the information vary greatly. It is thus often time-consuming to sort through the copious literature to find the useful articles. Several researchers, including Bersch, Katz, and Rice, also commented that the U.S. could be much more aggressive about screening and using the information that is currently available. Several researchers also commented that the published material contains overly optimistic information released by the public relations firms from various organizations in Japan. Thus, the importance of being able to separate exaggeration from reality was noted.

Ceramics is unique among the technical fields reviewed in this study in that ceramics development has been reviewed by different individuals and organizations who have described their observations in the literature. Publications in this field are listed in Table 4.4. These sources provide a good overview of the general extent of ceramics development activity in the public and private sectors in Japan. Researchers highly recommended the article "Ceramics in Japan" by Jack Wachtman. Finally, a study of ceramics development was conducted by the National Research Council (1984).

The primary need in improving information transfer via the literature therefore is to identify and translate important technical information that is available in Japan but not published in the international literature. The need to screen the existing literature was also mentioned, but this function was felt to be a responsibility of the research community.

Several other suggestions were offered to further improve the quality of information about ceramics developments in Japan. These suggestions included monitoring Japanese patents, encouraging the exchange of graduate students, faculty, and researchers, and encouraging onsite visits to Japanese facilities.

TABLE 4.4. Other Literature Describing Ceramics Development in Japan

Ceramics for High Performance Applications, Brookhill Publishing Company, 1983

"The Development of Structural Ceramics in Japan," JETRO, The Japan Industrial and Technological Bulletin, Special Issue No. 15, 1983

"The New Ceramics Industry in Japan: Present State and Future Prospects." Published by the Long Term Credit Bank of Japan Research, Special Issue Sept-Oct 1983.

"High Performance Ceramics in Japan," Science and Technology in Japan, Oct.-Dec. 1983.

"Japan Sets the Pace in Fine Ceramics Race," Mechanical Engineering, Nov. 1983.

"Ceramics in Japan," Jack Wachtman, Ceramics Industry, November 1983.

Pasto, Sprigs, and Wirth mentioned that monitoring patents would yield useful insight into development trends. Pasto noted that Japan has a system that translates U.S. patents within three weeks of their filing. Wirth cautioned, however, that a large number of patents are submitted from Japan, so the task of distilling useful technical information from these patents is not trivial. Torti also noted that Japanese patents are not published until 18 months after they are filed. However, unlike the U.S., patent applications in Japan are available soon after they are submitted.

The tremendous value of supporting graduate students, faculty, and other researchers to perform work in Japan was also noted. Several researchers, including Katz, Lange, Pask and Richerson, commented that this is a very effective way of allowing U.S. researchers to understand developments in Japan.

Finally, many of the researchers interviewed indicated that their preferred method for following Japanese research is through visits to Japanese laboratories. This allows the researchers to actually see the technology and how it is being used, and to talk with Japanese researchers. As mentioned earlier, a major drawback of the available literature is the reporting of results without a description of the experimental method. Visits to the facilities allow insight into some of these methods. It was also noted that visits to Japan would be valuable in circumventing the two-year publications delay.

4.3 SUMMARY OF PERSPECTIVES ON CERAMICS RESEARCH IN JAPAN

In recent years the research community and the general public have become increasingly aware of a very high level of research activity in Japan directed toward developing ceramic technologies. Ceramics has been targeted by the Japanese government as one of the high-growth, high-technology industries of the future. New ceramic products or ceramic development projects have already been announced for a broad range of end uses in areas including energy products, electronics, and medical science. Because of the significant role ceramics are likely to play in advancing future technologies, international developments in this area merit ongoing examination.

Assessments of the strength of the Japanese R&D effort compared with the U.S. effort differed depending on the stage of technology development. Opinions about the current comparative status of generic ceramics research were divided, with researchers alternately giving the edge to both the U.S. and Japan. In general, researchers agreed that the two countries seem to be at a rough parity in the research of fracture, life prediction, and material characterization. However, a significant technical push in Japanese ceramics development is clearly perceived to be under way by most researchers interviewed. They agreed that the research effort in Japan has definite areas of strength in which Japan might be considered superior to the U.S., and that this effort is gaining momentum in both the generic and applied areas. Several researchers noted that this momentum portends a very significant challenge to U.S. ceramics technology development in the near future.

Because of the wide applicability of ceramic technology, most U.S. researchers seem to be concerned primarily with the end-use-oriented research in Japan. Consequently, most of the researchers' comments touched upon these end-use-oriented, or applied, aspects of Japanese research.

The technical areas in which Japanese developments are considered to be notably superior are in the processing and manufacturing of ceramics. It was noted that Japanese processes seem to create more uniform and reliable materials than those produced elsewhere. This processing skill is substantially aided by a wider use of computer controls in conjunction with the processes, and by superior instrumentation and sensors. Other areas mentioned as being particularly strong in Japan include the development of structural ceramics, electrical ceramics (electronic substrates and packaging), high-temperature ceramics for heat engines, and cutting tool ceramics.

Important components of the strength of the Japanese effort were identified, including greater commitments to manpower and to equipment, and better coordination of research activities. It was noted that there is typically a greater level of commitment in Japan on the part of government researchers and particularly industry researchers to investigating ceramic technologies.

Several researchers commented that for every one researcher working on a problem in the U.S., the Japanese are willing to commit five to ten. The commitment to buying state-of-the-art analytic equipment was also noted to be greater in Japan than in the U.S. It was commented that while the U.S. has an excellent analytic facility at the Lawrence Berkeley Laboratory, Japan has ten similar facilities just a fraction less in quality.

Researchers also noted that the greater coordination of research activities in Japan permits a more effective use of resources. It was noted that although the MITI program commits only a small amount of funding to the industry, the real benefit results from the coordination brought about by that program. It was also noted that the private sector has associations, such as the Fine Ceramics Technology Research Association, which have monthly meetings in which participants can update each other on their work, thus minimizing duplication of effort.

Available technical information on current research in Japan might best be described as abundant yet insufficient. The researchers' consensus was that information published by Japanese researchers in English is lacking, and that merely sorting through the material available is a major task. However, many researchers noted that the information available in English suffers from several drawbacks: the information tends to be general, the coverage tends to be incomplete, and the literature is generally out of date by the time it is published. Several researchers noted that the information published in English is often very general and omits important technical information, such as compositions and temperatures, which would be critical to replicating the work. It was also noted that the literature is incomplete, because important publications exist that are available only in Japanese. It was further commented that references to reports not available in English are frequently seen in the international literature, and that the major companies in Japan have their own journals that are not translated into English. This is a serious gap, because there is little published in English from the industrial laboratories. The literature also typically lags the experiments by two years, a significant delay in a field advancing as quickly as ceramics. This delay, it was noted, often equals the lag between completion of the laboratory work and the emergence of a product in the marketplace.

Conferences provide an important, more timely source of information about work in Japan and appear to be the primary means used by researchers to keep abreast of the latest work overseas. The most significant conference is the Annual Meeting of the American Ceramics Society, which has an attendance of 3000 and attracts active Japanese participation. Although the Japanese are very active in attending U.S. conferences, it was noted that few U.S. researchers have the opportunity to visit Japan.

Largely as a result of increasing concern in the technical community about developments in Japan, ceramics development has received more attention than the other fields investigated in this study. The National Research Council (1984) study, released in the middle of 1984, has been the most significant study in this area. Overall, the information transfer from Japan to the U.S. in the ceramics area is better than in most of the other fields covered in this study. However, researchers identified significant gaps and offered suggestions for improving them. Researchers recommended identifying the significant work that is published only in Japanese, screening these publications, and making translations available to U.S. researchers. Monitoring Japanese patents was also recommended as a useful indicator of technology trends. It was also recommended that the U.S. increase the opportunity for U.S. researchers to visit and perform work in Japan. Increasing the interaction with researchers in Japan was strongly suggested as an important way to reduce the current information transfer gaps.

4.4 RESEARCHERS CONTACTED REGARDING CERAMICS RESEARCH IN JAPAN

The following researchers offered comments on this field.

Charles Bersch - NASA Headquarters

Dr. Bersch is the Manager of the Materials and Structures offices and is responsible for a broad range of materials research, including ceramics. To follow Japanese research, his office relies on researchers in the ceramics program at NASA and several academicians with whom NASA has large ceramics research contracts.

Richard Bradt - University of Washington

Dr. Bradt's research interests include material science in general, ceramics, refractories, and glass. He is particularly interested in fracture mechanics and lifetime prediction. Dr. Bradt has extensive exposure to Japanese research. He spent a year in Japan on sabbatical and has visited Japan on many occasions. He received the Richard Fulrath Award, which is given to four ceramic researchers annually; the American recipient uses the award to visit Japan for two to three weeks. Dr. Bradt has taught many students from Japan at the University of Washington and at the University of Pennsylvania. He also has extensive contacts in the industrial sector.

Robert Gottschall - U.S. DOE, Office of Basic Energy Sciences

As the Program Manager for ceramics at the Office of Basic Energy Sciences, Dr. Gottschall oversees 60 university programs and efforts within the national laboratories. This activity is quite broad, encompassing such subareas as materials characterization and life prediction. His main interest is basic research related to structural ceramics. Dr. Gottschall noted that a lot of material is published describing the basic ceramic research conducted in the Japanese universities. He uses this literature as a primary source of information on Japan. He also has research contacts in Japan and has visited Japan on several occasions.

Henry Graham - Air Force Materials Laboratory, Wright Aeronautical Laboratories

Dr. Graham's research interests are in the development and fundamental understanding of fine ceramic materials and their processing. Dr. Graham's ability to interact with the Japanese is restricted by the fact that many of his programs are covered under security regulations. He primarily relies on trip reports generated by governmental and industrial visitors to Japan and information developed by the Foreign Technology Division.

Robert Katz - Army Materials and Mechanics Research Center

Dr. Katz's technical emphasis is on materials testing and component fabrication. He serves as the contract monitor for the Metals and Ceramics Information Center. His division includes a materials testing facility that plays a central role in R&D related to the adiabatic engine. The division is also involved in the development of ceramics for temperature measurement systems.

Dr. Katz finds the most effective method of information transfer is direct communication with other researchers in the field. Therefore, he finds international conferences particularly valuable. Dr. Katz pointed out that trip reports on ceramics development in Japan are well circulated among the research community. To supplement these contacts, he follows the literature and uses several information services, including the Defense Technical Information Center's Metals and Ceramics Information Center, the Foreign Science and Technology Center, and the Office of Naval Research Far Eastern Office.

Roy Kamo - Adiabatic Inc.

Until recently, Dr. Kamo was the Executive Director for Research at Cummins Engine Company and played a major role as an advocate and researcher on the adiabatic diesel. His interest is the application of ceramics to heat engines. He will be organizing the heat engine ceramics session for the forthcoming SAE meeting.

As the Director for Research at Cummins Engine, Dr. Kamo frequently met the staff of Komatsu, with whom they had a licensing agreement. Through his contacts with Komatsu and others in the Japanese industrial community, Dr. Kamo feels he has developed a comfortable rapport in discussing meaningful technical topics. Dr. Kamo is fluent in Japanese and visits Japan about twice a year.

Dave Kotchiz - Garrett AiResearch Corporation

Dr. Kotchiz's research interest is in ceramic materials for heat exchanger applications. He notes that the effort at Garrett is quite broad and spans the entire research spectrum, including material development, lab experiments, prototype design and testing, and commercialization.

As a large end user of industrial ceramics, Garrett Corporation is constantly visited by ceramic suppliers, both domestic and Japanese. In this way, Dr. Kotchiz feels he is able to keep abreast of materials development. He also has contacts in the industry in Japan, follows the literature, and receives "NASA Scan," which contains abstracts of various articles dealing with ceramics.

Frederick Lange - Rockwell International Research Center

Dr. Lange's group is involved in a wide variety of ceramics activities that are oriented primarily toward material characterization and life-cycle prediction. Currently his group's work addresses such areas as how to shape ceramic powders, methods for reducing flaw propagation, and the formulation of lightweight ceramics for aerospace applications. In 1983 Dr. Lange was the recipient of the Richard Fulrath Award, given to four ceramics researchers annually. To follow activities in Japan, Dr. Lange relies primarily on the literature and conferences.

Joseph Pask - University of California, Berkeley

Dr. Pask's research interests include studying the interface between glass and alloys, investigating questions of adherence, and studying equilibria in silica-alumina systems. Personal contacts are his primary method for following Japanese efforts. He visits Japan about once a year, for two- to three-week periods. In addition, many Japanese visitors stop at the University of California. Dr. Pask is a member of the Japanese Ceramic Society and receives their publications, which contain mostly articles in Japanese with abstracts in English.

Arvid Pasto - GTE Research Laboratories

Dr. Pasto's research includes structural ceramics oriented toward engine hardware for autos, and electronic ceramics. Dr. Pasto uses a variety of techniques for following Japanese efforts, including visits to Japan, reading articles by Japanese authors in international journals, literature and patent searches. He noted that GTE is also visited frequently by Japanese representatives from the government and industry.

Roy Rice - Naval Research Laboratories

Dr. Rice's research interests include various aspects of high technology ceramics. Dr. Rice uses a variety of methods for following research activities in Japan, including reading the international professional journals, conferences, and his contacts in the U.S. ceramics community who keep him abreast of offshore developments. He also noted that they receive many visitors from Japan.

David Richerson - Garrett Turbine Company

Garrett Turbine Company is involved in a broad range of programs related to advanced ceramics, particularly ceramic components in heat engines. This includes work on the gas turbine, turbochargers, heavy duty diesels, and contact stress in general. Dr. Richerson noted that many Japanese firms approach Garrett with their components because Garrett is a major end user. In this way, he feels that he can keep up with the state of the art. He also noted that Garrett has a contacts in Japan that keep them abreast of developments in this area.

Richard Sprigs - National Research Council

Dr. Sprigs has devoted the past 30 years to ceramics research. He has published over 100 technical papers emphasizing ceramic properties and processing. Dr. Sprigs was involved with the National Research Council study of ceramics research in Japan released in the middle of 1984. He keeps abreast of research in Japan primarily through visits to Japan and conversations with others involved in ceramics efforts. He finds Japanese researchers to be very open in discussing technical work. He also finds international meetings to be a useful mechanism for understanding overseas developments.

Maurice Torti - Norton Company

Norton has recently augmented its traditional business in ceramics with a project on high-performance ceramics; the project group includes about sixty professionals. Dr. Torti uses various methods to follow work in Japan, including the information from Norton's sales office in Japan, the international literature, computer-based literature searches on specific topics, and patent searches.

Shelly Wiederhorn - National Bureau of Standards

Dr. Wiederhorn's research interests include mechanical testing, the development of techniques for predicting material properties, and the use of electron microscopy to characterize the mechanisms of materials. The work at NBS, he noted, covers a broad range of topics from optical and magnetic properties to processing techniques. There are about 80 people at NBS involved in work related to ceramics. To follow the work in Japan, he relies on a combination of the international literature and international conferences.

David Wirth - Coors Porcelain Division

Dr. Wirth's research interests include process manufacturing improvements and new product areas such as zirconia and aluminum oxide. His company also performs research into various aspects of ceramics, such as high-temperature ceramics for recuperators. Dr. Wirth primarily relies on visits to Japan to follow Japanese work. He feels that visits are invaluable for understanding the actual extent and details of research under way. He also shares information with industrial contacts and follows the technical literature and Japanese patents filed in the U.S.

5.0 COMBUSTION

Converting the energy in fuel into useful thermal energy often involves the intermediate process of combustion. The energy unlocked through combustion is used in a wide variety of technologies, from automobile and jet engines, to home furnaces, to steel furnaces, to utility power plants. As technologies advance, optimizing combustion processes becomes more and more important. The success of the direct-injection stratified charge engine or the dilute homogeneous charge engine, for example, is likely to hinge on the ability to closely control the combustion processes.

Advances in combustion science and technologies are of particular interest in Japan because of the national goal to shift from the use of petroleum to alternative fuels. In 1980 the Japanese government announced a goal of reducing its reliance on petroleum, from supplying 75% of the nation's energy needs in 1980, to supplying 50% by 1990. Much of this shift was envisioned to result from the increased use of coal, coal-derived fuels, and liquid natural gas (LNG). As a result of this goal, interest in improving combustion techniques has increased.

U.S. researchers who discussed their perceptions of the status of combustion research in Japan include the following:

Charles Amann	General Motors Research Laboratory
Gary Borman	University of Wisconsin
Thomas Bowman	Stanford University
John Clarke	Caterpillar Tractor Company
Ray CeBlois	United Technology Research Center
Jack Ekchian	Massachusetts Institute of Technology
Irwin Glassman	Princeton University
N. A. Harein	Wayne State University
Carlo Fernandez-Pello	University of California, Berkeley
David Mann	Army Research Dffice
Joe Rife	Geneva Group
C. William Robinson	Sandia National Laboratories, Livermore

Robert Sawyer	University of California, Berkeley
Hratch Semerjian	National Bureau of Standards
L. Douglas Smoot	Brigham Young University
Otto Uyehara	University of Wisconsin

The following sections contain discussions of notable aspects of combustion research in Japan and the status of information transfer to the U.S.

5.1 NOTABLE ASPECTS OF COMBUSTION RESEARCH IN JAPAN

Although the researchers discussed a wide variety of aspects of Japanese combustion research, there was surprising consensus in their comparison of research in Japan with research in the U.S. In basic combustion research, U.S. researchers agreed that the work in the U.S. is more broadly based than the work in Japan. Most of the researchers interviewed indicated that the effort in Japan appeared to be more focused and consequently that the strength of combustion research in Japan is in its application. In these applied research areas, many researchers noted that the quality of the research in Japan is achieving parity with and in some cases surpassing the quality of research in the U.S. Because of this focus on applied research, researchers also noted that the work in Japan is often better translated to end uses. The following discussion will touch on some of the areas highlighted by the researchers interviewed.

Areas of combustion research in Japan noted by the researchers include work that addresses the adiabatic diesel, general automotive engines, general combustion processes, emissions, coal combustion, instrumentation and combustion control, laser diagnostics, and combustion modeling. It was interesting that many of the researchers' comments were independently corroborated by their peers. Only in the areas of combustion diagnostics and modeling did contradictory comments surface.

Researchers, including Borman, Clarke and Uyehara, noted that a significant level of activity in combustion research in Japan is related to the adabiatic diesel engine. Uyehara noted that the Japanese are particularly attracted to the engine's fuel flexibility. The adiabatic diesel, for example, reduces the emission of soot from the combustion of coal-derived fuels. This feature will be very important if the country continues its plans to decrease its dependence on oil and increase its use of coal.

Should Japanese researchers continue to pursue adiabatic diesel technology, the advancement of the technology will be assisted substantially by the advanced development of ceramics in Japan. Amann, Borman, Clarke, Ekchian, Mann, Sawyer and Uyehara commented that the advanced ceramics industry would be very likely to provide Japanese researchers with an edge in the development of the adiabatic diesel. Clarke further added that the development of ceramic light duty engines is being pursued in Japan but not in the U.S. U.S. manufacturers seem wary that the cost of the engine will be too great a barrier for the commercial success of this engine.

The general emphasis on the study of automotive engine combustion was noted by Bowman, Glassman and Sawyer. Japanese research of combustion chamber design was noted by Harein and Sawyer. Rife and Ekchian pointed to Japanese research of turbulent, fast-burn, high compression ratio combustion as an area of particular strength. Sawyer noted the pursuit of new combustion design concepts for spark injection and diesel engines. Harein pointed in particular to the Wankel engine, the stratified charge, and small, low-emissions engines. Harein and Ekchian further noted the significant level of effort in turbocharger development.

In the nearer-term development of engines, Sawyer noted that Japanese researchers lead in the area of production design. For example, in the design of pistons, he noted the superior work in reducing weight and enhancing performance.

Researchers also noted very significant work in the more fundamental combustion processes applicable to engines. Clarke noted Japan's work in gaseous injection at very high pressures; this is a particularly attractive process for use in diesel engines. There seems to be little equivalent work in this area in the U.S. Investigating the mechanisms of fuel dispersal in engines is another active research area. Bowman, DeBlois and Clarke noted the research of fuel injection, fuel spray, droplet formation, and spray penetration. Clarke also noted research performed at the Tokyo Institute of Technology on heat transfer from the flame on cylinder walls. He stated that there appears to be no parallel to this work in the U.S.

In stationary combustion processes, Fernandez-Pello noted Japan's development of catalytic burners and research on unstable combustion. He commented that Japan is probably ahead in developing unstable combustion because U.S. researchers initially rejected this process because of its high noise level.

Smoot commented that significant coal combustion research is under way because of the government's interest in reducing oil use. He noted Japan's research into coal-water mixtures for combustion in power generation. He and Fernandez-Pello also noted the development and application of fluidized bed combustion; they feel the two countries are at an approximately parity in this area.

Combustion research for emissions control was also mentioned as an area of significant interest. Semerjian noted Japan's work in controlling particulate emissions and soot formation, and Smoot noted the advanced state of their nitrogen oxides (NO_x) control work.

Instrumentation and the microprocessor-based control of combustion processes were noted by several researchers as another strength of Japan's work. Amann, DeBlois, Fernandez-Pello, Harein, and Sawyer described Japanese work in this area to be at the leading edge of the technology. Fernandez-Pello further observed that, although the measurement work he has seen in Japan has been excellent, U.S. researchers seem to be better at analyzing the data and interpreting the results.

In the areas described above there was little difference of opinion regarding the general status and quality of work in Japan. There are, however, two areas of Japanese research for which significantly different opinions were offered. These areas are laser diagnostics and computer modeling. DeBlois and Robinson commented that they have seen evidence of some sophisticated research in Japan involving laser diagnostics. However, the opposite view was expressed by Harein and Semerjian, who commented that there seems to be little such activity under way in Japan and that the U.S. has a significant edge. Bowman noted that the importance of laser diagnostics has been keenly recognized in

Japan, with steps being taken to expand the scope of diagnostics research activities. Similarly, in computer modeling, Rife and Robinson noted that there appears to be very little multidimensional modeling such as that performed at Sandia Laboratories. Semerjian, on the other hand, mentioned that there appears to be a significant level of large-scale computational modeling of combustion. The reasons for these differing perceptions are not clear; however, one hypothesis is discussed in the following section on information transfer.

As a final observation, many of the researchers interviewed commented that although the U.S. has a stronger, more broadly-based effort overall in combustion research than Japan, the technological lead is being challenged in many areas. Clarke and Borman observed that Japanese researchers seem to be more aggressive than U.S. researchers in exploring new areas. Fernandez-Pello noted that because Japan has just achieved parity with the U.S. in several areas, there appears to be a redirection toward the pioneering of new research areas. Finally, Bowman, Ekchian, Sawyer and Semerjian commented that the work in Japan has substantial momentum that threatens to propel their technology development beyond that in the U.S. in the near future.

5.2 QUALITY OF INFORMATION TRANSFER

Discussions with researchers regarding information transfer revealed an apparent polarity of opinions. Several researchers strongly asserted that the technical information available is timely, of high quality and in need of little improvement. Other researchers, familiar with the same information sources, feel uncomfortable about a clearly perceived information gap. The following discussion begins with a review of the information sources used by U.S. researchers and an assessment of the relative merits of these sources. After this review, the two positions on the quality of the information will be explored, and suggestions will be offered for improving information transfer. The implications of information transfer for the long-term competitive position of U.S. research will also be discussed.

5.2.1 Review of Information Sources

Researchers cited a substantial body of English language literature that has combustion or combustion-related articles by researchers from Japan. These literature sources are summarized in Table 5.1, along with an indication of whether the sources are considered primary or secondary. Primary sources are those that were noted as being particularly useful by at least several researchers, and secondary sources are those that were only mentioned. In addition to the literature, several conferences were identified as valuable forums for information transfer. These conferences are listed in Table 5.2.

The lists presented in the tables illustrate a range of literature ranging from basic combustion research journals to publications that contain descriptions of applications-oriented combustion research. The list also illustrates that while many literature sources and conferences exist, only a few are considered primary sources of information regarding research in Japan.

Publications that are devoted to basic research related to combustion include Combustion Science and Technology, Combustion and Flame, and Progress in Energy and Combustion Science. Combustion Science and Technology and Combustion and Flame were particularly noted by U.S. researchers for articles by Japanese researchers. The International Journal of Heat Transfer also addresses very fundamental topics, but its scope is narrower than the above combustion journals. The work presented in that journal tends to concentrate on the heat transfer aspects of combustion. The JSME Review is published in English by the Japanese Society of Mechanical Engineers. It consists of a cross section of Japanese articles, some related to combustion.

The other literature is more specialized, being devoted to applied combustion related to engine applications. The main forum for such work is the SAE Journal, the JSAE Review, and the Transactions of Mechanical Engineers. Riccardo Engineers also publishes a series that contains summaries of all the significant conferences on combustion, based on a writeup provided by the Riccardo attendee. Riccardo also produces a series of papers describing diesel engine research in Japan.

TABLE 5.1. Literature Sources Containing Technical Information on Combustion Research in Japan

Literature	Primary	Secondary
American Scientist		x
American Society for Testing Materials		x
Automotive Engineering (England)		x
Bulletin of the Japanese Chemical Society		x
Combustion Science and Technology	x	
Combustion and Flame	x	
Combustion papers published by industry (Nissan, Toyota, Mitsubishi)		x
International Journal of Heat and Mass Transfer		x
Japan Economic Journal		x
JSAE (Japanese Society of Automotive Engineers) Review	x	
JSME (Japanese Society of Mechanical Engineers) Review	x	
Journal of Applied Fluid Mechanics		x
Journal of Applied Optics		x
Lubrication Journal		x
Progress in Energy and Combustion Science		x
Riccardo Engineers, Internal Review Papers		x
SAE Transactions	x	
Transactions of Mechanical Engineers		x
Ward's Engine Update		x
Fire Science and Technology		x
Fuel Association Magazine (Nenryo Kyokaiski)		x
Fuel and Combustion (Nenryo Oyobi Nensho)		x

TABLE 5.2. Conferences with Papers Describing Combustion Research in Japan

Conferences	Primary	Secondary
American Chemical Society Meeting		x
American Institute of Chemical Engineers		x
American Society of Mechanical Engineers		x
Gordon Conference		x
Institute of Mechanical Engineers Conference		x
International Combustion Symposia	x	
International Conference on Coal Slurry		x
International Conference on Ceramic Components for Combustion		x
SAE Annual Congress	x	
Thermophysics Conference		x

Finally, there is a segment of the literature that is non-technical but provides general information on industry trends, new product announcements, and major R&D projects. Relevant publications include the Japan Economic Journal and WARD's Engine Update.

The researchers generally agreed, however, that conferences provide for a much more timely exchange of information. In particular, the International Combustion Symposia, held every two years, was singled out for its active Japanese participation and value to members of the combustion community. This meeting addresses such fundamental issues as chemical kinetics, pollution formation, detonation, two-phased combustion, and laser diagnostics. Japanese participation at the Annual Congress of the Society of Automotive Engineers was also significant.

Other conferences with high levels of Japanese participation include the Sandia Laboratories' combustion meetings, the Gordon Conferences, American Chemical Society meetings, American Society of Mechanical Engineers (ASME) meetings, and Thermophysics conferences. The Gordon Conference is held every year; every two years it offers a session focusing on laser diagnostics in combustion. The ASME holds a large annual meeting, at which its Fuels Division hosts a session that addresses combustion, surface chemistry and catalysis. There are also national ASME meetings, approximately four per year, in which a few divisions participate. The American Society of Mechanical Engineers has an annual meeting, the Winter Annual Meeting, with a session held by the Committee on Heat Transfer in Combustion and Fire. The papers presented in this session cover a narrow field, focusing on the heat transfer aspects of combustion. The Thermophysics Conference is an annual meeting hosted by the American Institute for Aeronautics and Astronautics (AIAA) that tends to focus on laser diagnostics rather than the broader question of combustion science.

5.2.2 Positive Aspects of Information Transfer

As mentioned earlier, the researchers interviewed disagreed as to whether the availability of technical information from Japan is sufficient. These differences of opinions and possible reasons for the differences are discussed here.

Several researchers, including Borman, Bowman, Clarke and Glassman, stated that they are generally very comfortable with the current state of information transfer from Japan. They believe that conferences, most notably the International Combustion Symposia, provide an effective and adequate forum for dialogue, and that the literature is both timely and of high quality. Conferences are generally considered to be a superior mechanism of information transfer because the work presented at a conference tends to be more recent, and conferences provide the opportunity for researchers to discuss their work on a one-to-one basis. It should be noted, however, that not all researchers spoke highly of this verbal information exchange. Borman, Harein, Fernandez-Pello, and Robinson felt that the Japanese researchers tend to be very open, whereas Ekchian and Semerjian felt that they received only superficial information on the work in Japan.

The researchers noted that journal articles tend to be substantially older than conference material but are still relevant to the state of the art. In fundamental research, it was noted, the state of the art advances slowly. The problem Clarke noted with the literature is sifting through the large volume of material being published. He commented that so much is published that it is difficult to identify the emphasis of combustion research in Japan. For example, Komatsu surprised the U.S. industry with the advanced state of its work on the adiabatic diesel engine, as described in a recent SAE paper.

While these researchers feel that the information available is timely and of high quality, room for improvement was still noted. Glassman commented that he seemed to be seeing all of the good work in basic research in the universities but that he knew little about applied research, particularly in the industry. This view was echoed by Semerjian, who felt that there is a significant gap in our understanding of applied research in Japan. Borman commented, on the other hand, that any gap in information probably reflects the proprietary nature of the work.

Borman and Bowman noted a second deficiency--the lack of important details in technical publications. They expressed that while the literature from Japan is generally adequate, results are often presented without a description of the methodology. This causes a somewhat superficial understanding of the research actually being performed in Japan. This concern is echoed by other researchers including Harein, Robinson, and Uyehara, who are among those that perceive other major gaps in the availability of Japanese research results to U.S. researchers.

5.2.3 Shortcomings of Quality Information Transfer

Fernandez-Pello, Harein, Rife, Robinson, Sawyer, Smoot and Uyehara emphasized that very notable shortcomings exist in the information available to U.S. researchers on combustion research in Japan. While these researchers generally did not deny the availability of high quality technical information about work in Japan, they did express a sense that a significant amount of information is not generally known.

One issue raised by several researchers was evidence of relevant work performed in Japan that was not translated to English. Sawyer noted that after having received a steady stream of Japanese visitors and having attended the significant meetings, he felt comfortable that he was effectively following

Japanese efforts. However, he found that this assumption was not entirely correct. In the course of work with a Japanese postdoctoral student, the Japanese student was translating and bringing to Sawyer's attention work he was not aware of, including papers that were very relevant to Sawyer's research. Both Sawyer and Borman have the impression that only a fraction of both fundamental and applied research work is being published in English. Most of this untranslated work is being carried out at universities.

Rife offered a similar observation. He mentioned that while he was a professor at MIT, his Japanese students translated selected articles from the Japanese technical literature. From these translations he became aware of a significant body of information in other Japanese journals. For example, Rife noted that there is significant work under way in spray combustion and in heat transfer related to combustion in Japan. Little of this work is published in English. Additionally, Rife noted that Japanese researchers seem to be active in the computational design and modeling of combustion chamber shapes, but that few papers are published in English. He was also surprised by the small number of papers related to gas turbines, in light of the push to develop an aircraft engine in Japan.

The existence of a significant body of untranslated technical literature is further corroborated by Robinson, Harein, Smoot and Uyehara. Robinson added that Japanese visitors to Sandia Laboratories often bring copies of their articles, which are not available in English. Harein added that many articles referenced in the Bulletin of the Japanese Society of Mechanical Engineers are not available in English. Smoot noted that there are several Japanese journals dealing with combustion research that are not translated into English.

Rife, Robinson, and Sawyer noted that the two-year delay typical in placing the results of Japanese research into English language papers does create a problem. Although a two-year delay may not be a major concern for purely fundamental work, it is a concern for more applied combustion research. Rife noted, however, that this lag in Japanese translations is not universal, because landmark papers (such as those by Furuhama) are published in English and Japanese simultaneously.

5.2.4 Improving Information Transfer

Researchers recommended several measures to improve the comprehensiveness of the technical information transferred from Japan to the U.S. and to amelioriate the other shortcomings of the current state of information transfer. These measures include ways to monitor technical developments in Japan and to improve the flow of meaningful technical information to U.S. researchers.

Fernandez-Pello commented that the U.S. can learn more about monitoring overseas efforts by observing the way the Japanese perform this task. He noted that Japanese government agencies exist that track all new patents. In addition, the Japanese seem to receive all of our technical journals and have access to American computer data services. He added that Japanese researchers often review the worldwide literature in their fields. A standard practice is for a research group, consisting of university members and researchers from companies, to get together periodically and discuss an American article. These sessions are typically led by a senior professor.

Based on these observations, exploring the extent and quality of literature published only in Japanese is highly recommended. Researchers also mentioned that monitoring Japanese patents would provide useful information about some of the applied work that may not be published. Expanding on this theme of improving the study of Japanese work, Rife, Smoot, and Uyehara pointed to the need to learn more about research planning in Japan. They noted that Japan easily obtains this information on programs in the U.S., but that U.S. knowledge of Japanese research directions is rudimentary. Developing information on research plans, goals, support, and target dates would fill a valuable information gap for U.S. researchers and research planners.

Several researchers commented that a major shortcoming of our understanding of research in Japan stems from the fact that few visitors perform work there as guest researchers, or even have the opportunity to visit. Bowman, DeBlois, Semerjian, Smoot and Uyehara specifically mentioned that the opportunities for onsite visits in Japan need to be significantly enhanced. Harein noted that to have an in-depth understanding of research efforts, the experiment and its equipment must be visited and examined. Japanese researchers, he further observed, frequently come to the U.S., and these onsite visits provide them with a comprehensive understanding of U.S. activities. Semerjian noted that although trip reports by other researchers do provide some insight into Japanese research activities, they are usually limited to the technical speciality of the visiting researcher. Thus, information about important activities in related fields is usually not passed on. Glassman and Semerjian observed that there is a particular need to visit the industrial research laboratories, since we have little information about the research activities under way in those organizations.

To allow researchers the opportunity to truly understand the extent of the research under way in Japan, several researchers, including Borman, Ekchian, Robinson, and Sawyer, recommended supporting more frequent exchanges of faculty and researchers to Japan. They noted that this mechanism is used heavily by Japanese researchers visiting the U.S., but that few U.S. researchers have similar opportunities. Ekchian noted that Japanese universities seem to truly desire to participate in the exchange of technical information. Borman commented that establishing a cooperative research program through the National Science Foundation would be an excellent way of improving information transfer.

Finally, the apparently contradictory opinions offered on the quality of information transfer may, on closer examination, be easily explained. According to several researchers, including Robinson, Sawyer, and Rife, these differences apparently depend on which literature is being received. When only the English language literature is reviewed, the large number of articles gives the impression that the Japanese effort is extensively covered. However, when research is discussed with Japanese students, faculty, or researchers, it becomes obvious that there is a significant body of literature published only in Japanese.

This significant disagreement about the comprehensiveness of U.S. researchers' understanding of Japanese research reflects the underlying inadequacies in the accessibility of Japanese research information. This disagreement further indicates that there is an incomplete understanding of work in Japan and that the magnitude of this gap is not well defined.

5.3 SUMMARY OF PERSPECTIVES ON COMBUSTION RESEARCH IN JAPAN

Reviewing researchers' opinions on combustion research in Japan reveals generally consistent comments about the overall comparative position of combustion research, but widely divergent views on the quality of Japanese technical information transfer to the U.S. In general, researchers feel that the U.S. combustion research effort seems more broadly based than the effort in Japan, and that basic combustion research in the U.S. continues to maintain its position at the leading edge of the science. Researchers commented, however, that while the Japanese effort is not as wide-ranging, it does appear to be better focused and generally more closely related to the end use. It was noted that in these applied areas Japanese researchers are achieving parity with and in some cases exceeding the quality of work in the U.S. In addition to the high-quality effort in these applied areas, researchers noted increasing combustion research activity in Japan, and that this will further increase the challenge of Japanese technical development in the future.

Particular areas of combustion research emphasized in Japan identified by U.S. researchers include the adiabatic diesel, general combustion processes in automotive engines, emissions, coal combustion, instrumentation and combustion control, laser diagnostics, and combustion modeling. Researchers commented that Japanese development of the adiabatic diesel engine will be substantially aided by Japan's advanced development of ceramics technology, thus giving Japan an edge over U.S. development. It was also noted that development of light-duty ceramic diesel engines is being pursued in Japan but not in the U.S., apparently because of U.S. manufacturers' concern about the ultimate price of the technology. Researchers mentioned several areas in general automotive combustion research in which significant work is being conducted, including combustion chamber design; turbulent, fast-burn, high compression ratio combustion; alternative concepts for spark ignition and diesel engines such as the Wankel, stratified charge and light duty diesels; and turbochargers.

In 1980 the Japanese government announced a goal of reducing the use of oil from 75% of the nation's energy consumption to 50% by the year 1990. Coal is one of the primary fuels expected to fill the resulting energy gap, and thus the research in coal combustion, particularly for power generation, has been increasing. Topics being addressed include fluidized bed combustion, coal-water mixtures for power generation, and combustion related to blast furnaces. In the field of instrumentation and microprocessor-based process controls, there was a general consensus that Japanese technology has surpassed that of the U.S.

Researchers did not agree, however, on the comparative status of the research effort in all the technical areas. Varying opinions were offered in particular about Japanese research in laser diagnostics and computer modeling. While some researchers feel there is a solid effort in these areas, others commented on the lack of any such activity. Part of this disagreement may result from variations in the quality of information received about Japanese research.

An unusually diverse range of opinions was expressed concerning the timeliness and quality of technical information on research conducted in Japan. Several U.S. researchers strongly asserted that the information available was very timely, generally of high quality, and in need of little improvement. Researchers did note that conferences are much more effective than the literature in permitting effective and timely information transfer. Other researchers agreed that the information from Japan is timely and high quality, but it is not comprehensive, since there appears to be a significant body of research literature not translated into English. Finally, still other researchers described the literature as inadequate in quality and somewhat superficial, and also noted that there is significant literature that is not translatec.

Although these differences are striking when first presented, further analysis reveals apparent reasons for the difference in perceptions. The different perceptions of the completeness of the literature can be explained by comments from Robinson, Sawyer, and Rife. They noted that when only the English language literature is reviewed, a significant number of articles give the impression of representing the major efforts under way in Japan. However, when research is discussed with Japanese students, faculty or researchers, it becomes evident that there is a body of relevant technical literature that is not translated into English. These researchers noted that without their contacts in Japan they would probably have concluded that the information transfer was adequate.

The comments offered by researchers regarding information transfer indicate that the quality of information transfer from Japan is, at best, uncertain. Researchers noted that articles often describe results without explaining the method used to obtain them. SAE articles, it was noted, typically have this flaw. With evidence of significant literature published only in Japanese and with prominent U.S. researchers apparently unaware of the existence of much of this literature, there is a definite need to evaluate the extent of this information gap.

Several measures were recommended by researchers for improving information transfer of Japanese research. It was noted that the Japanese practice of monitoring overseas work might provide useful guidance for effectively monitoring research activities worldwide. Monitoring patents, screening and translating Japanese abstracts and articles, and promoting more onsite visits by U.S. researchers were a few of the other suggestions proposed. Additionally, researchers felt that increasing support for international exchanges of students, faculty, and other researchers would provide insight to work overseas that cannot be obtained merely through publications and conversations with visitors to the U.S.

5.4 RESEARCHERS CONTACTED REGARDING COMBUSTION RESEARCH IN JAPAN

The following researchers offered comments on this field.

Charles Amann - General Motors Research Laboratory

Dr. Amann is the head of the Engine Research Department at General Motors Research. His technical specialties are engine combustion and combustion applications. To follow the work in Japan, he reads a wide variety of literature that contains articles on Japanese technology.

Gary Borman - University of Wisconsin

Dr. Borman is the Director of the Combustion Laboratory at the university. The work at the laboratory covers combustion experiments with a broad range of engines and fuels. Dr. Borman's specialty is combustion modeling. He keeps abreast of developments in Japan through his position on the editorial board of Combustion Science and Technology, by attending meetings, and by interacting both with a network of Japanese researchers with whom he has developed close relationships and with Japanese graduate students studying in his laboratory.

Thomas Bowman - Stanford University

Dr. Bowman's research interests include combustion chemistry, the interaction of fluid mechanics with combustion processes, toxic waste incineration, and spray combustion. Dr. Bowman follows research in Japan through regular correspondence with Japanese researchers, visits of Japanese researchers, and interactions with students from Japan studying in the graduate program.

John Clarke - Caterpillar Tractor Company

Dr. Clarke's research interests include engine combustion modeling, heat transfer, simulation and prototype development. Much of this work entails applied research toward new generations of heavy-duty diesel engines.

Dr. Clarke monitors Japanese R&D by reading journal articles published by Japanese authors, by attending conferences, participating in in-house meetings where Caterpillar's professionals who have visited Japan discuss their impressions, and by participating in academic research consortia. In addition, as a potential customer, Caterpillar is provided with information on technical developments by Japanese suppliers.

Ray DeBlois - United Technology Research Center

Dr. DeBlois' research interests include basic and applied research into engine combustion processes, and experimental analysis with single and multi-cylinder engines to establish how engine parameters and fuel quality affect fuel consumption and emissions. Dr. DeBlois relies on a combination of English language literature and discussions with Japanese researchers at conferences and meetirgs to follow Japanese work.

Jack Ekchian - Massachusetts Institute of Technology

Dr. Ekchian is a manager at the Sloan Automotive Laboratory. His research interests include experiments in combustion, single cylinder testing, and combustion modeling. Dr. Ekchian follows research in Japan by monitoring the English language literature (SAE, JSAE, Automotive News) and by attending conferences.

Irwin Glassman - Princeton University

Dr. Glassman is internationally known for his combustion research and was the founding editor of Combustion Science and Technology. He follows Japanese research through an extensive network of contacts with Japanese companies and researchers who keep him abreast of Japanese developments in this field. The combustion program at Princeton also receives several graduate and postdoctoral students from Japan.

N. A. Harein - Wayne State University

Dr. Harein's research interests include flame propagation, combustion ignition, thermodynamics of combustion systems, and diagnosis. Dr. Harein finds that the most effective means of following research in Japan is through discussions with Japanese researchers. Thus, he places a high value on attending key technical meetings. He has also consulted for a Japanese firm and uses the English language literature services.

Carlo Fernandez-Pello - University of California, Berkeley

Dr. Fernandez-Pello's research interests are in flame propagation over liquid and solid fuels, spray combustion related to engines, combustion simulation in enclosures, and experimental and theoretical studies of droplet combustion. He recently spent eight months in Japan while on sabbatical. This included four months at Tokyo University and four months at Osaka University. He also met with other researchers while in Japan in both the public and private sectors.

Dr. Fernandez-Pello keeps abreast of Japanese research activities through an extensive network of Japanese contacts. He regularly receives graduate and postgraduate students from Japan. He also collaborates with researchers in

Japan on research. He is considered one of the most knowledgeable experts regarding Japanese research in this field.

Joe Merrill Rife - Geneva Group

Dr. Rife was the former manager of the Sloan Automotive Laboratory at MIT and is an advisory member of the National Research Council, where he advises on Defense Department combustion research. His technical emphasis is on combustion research applied to engines. Dr. Rife follows work in Japan by reading all the primary combustion related journals. He also received graduate and postdoctoral Japanese students while at MIT.

C. William Robinson - Sandia National Laboratories

Dr. Robinson is the manager of the U.S. DOE Energy Conversion and Utilization Technologies (ECUT) Program's Combustion Project. His technical emphasis includes combustion modeling and laser diagnostics with further emphasis on the application of laser measurements to quantify the combustion process. The work tends to be fundamental. The primary method used to monitor research in Japan is extensive contacts with Japanese researchers who visit Sandia. Sandia has currently initiated an exchange program with Toshiba, which allows a researcher to spend 18 months at Sandia. Dr. Robinson does not view the literature as an important element in information transfer.

Robert Sawyer - University of California, Berkeley

Dr. Sawyer's research interests include the fundamentals of combustion processes in engines and pollution formation. He has many contacts with Japanese researchers and has been to Japan twice, on visits supported by the National Academy of Engineering. He is currently on a sabbatical leave in Japan. He will be spending time at the University of Hokkaido, which has a superb group in the area of diesel engine combustion. In addition to his visits, Dr. Sawyer follows the English language literature and receives graduate and postdoctoral Japanese students at Berkeley.

Hratch Semerjian - National Bureau of Standards (NBS)

Dr. Semerjian's research interests include the development and application of measurement techniques to study combustion processes and soot formation.

His recent work includes the use of laser tomography to study flame propagation in the combustion chamber and the development of a fiber optic probe to measure high temperatures.

He relies on a variety of methods to follow research in Japan. NBS receives many Japanese visitors who provide information on their research efforts. NBS currently has a guest researcher from the University of Hokkaido who is studying combustion modeling. Dr. Semerjian also uses conferences and meetings to interact with researchers from Japan, and he follows the English language literature.

L. Douglas Smoot - Brigham Young University

Dr. Smoot is the Dean of the Department of Engineering and Technology and the head of the Combustion Laboratory. His research interests include modeling and experimental work related to the combustion of fossil fuels, and the analysis of the process of combustion, flame propagation, and explosion.

Dr. Smoot relies on a variety of techniques to keep abreast of Japanese activities. His laboratory receives many visitors from Japan who will typically give half-day seminars on their work. Currently, there are two Japanese researchers at the Combustion Laboratory as visiting experts. These visitors, one from Hitachi and one from Kobe Steel, will spend a year at the laboratory. Both have masters' degrees and about five years of experience. Dr. Smoot visited Japan last year and toured combustion laboratories at the universities and in the industry. He also follows the English language literature and interacts with researchers from Japan at conferences and meetings.

Otto Uyehara - University of Wisconsin

Dr. Uyehara's research interests include engine combustion and emissions properties and the sensitivity of combustion to fuel properties. Dr. Uyehara relies on his contacts in Japan to keep abreast of the research under way there. He has also recently visited several Japanese combustion laboratories in universities and in the industry. In addition to his contacts, Dr. Uyehara follows the English language literature.

Dr. David Mann - U.S. Army Research Office

Dr. Mann's research interest is in combustion science. This program is assisting in the creation of a data base for the Army. His current projects include spray formation and combustion, turbulence modeling, flame propagation, and laser diagnostics. Dr. Mann relies upon his contacts with U.S. and Japanese colleagues to keep abreast of developments in Japan.

6.0 ELECTROCHEMICAL ENERGY STORAGE

Electrochemical energy storage involves a wide variety of battery formulations and system designs that address a range of end uses from electric vehicles to utility load leveling to consumer electronics. Research must address a variety of issues for each type of battery, including material properties, corrosion problems, degradation, etc. Because a comprehensive review of all electrochemical energy storage technologies in Japan would be beyond the scope of this effort, this investigation focused upon the technologies that seem to be receiving the most attention in Japan. To identify these areas, the study relied upon the U.S. researchers' perceptions of the principal technical interests of the Japanese in electrochemical energy storage and of Japanese government support of the development of this technology for specific applications.

Researchers who contributed to this discussion include the following:

Ron Gordon	Ceramatec, Incorporated
Kim Kinoshita	Lawrence Berkeley Laboratory
Akiya Kozawa	Union Carbide Corporation
Marjorie McClanahan	Ford Aerospace & Communications Corporation
Paul Shimotake	Argonne National Laboratory
Robert Weaver	Electric Power Research Institute
Ernest Yaeger	Case Western Reserve University
Michael Yao	Argonne National Laboratory

The following sections contain discussions of notable aspects of electrochemical energy storage research in Japan and the status of technical information transfer to the U.S.

6.1 NOTABLE ASPECTS OF ELECTROCHEMICAL STORAGE RESEARCH IN JAPAN

Evaluating the overall comparative status of research in Japan is inhibited by the large variety of electrochemical energy storage technologies. During the interviews it became clear that the researchers tended to be more familiar with applied R&D activities specific to certain technologies.

Although comments were offered on the overall status, these comments were typically biased by the researcher's knowledge of his/her technical specialty. Therefore, before exploring overall perceptions of comparative status in electrochemical energy storage research, the specific technology areas discussed will be described first.

A principal problem in discussing perceptions of electrochemical research strengths in Japan is that applied research is directed toward so many different technologies. For example, the types of batteries being developed in Japan include sodium-sulfur, zinc-bromide, zinc-chloride, redox, lithium/manganese-dioxide, and lithium-CF_x. Fuel cell technologies are also being developed.

Japanese interest in the sodium-sulfur battery, which began in the industry in the mid-1960s, has been accelerating under MITI's promotion. In 1971, MITI initiated a six-year program to develop the sodium-sulfur battery, along with alternative advanced batteries and improved lead-acid batteries, for electric vehicles. By the end of this program, the Yuasa Battery Company developed a 30 kWh sodium-sulfur battery that powered an electric vehicle. Yao, one of the researchers interviewed, noted that in the 1980s, the emphasis in MITI has shifted from developing batteries for electric vehicles to developing batteries for utility load leveling.

Development of the sodium-sulfur battery is currently being promoted in Japan as part of MITI's Moonlight Project. The purpose of this 11-year MITI program, which began in 1980, is to investigate various electrochemical storage systems for load leveling in utilities. In addition to the sodium-sulfur battery, three other types of batteries are being investigated: the zinc-chloride, the zinc-bromine, and the redox flow battery. The lead acid battery is also being used in the design of a energy storage system. An approximate schedule for the project's 11-year duration is shown in Figure 6.1. Total government funding over the 11-year period is about $75 million (17 billion yen).

The sodium-sulfur battery consists of a series of cells with beta-alumina tubes as the electrolyte and molten sodium and sulfur as the active materials.

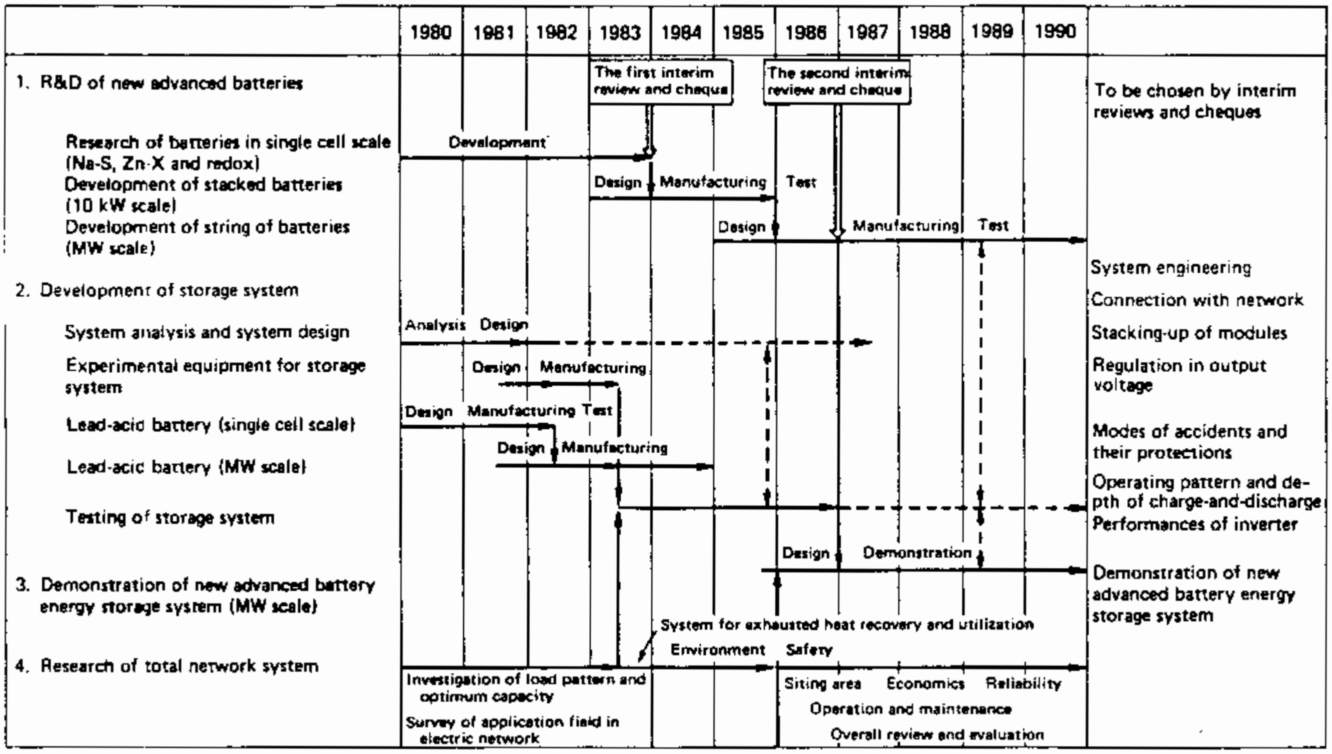

FIGURE 6.1. Advanced Battery Energy Storage System Development in Moonlight Project (Fuchida et al. 1982)

Weaver and Shimotake noted that the work in Japan currently seems to be focusing on the ceramic development for the electrolyte. Shimotake further added that the technical emphasis is on the conductive polymers and the current-collector material.

Opinions regarding the current status of beta-electrolyte development in Japan varied widely, with researchers alternately claiming parity and a U.S. lead. Gordon commented that the U.S. has performed most of the innovative work in developing beta-alumina and that beta-electrolytes made in the U.S. currently have longer lives than those produced by NGK in Japan. Others note, however, that with the advanced ceramics industry in Japan and the presence of advanced ceramics companies such as Kyocera, the Japanese can readily replicate U.S. work. In addition to the beta-electrolyte work, McClanahan noted the push in basic materials research to address the problem of cathode corrosion. Shimotake also noted the concern for the safety of the sodium-sulfur storage system.

Most of the researchers interviewed were most familiar with Japanese work in developing sodium-sulfur batteries. The general consensus of researchers, including Gordon, McClanahan, Weaver and Yao, was that the Japanese started late in this technology and still lag behind the U.S. McClanahan and Weaver estimated the work in Japan to be about three years behind that in the U.S. Researchers noted in particular the advanced work at Ford Aerospace, General Electric and Ceramatec.

Although many of the researchers interviewed commented about the development of the sodium-sulfur battery in Japan, few commented on the development of the other battery technologies. Concerning the Moonlight Project battery technologies, Yao noted that the Japanese are still behind the U.S. in the development of the zinc-bromide, zinc-chloride and redox batteries. He also noted, however, that their technology development appears to be developing quickly and may soon achieve parity with the U.S.

One battery technology in which Japanese development appears to be leading U.S. development is the manganese-dioxide battery. Kozawa noted that U.S. work is several years behind Japanese efforts, and that the firms are paying a premium for the Japanese batteries, which have captured about 70% of the world market. Yaeger observed that another area in which the Japanese lead is in lithium-magnesium technology; Japan developed its power cells ahead of Union Carbide.

Yaeger also commented that although the Japanese often rely upon initial work in the U.S., this certainly does not mean that they will continue to lag behind in the technology. For example, he noted that the U.S. Army's laboratory at Fort Belvoir did the background research on lithium-CF_x cells. While the Army lost interest in that area, the Japanese saw the potential and began to focus their research efforts on the technical hurdles. Now Japan is ahead in lithium-CF_x technology.

Several researchers noted that a significant effort is also under way in Japan in the related technology of fuel cells. While several researchers agreed that this area has received increasing interest, some disagreed on the comparative status of the technology. Gordon noted that by building larger fuel cells in the U.S., this country has a lead in scaleup experience and is thus several years ahead in technology development. On the other hand, Kinoshita commented that the two countries are heading toward approximate parity. He noted that the 4.8-MW fuel cell, bought from United Technologies but improved in Japan, is currently the largest cell undergoing testing in the world. He noted that this current status is particularly interesting, since just five years ago there seemed to be little interest in Japan in fuel cells.

Fuel cell development in Japan is also being aided by an R&D effort under the Moonlight Project. The purpose of this effort is to develop highly efficient fuel cell power generation systems capable of burning a variety of fuels (e.g., natural gas, methanol, coal gas) for use in electric utility applications. Fuel cells are desired for use in small, dispersed plants as well as in large-scale generating plants. The types of fuel cells being developed are phosphoric acid fuel cells for a 1,000-kW system, 10-kW molten carbonate fuel cells, 1-kW solid oxide fuel cells, and 5-kW alkaline fuel cells.

Because of the variety of batteries being researched, only some of which have been introduced above, generalizing about the comparative status of research in the field as a whole is very difficult. Some researchers confidently asserted that the U.S. is still significantly ahead in the field, while others pointed to specific areas in which Japanese battery technology is already superior. Researchers generally agreed, however, that battery technology developments in Japan have relied heavily on innovations and basic research first performed in the U.S. and West Germany. One example of this is the lithium-CF_x cell described by Yaeger. Gordon commented that most of the major innovations in battery technology in the last 20 years have occurred in the U.S.

There is also a perception that battery development in Japan largely mirrors developments in the U.S. McClanahan indicates that the DOE/EPRI-sponsored Sodium-Sulfur Battery Workshops, which occur about every two years, provide a forum for translating technology between all developers. Some Japanese papers contain information closely resembling that presented by others at earlier workshops. Kozawa noted that while the ideas are generally the same, the approach differs in the two countries. He and Yao commented that Japan is pursuing, in a directed and balanced way, improvements to primary batteries such as the zinc, lead-acid and manganese-dioxide batteries. In contrast, the U.S. efforts in batteries and fuel cells are much more widespread, touching on a much broader range of options. Yao further noted that Japanese researchers have tended to wait to see the results of the shotgun approach of U.S. work, and then focused on the most promising alternatives. Yao also noted that U.S. efforts tend to be less stable than Japan's. Although the Japanese may take longer to agree on a program, once the program is set in motion, the effort will continue largely unaffected by external changes, such as changes in the government.

Several researchers noted that any lag that may exist in battery technology development in Japan is quickly diminishing as Japanese research continues to advance. Weaver also noted a seemingly increasing general interest in electrochemistry.

Finally, Japan's record in making an effective transition between laboratory and commercial work was predicted to become a major factor once the battery technologies near commercial development. Weaver noted that once the technology is near commercialization, Japanese researchers excel at making the transition from a laboratory device to a commercial product. He observed that this strong manufacturing capability stems from solidly trained engineers and sophisticated manufacturing techniques that have made Japan competitive in the primary battery field.

6.2 QUALITY OF INFORMATION TRANSFER

In the electrochemical energy storage field, Kozawa, Shimotake and Yao have followed both the English language and Japanese language literature. These researchers have compared the information available in Japanese and English and thus provided points of comparison with the opinions of other researchers whose perceptions were based solely on English sources. Perceptions of information transfer by researchers principally familiar with the English language sources will be summarized first, followed by comments from the researchers who also used Japanese language sources.

Researchers principally familiar with the English language literature that describes Japanese technical work commented that there is generally an adequate amount of information available. These researchers noted that there are several prestigious journals in which Japanese researchers publish. These include the Journal of the Electrochemical Society, the Journal of Electroanalytical Chemistry and Interfacial Electrochemistry, and Electrochimica ACTA. Researchers also noted that the Japanese Journal of Electrochemistry (Denkikagaku) contains English abstracts of the Japanese articles. The literature identified is summarized in Table 6.1.

Researchers also noted that Japanese companies are quick to publicize product announcements, which helps the U.S. monitor some of their developments. These researchers also commented on the significant participation of Japanese researchers at international conferences. Researchers noted in particular the American Electrochemical Society's Annual Meeting and the Meeting of the International Society of Electrochemistry. Conferences identified as having active Japanese participation are listed in Table 6.2.

In addition to the conferences, most of the researchers mentioned personal contacts with Japanese colleagues as an important element of their monitoring activities. Contacts, it was often noted, are particularly important in overcoming some of the literature and conference shortcomings. For example, the research presented in the literature was typically one to two years old. While this is not unlike the lag that exists in the U.S., it does make the information somewhat dated.

Also, the literature and the papers presented at the conferences still leave gaps in the understanding of the overall activities and often neglects important details. For example, Gordon commented that he senses significant corrosion work to be under way but does not know the extent or details of the work. Similarly, McClanahan noted that while we often know the general objectives of Japanese work, we do not know its specific technical problems. Also, as more of the work shifts toward development in the private sector, less fundamental work is published by university researchers. Weaver noted that while there is good general information available on government activities, much less is known about industry work.

TABLE 6.1. Publications Containing Information on Electrochemical Energy Storage Research in Japan

Publication	Primary	Secondary
Advanced Battery Technology		x
Analytical Chemistry		x
Ceramics Japan; Seramikkusu		x
Chemical Abstracts Selects; Analytical Electrochemistry		x
Electric Transportation Program Review, EPRI		x
Electrochemical Reactions		x
Electrochemistry and Industrial Physical Chemistry (Denki Kagaku, Oyobi Kogyo Butsuri Kagaku, published by the Electrochemical Society of Japan)	x	
Electrochimica ACTA	x	
International Electrochemical Progress		x
Journal of Applied Electrochemistry		x
Journal of Electroanalytical Chemistry and Interfacial Electrochemistry	x	
Journal of the Electrochemical Society	x	
Journal of the Metal Finishing Society of Japan (Kinzoku Hoyomen Gijutsu)		x
Journal of Power Sources		x
Trends in Analytical Chemistry		x

Other Publications:

New Materials and New Processes in Electrochemical Technology (Special Issues on Batteries), JEC Press, Inc.

Progress in Batteries and Solar Cells, JEC Press, Inc., 14731 Sprengel Ave., Cleveland, Ohio 44135

TABLE 6.2. Conferences and Meetings with Papers Describing Electrochemical Energy Storage in Japan

Meeting	Primary	Secondary
Battery Material Symposium, Vol. 1 Brussels, Belgium		x
Battery Industry Conference		x
American Electrochemical Society Annual Meeting	x	
International Society of Electrochemistry	x	
Intersociety Energy Conversion Engineering Conference		x
Joint DOE/EPRI Sodium Battery Workshop	x	
Fuel Cell Seminar, Annual Meeting		x
New Japanese Technologies and Materials in Relation to Electrochemical Technology, October 25-26, 1983	x	

Although these researchers identified some gaps in the understanding of Japanese research, most felt the overall level of information available is adequate. Following the work closely was not perceived to be too important because many of these same researchers feel the U.S. has a definite lead in battery development.

Although good information describing R&D in Japan is available in English, it does not appear to be a complete description of the research results published in Japan. Researchers familiar with the Japanese literature noted that a substantial body of information is disseminated in Japan but not translated into English. Significant information sources (primarily in Japanese) are listed in Table 6.3. Researchers noted that although the Japanese Journal of Electrochemistry has English abstracts, the details of the work are still in Japanese, and often the abstracts do not have enough information to indicate if the article is worth translating. Additionally, the researchers observed that most of the work published in the journals tends to be university research, which is typically fundamental. This is true of both the Japanese and international journal literature. Because much of the applied work occurs in

TABLE 6.3. Significant Japanese Literature and Conferences Relevant to Electrochemical Energy Storage Technologies

Annual Meeting of the Japanese Electrochemical Society

Battery Symposium

Chemical Industry (magazine) (Kagaku Kogyo)

Japanese Journal of Electrochemistry (Denkin Kagaku)

Japanese Journal of Industrial Chemistry (Kogyo Kagaku)

Japan Electric Vehicle Association Publications

Industrial Science and Technology (Kogyo Gijutsu) (published monthly by MITI/AISI)

Daily Industrial News (Nihon Kogyo Shimbun)

industry, Shimotake emphasized the importance of magazines such as Chemical Industry (in Japanese) for keeping abreast of industrial developments.

Yao noted that the Government Industrial Research Institute (GIRI) in Osaka publishes a technical report that is available only in Japanese. This institute is the national coordinating laboratory for advanced battery activity in Japan, and its technical reports describe their advances in battery technology. In addition to this untranslated literature, researchers also pointed to important electrochemical conferences held in Japan. Two important conferences in Japan are the Battery Symposium, held every November, and the Annual Meeting of the Japanese Electrochemical Society. Kozawa noted that the former publishes a 300-page extended abstract that is quite comprehensive. The latter meeting is held in the spring and involves a lot of thesis and dissertation material, because Japanese students are required to publish to obtain their degrees. Kozawa feels that about 20% of the papers are of particular interest. Kozawa also noted that few, if any, U.S. researchers attend these meetings.

Researchers familiar with the Japanese literature feel that the inaccessibility of this information to most U.S. researchers results in a notable deficiency in understanding their projects and the status of their work. To improve the transfer of information, several suggestions were offered. Shimotake, Yaeger and Yao commented that screening and translating Japanese technical information would fill an important gap. As a related issue, Yaeger commented that some Russian literature is being translated and published by Plenum Press. Yaeger also noted that this might be readily supplemented with a newsletter type of service that reviews industrial activities as well as the university research.

Because personal discussions are a very important element of information transfer, encouraging interactions was also highly recommended. In particular, researchers noted that visits to facilities in Japan provide a great deal of insight into their technical capabilities and into the details of experiments that are not available otherwise. Researchers noted that U.S. researchers currently rely upon the trip reports from visits sponsored by organizations such as the Electric Power Research Institute (EPRI). It was further noted that the Japanese are very aggressive about attending U.S. meetings and visiting U.S. facilities, but that the reverse is not true. One drawback observed by Gordon is that this allows for limited exposure to the work in Japan. For example, he noted that through a fortuitous conversation with a Toyota researcher, he recently learned Toyota is involved in sodium-sulfur battery development.

Workshops were also noted as a useful vehicle for discussing the details of research and establishing contacts with peers in Japan. Several researchers commented that the DOE/EPRI-sponsored Sodium-Sulfur Battery Workshop is useful in this regard. Holding such workshops in Japan, it was noted, has the added benefit of allowing researchers to visit Japanese laboratory facilities.

In addition to visits to Japanese facilities, Shimotake commented that developing relationships with researchers in Japan is also important. One way of doing this in a research setting is through binational research exchanges. Such exchanges, involving graduate students, professors, or other researchers, would promote the in-depth understanding of Japanese research and the long-term professional relationships that ensure the continuation of this exchange of information. It was noted that there are currently formal information exchange agreements with Sweden and West Germany through the International Energy Agency, but no similar agreements with Japan.

Few researchers found information services or computer literature searches to be very useful. It was noted that the U.S. Defense Intelligence Agency conducts biennial reviews of international battery technology, but that the distribution is limited.

6.3 SUMMARY OF PERSPECTIVES ON ELECTROCHEMICAL ENERGY STORAGE RESEARCH IN JAPAN

The wide variety of battery technologies being developed in the U.S. and Japan makes generalizing about the comparative status of their technology developments difficult. Researchers interviewed indicated that the U.S. is ahead in some areas, and Japan is superior in others. It is generally agreed, however, that the U.S. effort addresses a wider range of technologies and technical questions, and that much of Japanese development has relied on work previously performed in the U.S. and West Germany.

The battery technology familiar to most of the researchers interviewed was the sodium-sulfur battery. While opinions about comparative status varied from a rough parity between the countries to an obvious U.S. lead in the technology, a majority feel that the U.S. development is currently several years ahead of Japan's. It was noted, however, that this battery technology is being developed as part of an 11-year R&D program sponsored by MITI to investigate advanced batteries for utility load leveling. In addition to the sodium-sulfur battery, other advanced batteries being developed in this MITI program are the zinc-chloride, zinc-bromide, and redox battery. In all of these areas, Japanese technology development is also perceived to be slightly behind U.S. development. However, given that the Japanese researchers were new to this field, and the track record of MITI in promoting the development of technologies, Japanese advances in these batteries should be carefully monitored. Several researchers perceived Japanese development to be catching up to U.S. technology very quickly.

Battery technologies in which the Japanese have advanced beyond U.S. development include the manganese-dioxide, lithium-magnesium and lithium-CF_x.

This latter technology is a clear example of an instance in which the U.S. pioneered the initial development but the Japanese have taken the further step to commercialization.

Several researchers interviewed are very familiar with both the English and Japanese technical literature relevant to electrochemical energy storage. They observed that while there is a significant amount published in English in the international literature, there is also a significant amount published only in Japanese. These Japanese publications and conferences contain information that is more timely, more comprehensive, and more relevant to private sector activities than the material available in English. Thus, although the international literature is a good source of information about Japanese R&D activities, these researchers noted that information transfer could be improved by screening and translating documents available only in Japanese.

Another major issue impeding effective information transfer is the poor interaction of U.S. researchers with their Japanese peers. While Japanese researchers are notably aggressive about attending U.S. conferences and visiting U.S. facilities, the converse is far from true. Many of the researchers interviewed expressed a strong need to encourage more interaction of U.S. researchers with those in Japan. This would allow researchers to view facilities and understand details of research often unavailable in the U.S. Mechanisms recommended for this interaction include workshops, binational exchanges, and general visits.

6.4 RESEARCHERS CONTACTED REGARDING JAPANESE RESEARCH IN ELECTROCHEMICAL ENERGY STORAGE

The following researchers offered comments on this field.

Ron Gordon - Ceramatec Corporation

Mr. Gordon's technical interests are in beta-alumina and related technologies. He noted that his company produces the beta-alumina electrolyte that is used in the sodium-sulfur battery and sells to most of the developers of the battery, including Ford and Yuasa. Mr. Gordon follows research in Japan primarily through three means: a) visits by his Japanese peers, b) trips to Japan, and c) Japanese-authored papers at U.S. workshops. He noted that the first is the primary source, since his company is regularly visited by Yuasa and Hitachi. He tries to visit Japan once every two years.

Kim Kinoshita - Lawrence Berkeley Laboratory (LBL)

Dr. Kinoshita is a technical manager of the Technology Base Research Project for Electrochemical Energy Storage at LBL. He noted that their efforts cover a wide range of areas, including advanced batteries, new couples, battery components and materials, and engineering principles applicable to electrochemical energy storage.

Japanese work is primarily followed through the journals and conferences. To supplement this information, LBR receives occasional visitors from Japan and reports from U.S. researchers who visit Japan.

Akiya Kozawa - Union Carbide Corporation

Dr. Kozawa's research emphasizes the primary battery group and includes both applied research and development. Dr. Kozawa is an editor of the Progress in Batteries series and chaired a session at the Battery Material Symposium held in Brussels. He also played a principal role in establishing a U.S. office for the Electrochemical Society of Japan. Dr. Kozawa has a long involvement in this area, including serving as a postdoctoral research assistant under Professor Yaeger of Case Western Reserve University, prior to which he was a professor in Japan.

To keep abreast of the research in Japan, Dr. Kozawa visits Japan about twice a year. These visits allow him to keep current on activities in the government and industry and also allow him to attend two key meetings in the field: the Battery Symposium and the Annual Meeting of the Electrochemical Society. Dr. Kozawa is fluent in Japanese and is a primary expert on developments in Japan in his field.

Marjorie McClanahan - Ford Aerospace & Communications Corporation

Ms. McClanahan is the Deputy Manager of Advanced Battery Program Development. Her technical interest is the sodium-sulfur battery. She noted that Ford Aerospace is one of the world leaders in developing the sodium-sulfur battery. Her primary method for following Japanese research is through the presentations of Japanese visitors to Ford Aerospace, the papers given at the major symposia, and trip reports from subcontractors and funding agencies.

Paul Shimotake - Argonne National Laboratory

Dr. Shimotake's research interest is in primary and secondary batteries and in fuel cells. His emphasis at Argonne is on the lithium-metal sulfide battery. He is the General Editor of Progress in Batteries and Solar Cells, which is published by the U.S. Office of the Japan Electrochemical Society of Japan. Dr. Shimotake keeps abreast of the work in Japan through his personal contacts in Japanese firms and academia. He also visits Japan once or twice a year, reads Japanese technical journals and attends conferences in Japan. He is fluent in Japanese and is one of the more knowledgeable persons identified regarding electrochemical energy storage work in Japan.

Robert Weaver - Electric Power Research Institute (EPRI)

Mr. Weaver is the Project Manager of the Battery Technology program at EPRI. His technical interests include the sodium sulfur battery and the lithium-metal sulfide battery. His program co-sponsored an international sodium battery workshop with representatives from Hitachi, Yuasa, and NEDO. To keep abreast of developments in Japan, Dr. Weaver relies on researchers in the U.S. community and other staff at EPRI who visit Japan. Dr. Weaver also has some contacts in Japan and supplements this information through information presented in the literature and at international conferences.

Ernest Yaeger - Case Western Reserve University

Dr. Yaeger is the Director of the Case Center For Electrochemical Sciences, one of the largest domestic programs of fundamental research in electrochemistry. The program has 35 faculty members and senior research staff. Areas researched are very diverse and include research on electrolytes, corrosion and passivation, electrocatalysis, and electrochemical engineering. Dr. Yaegers' group has also sponsored workshops on activities in Japan. The latest was a seminar held on October 25-26, 1983, entitled "New Japanese Technologies and Materials in Relation to Electrochemical Applications." Firms participating included Snayo Electric Company, Toshiba, Hitachi, TDK Electronics, Asahi Glass, and Nippon-Carbon.

Dr. Yaeger has a network of professional contacts; of primary importance are his postdoctoral research assistants, some of whom are now performing research in Japan. He also communicates and exchanges papers with academics in Japan. Dr. Yaeger is considered one of the principal experts in the U.S. on electrochemistry research in Japan.

Michael Yao - Argonne National Laboratory

Dr. Yao is the Director of the Office for Electrochemical Project Management at Argonne. His program and research interests are quite broad and include electrochemical research, processing, and instrumentation.

To keep abreast of research in Japan, Dr. Yao relies on several mechanisms. The primary mechanism is a network of contacts in Japan. He visits government and industry laboratories in Japan about once a year. He also follows the Japanese technical literature, which he feels is more current and detailed that the literature available in English. Dr. Yao is fluent in Japanese and is one of the principal experts on Japanese research in electrochemistry.

7.0 HEAT ENGINES

In an effort to convert energy to power more effectively, researchers are constantly searching for ways to improve the performance of existing conversion equipment and to achieve more efficient conversion from alternative thermodynamic cycles. For several of these technologies, the driving force is the high temperature to which the fuel is converted. Engines that take advantage of this high temperature are frequently termed "heat engines." Two widely used thermodynamic cycles for the conversion of energy are the Brayton cycle, which is used in operating gas turbines, and the Stirling cycle, used by the Stirling engine. Because of the current widespread use of the gas turbine in the utilities and industry, and the potential use of the theoretically more efficient Stirling engine, these technologies have received increasing R&D attention in Japan.

The purpose of this chapter is to summarize researchers' perceptions of the strengths and the comparative status of heat engine research in Japan and the U.S. An effort was made to identify researchers familiar with the work under way in Japan. Because more researchers could be initially identified in the Stirling engine field, the following discussion focuses primarily on their perceptions. A few researchers in the gas turbine field were also contacted to obtain their general impressions of activity in Japan in this field.

Researchers who contributed to the discussion of this field included the following:

Robert Alff	General Electric Corporation
William Beale	Sunpower Corporation
Donald Beremand	NASA Lewis Space Center
John Eustis	U.S. Department of Energy
Frank Kutina	NASA Lewis Space Center
William Martini	Martini Engineering
Noel Nightingale	Mechanical Technology, Inc.
John Ryan	U.S. Department of Energy
Duane Ruckle	Garrett Turbine Engine Company
Colin West	Oak Ridge National Laboratory

The following sections will discuss perceptions offered on notable aspects of the work in Japan and on the quality of technical information available to the U.S. researchers describing the research in Japan.

7.1 NOTABLE ASPECTS OF HEAT ENGINE RESEARCH IN JAPAN

A noted feature of the information describing heat engine research in Japan is its sparsity in describing the applied and developmental research efforts. Thus, while the researchers interviewed were familiar with work in Japan, it should be noted that no "Japan experts" were discovered as in most of the other technology fields reviewed in this study. Because most of the researchers interviewed were more familiar with Stirling engine development in Japan, this discussion will open with a summary of their opinions. This will be followed by the brief comments offered on gas turbine development.

7.1.1 Stirling Engine Research

The unanimous opinion of the researchers interviewed was that U.S. development of the Stirling engine appears to be ahead of Japan's. Beale, Beremand, Kutina, Martini, Nightingale, and West each commented that the program in Japan is still trying to gain parity with the U.S. However, many of the researchers, including Beale, Beremand, Kutina, and West, further noted that the program in Japan is building momentum and that within a short time Japanese researchers are certain to gain parity with U.S. researchers. Beale added that development of this began late in Japan, but he feels they are catching up quickly. Beale, West, and Kutina observed that this accelerated effort is aided by careful planning and a willingness to make a strong commitment to the research.

The primary technological emphasis noted by the researchers interviewed is the government and industry promoted projects coordinated through MITI. Beale, Kutina, and Martini noted that Stirling engine development in Japan is not being directed toward automobile applications as it has been in the U.S. Instead, stationary heat pumps are the focus of the initial work. They noted that this difference is reflected in the two Stirling engine projects sponsored by MITI. One project is directed toward developing residential and commercial building Stirling heat pumps that would have a multifuel capability, with a particular emphasis on LNG. This is a six-year program begun in 1982 that includes all facets of Stirling engine design. The technological goal is to produce an engine with an efficiency of 32% to 37% with a 10-year life span. Heat pumps in the 3 to 30 kW power range are being targeted. Over the six-year period of the program, this project is funded at approximately $44.4 million (10 billion yen).

The second project is directed toward Stirling engines for use in small marine vessels (fishing boats), which support an important industry in Japan. West, Kutina, and Nightingale noted that Japanese researchers seemed to be emphasizing the kinematic Stirling engine design. This may reflect the abundance of literature already available on this technology as a result of work in the U.S. Although the U.S. DOE automotive program has also focused on the kinematic design, they noted relatively greater activity in free piston Stirling engine work in the U.S.

Researchers also noted that the information available in English indicates an emphasis on the fundamental research of Stirling engines. Beremand, Kutina, Martini, and Nightingale all noted the apparently fundamental nature of Japanese research. There is a strong suspicion, however, that this impression results from an information flow problem and thus does not reflect the actual balance of Japanese R&D efforts. Beremand commented that researchers in Japan are doing a commendable job in building their data base. Kutina added that, although Japanese researchers have reported analytic methods and some component development, they have yet to report a fully developed system. One researcher noted that a ceramic Stirling engine has also been developed in Japan.

7.1.2 Gas Turbine Research

Although only a few researchers were interviewed on gas turbine research in Japan, their comments do provide some preliminary sense of efforts under way. The researchers interviewed observed that the U.S. was ahead overall in developing gas turbine technology. As in the case of the Stirling engine, however, there was also some sense that Japan is developing substantial momentum and will be achieving parity with the U.S. in the near future.

Alff noted that Japan has developed a particular strength in low emissions gas turbine technology. He commented that emissions standards affecting gas turbines are stricter in Japan than in the U.S., and this has provided the impetus for superior low emissions technology.

MITI has also sponsored a gas turbine development project as part of the Moonlight Project. The purpose of this project is to develop a gas turbine for electric power generation, used in a combined-cycle arrangement, in which the overall efficiency would exceed 55%. The R&D was directed toward high-temperature materials and component technology that would enable the temperature at the turbine inlet to be raised to 1500°C. The project is scheduled from 1978 to 1984 at an overall funding of about $92 million (21 billion yen). In 1982 a 100,000-kW system with a 50% efficiency was tested.

7.1.3 Other Comments

Researchers also noted that when substantial commercial production of advanced heat engine technologies does get under way, the technology in Japan will be significantly aided by the advanced, automated production facilities used throughout the industry. Ruckle noted that important elements will include quality control, laser production techniques, and other specialized production techniques.

Eustis added that, in addition to the heat engine work discussed above, Japan is also excellent in developing organic Rankine cycle technology. He felt that Japan currently leads worldwide in this technology.

7.2 QUALITY OF INFORMATION TRANSFER

Comments provided by the researchers indicate that the conventional means of information transfer (the literature and conferences) in this field are very poorly developed for providing information on Japanese R&D activities.

The consensus of the researchers was that the most effective way to keep abreast of developments in Japan is through personal contacts and visits to Japanese laboratories. Additional sources of information identified include contact with peers through industrial interactions, visits by Japanese researchers, and trip reports. When discussing interpersonal contacts, researchers pointed out that they must rely on the Japanese to visit the U.S. and that the reverse is still occurs all too infrequently. Thus, encouraging the visits of U.S. researchers to Japan's facilities was recommended by several of the researchers interviewed.

Literature identified as containing papers from heat engine research in Japan are listed in Table 7.1; all of the journals are considered secondary sources. Comments about shortcomings of the literature were related to its detail anc its age.

The most significant shortcoming of the literature that was identified is the frequent lack of detail. Several researchers observed that the literature is very general, often lacking detailed discussions of the data. It was further noted that while papers from Japan are technically correct, they do not reveal how the basic research is intended to be used. Several researchers also feel that another shortcoming in only relying upon the literature is that the material is carefully screened and that Japanese researchers are reluctant to indicate that they are gaining an edge in technology development. It was also mentioned that the literature is typically one to two years old and consequently generally out of date. Finally, researchers commented that much of the Japanese literature is not translated into English.

Although several conferences were identified with international attendance, as shown in Table 7.2, none are regarded as particularly noteworthy in reporting Japanese work. By far the most significant conference on Stirling engine work is the Intersociety Energy Conversion Engineering Conference, which has seen increasing Japanese participation over recent years. However, the papers presented were again noted to be fundamental or basic, yielding little insight into the applied efforts in Japan. The most significant conference on gas turbine development is the SAE Annual Congress.

The apparent gaps in information on applied research and developmental work seem to be largely related to the end use toward which the R&D efforts are directed. For example, in the longer-term research areas such as combustion, researchers complained that results are provided but not the methodology. In heat engines, the opposite comment was made, that the experiments are generally described, but the data are frequently not provided. This is somewhat similar

TABLE 7.1. Publications Containing Information on Heat Engine Research in Japan

Publications	Primary	Secondary
ASME Journal		x
Automotive Engineer		x
Aviation Week and Space Technology		x
Energy Daily		x
Energy Research Abstracts		x
Gas Turbine Magazine		x
Power Magazine		x
SAE Transactions		x
Stirling Engine Newsletter		x

TABLE 7.2. Conferences and Meetings with Papers Describing Heat Engine Research in Japan

Conferences	Primary	Secondary
AIME Conference		x
ASME Winter Annual Meeting		x
American Power Conference		x
Annual Energy Sources and Technical Conference and Exhibition		x
DOE Automotive Contractor Coordinators Meeting		x
Energy Technology Conference		x
Intersociety Energy Conversion Engineering Conference	x	
SAE Annual Congress		x

to the ceramics research which is also closer to the end use. However, the lack of information on the applied R&D efforts is striking and relatively worse than in most of the areas covered in this study. Developing a more complete understanding of the applied R&D efforts is an important need that needs to be addressed.

7.3 SUMMARY OF PERSPECTIVES ON HEAT ENGINE RESEARCH IN JAPAN

The development of advanced heat engines has been receiving significant attention in Japan in an effort to use energy resources more efficiently and to increase the flexibility in using different fuels. This study focused on Japanese developments in advanced Stirling engine technology because of its promise for greater fuel efficiency and flexibility. Because of the continuing importance of gas turbine development, some comments on research in this technology were also solicited.

In the development of both the Stirling engine and the gas turbine, the broad consensus of the researchers interviewed was that the U.S. is still ahead in overall technology development. However, several researchers cautioned that in both areas a significant commitment has recently been made by sectors of Japanese industry and the government, and as a result, there is a significant amount of momentum in the effort that will shortly bring them to an overall position of parity with U.S. technology development.

Researchers noted that most of the technical information available in English on Stirling engine research describes fundamental research efforts. It was noted that although this work contributes toward developing a solid data base, the potential end uses of this research are not clear from the literature. Thus, there is little technical information published about the applied aspects of Stirling engine research; however, two government projects administered by MITI were identified as indications of important end uses of the Stirling engine.

Notable aspects of gas turbine R&D were noted to be in the development of low emissions gas turbine technology and a government-sponsored, high-efficiency, combined-cycle gas turbine project.

The conventional means of information transfer--professional literature and conferences--were noted to be of only marginal value in indicating the work under way in Japan. The Intersociety Energy Conversion Engineering Conference was described as the most important for Stirling engine R&D, but it was noted that the papers from Japan tended to be extremely fundamental and basic. A significant conference concerning Japanese gas turbine work was not identified. Because of the shortcomings of these conventional means of information transfer, most researchers have relied on personal interaction with Japanese researchers. It was noted that a primary component of this interaction was the visits of Japanese researchers to the U.S., but that there are few opportunities for U.S. researchers to reciprocate. Thus, while many of the researchers sense that the level of activity in Japan in heat engine development is increasing, they noted that the current means of information transfer is largely inadequate to provide meaningful information. Suggestions for improving this information transfer included identifying and translating significant articles currently not available in English, encouraging visits by U.S. researchers to Japanese laboratories, and performing a detailed overview of the efforts under way in Japan.

7.4 RESEARCHERS CONTACTED REGARDING HEAT ENGINE RESEARCH IN JAPAN

The following researchers offered comments on this field.

Robert Alff - General Electric Division

Mr. Alff's technical emphasis is in the development of the gas turbine technology. Mr. Alff notes that GE maintains substantial R&D effort in this area to maintain its competitive edge. He also notes that GE has industrial interactions with Toshiba and Hitachi, and he feels that these interactions allow him to keep abreast of the activities in Japan.

William Beale - Sunpower Corporation

Dr. Beale's technical specialty is in the development of the Stirling engine. He notes that Sunpower currently has an exchange agreement with Kawasaki to use Sunpower-developed technology. He relies on his interactions with Kawasaki to keep him abreast of developments in Japan.

Donald Beremand - NASA Lewis Space Center

Mr. Beremand manages DOE's Stirling engine program designed to adapt the engine for automotive purposes. In addition, he noted his laboratory is working on the SP-100 program, designed to develop a Stirling engine for space applications. To keep abreast of developments in Japan, Mr. Beremand relies primarily upon discussions with Japanese visitors to NASA Lewis and attending the Intersociety Energy Conversion Engineering Conference (IECEC).

John Eustis - U.S. Department of Energy

Dr. Eustis' technical emphases are on coal-fired gas turbines, gas turbines, natural gas turbines, oil fired turbines, and generators. Dr. Eustis follows Japanese developments by attending various conferences that have active Japanese participation.

Frank Kutina - NASA Lewis Space Center

Mr. Kutina is currently responsible for the management of all of the energy related work at NASA Lewis. He is involved with the SP-100 and the DOE automotive Stirling and gas turbine engine programs. He was in Japan a year ago and met with numerous individuals working on the Stirling engine. This has resulted in some reciprocal visits to the U.S. He noted that the IECEC is currently the best U.S. conference for following work in Japan.

William Martini - Martini Engineering

Dr. Martini presently serves as a consultant and promoter of the Stirling engine and is interested in all aspects of this technology. He publishes a quarterly newsletter that describes the nonproprietary developments in Stirling technology. To follow developments in Japan, Dr. Martini communicates with peers in Japan and other U.S. Stirling researchers.

Noel Nightingale - Mechanical Technology, Inc.

Mr. Nightingale is the Director of Stirling Programa at MTI. He is also interested in the general applications of the Stirling engine. Mr. Nightingale follows the work in Japan primarily through the international conferences that also attract Japanese participation.

John Ryan - U.S. Department of Energy

Mr. Ryan is interested in the use of Stirling engines in heat pumps for residential and commercial buildings. Mr. Ryan visited Japan a year ago, and although his primary interest was in absorption heat pumps, he met with members of MITI to discuss their program.

Duane Ruckle - Garrett Turbine Engine Company

Mr. Ruckle's interest is in the manufacturing and production of gas turbines. His primary method for keeping abreast of developments in Japan is through the industry contacts he has made in his dealings with industrial firms in Japan such as Mitsubishi.

Colin West - Oak Ridge National Laboratory

Dr. West's current work involves investigating the Stirling engine as a driver for a fossil-fuel heat pump. The primary sources of his information on developments in Japan are the international conferences that attract Japanese participation.

8.0 HEAT TRANSFER

Heat transfer processes occur as an integral element of most energy conversion, utilization, and storage processes. Because entropy is increased during all heat transfer processes, some energy inefficiency is inevitable. Minimizing this inefficiency and maximizing the effectiveness of the heat transfer interface is therefore a constant challenge.

The research of heat transfer processes spans the broad range of development from very fundamental investigations of generic processes (such as turbulent boundary layer studies) to process investigations that are more applied, (such as enhanced surfaces for more efficient boiling at low temperatures), to commercial design (such as the design of recuperators). This survey will focus on fundamental to applied heat transfer research areas.

The purpose of this chapter is to investigate U.S. researchers' perceptions of the strength and comparative status of research in Japan and the U.S. in heat transfer and to survey the quality of technical information of Japanese work available in the U.S.

The opinions of technical experts in the field formed the foundation of this investigation. Researchers interviewed were chosen as being well established in the field and aware of developments in Japan. The researchers who contributed to this discussion include the following:

Win Aung	National Science Foundation
Arthur Bergles	Iowa State University
Ernst Eckert	University of Minnesota
Keith Ellingsworth	Office of Naval Research
Warren Rohsenow	Massachusetts Institute of Technology
Jerry Taborek	Heat Transfer Research, Inc.
William Thielbahr	U.S. Department of Energy, Idaho Operations

The following sections contain discussions of the strengths and comparative status of Japanese research and the quality of the technical information available to U.S. researchers in the field of heat transfer.

8.1 NOTABLE ASPECTS OF HEAT TRANSFER RESEARCH IN JAPAN

The researchers interviewed generally agreed on the strength of research in Japan and the relative position of the U.S. and Japan in heat transfer research. In the fundamental research of heat transfer, the consensus was that the work in the two countries is comparable, with the U.S. perhaps maintaining a slight edge. However, Japan's program emphasizes the applied areas of heat transfer research. While the researchers generally agreed on this emphasis, comments differed about the comparative status of R&D. The level of agreement was nonetheless greater than in any of the other technical fields covered in this study.

Bergles and Eckert noted that the extensive exchange of technical information between researchers in the U.S. and Japan has revealed that fundamental research in the two countries is comparable. Bergles added that this information exchange helps to maintain this parity. Rohsenow noted, in particular, that parity exists in the condensation and boiling research, and Ellingsworth noted that parity seems to exist in the conduction research. However, Ellingsworth and Aung feel that the fundamental research effort in the U.S. is stronger overall. Aung commented, for example, that the U.S. appears to be superior in developing analytic techniques to describe heat transfer processes.

Several researchers noted that the strength of the heat transfer effort in Japan is in the applied development of technologies. Bergles summarized this observation by saying that research in Japan is typically driven by the commercial imperative. Thielbahr also commented on the intent manner in which technology developments are put into commercial use. Researchers noted several target applications of the heat transfer R&D that motivate some of the more significant efforts in Japan. These applied research areas, some of which overlap with fundamental research areas, include enhanced surfaces, boiling, condensation, high temperature, and heat transfer in electronic components.

Taborek, Bergles, Ellingsworth, Eckert, Rohsenow, and Thielbahr all noted that Japan has a very high level of research activity examining enhanced surfaces in various modes of heat transfer. Taborek noted that over the past 15 years most of the innovative surfaces have come from Germany or Japan. Bergles concurred that some very innovative work has been achieved by Japan, such as the Thermoexel surface developed by Hitachi for use in refrigeration. However, he commented that much of this innovative work involves taking an existing concept and refining it or building it on a larger scale. Rohsenow echoed this view by observing that Japanese researchers have taken the initiative in developing unusual boiling and condensation surfaces, producing technology with excellent design. He noted that although Japanese researchers have been creative in their development of surfaces, much of this work could be replicated by U.S. researchers.

Ellingsworth noted that the major R&D efforts on boiling heat transfer enhancement in Japan during recent years have been directed toward developing effective porous or rough surfaces for enhanced boiling and toward conducting experimental and empirical studies of various fabricated heat transfer surfaces.

Ellingsworth views the enhancement work as part of one of the two major objectives of recent heat transfer R&D in Japan. These objectives are: 1) to harness abundant low-grade energy more economically, and 2) to improve the reliability of many new high-technology products that require high heat transfer rates to function properly. He noted that new techniques for boiling and condensation heat transfer enhancement have received more attention than convection, perhaps because of their direct relevance to improving the organic Rankine cycle power system for more economical use of Ocean Thermal Energy Conversion (OTEC) and geothermal energy sources. Bergles also noted this development associated with OTEC.

Eckert also observed this emphasis in the fields of boiling and condensation and commented on the importance of considering the end use in evaluating the motivation behind Japanese research. He commented that Japanese researchers are attempting to better understand the underlying processes to enhance heat transfer in a broad range of equipment that relies on these processes. Rohsenow pointed out that one of these applications is in boilers for nuclear power plants.

Significant heat transfer R&D activity was also identified in high temperature processes. Aung and Thielbahr noted that Japan is active in high-temperature heat exchanger research as well. Thielbahr noted that a major component of this research involves the development of high-temperature materials, and Aung commented that he has identified applications in solar power generators and for use in conjunction with nuclear heat for steelmaking.

Finally, Aung noted Japan's development of heat transfer equipment for use in the cooling of electronic equipment, such as in the coming generation of supercomputers.

In addition to the end-use orientation of current research, Ellingsworth noted that in a trip report from a visit to Japan, Simion Kuo identified several probable areas of future Japanese emphasis:

- spray or mist cooling
- analytic flow models for boiling heat transfer from porous surfaces
- anti-fouling characteristics of selected boiling and condensation surfaces
- a unified approach for rating or ranking the large number of heat transfer enhancement techniques proposed.

If Japanese heat exchanger technology has a competitive edge, it is in the actual production of the technology. Taborek commented that the greater commitment to innovation in Japan has led to their competitive edge in applying heat exchanger technology to new products. Thielbahr also noted this superiority in improved production equipment. He added that the apparent willingness of Japanese organizations to commit to long-term, high-risk areas has also contributed to this level of technical development.

8.2 QUALITY OF INFORMATION TRANSFER

There was widespread recognition that the international coverage provided by the heat transfer literature is quite comprehensive, providing researchers with a good sense of activities in Japan. This positive situation reflects the sophisticated infrastructure that exists to facilitate the binational flow of information.

In many ways, the mechanisms of information transfer in the heat transfer field could provide a model for other technical fields. Components of an effective information transfer program, as synthesized from the comments of researchers in a variety of fields, include the following.

- timely journals with quality papers from Japan
- quality conferences with active Japanese attendance
- binational seminars that allow for focused technical discussions as well as casual interaction
- mechanisms for identifying screening and translating key Japanese literature
- articles that survey international research.

The following discussion will summarize comments offered by researchers on each of these components.

The most significant publication containing technical papers describing research in Japan is Heat Transfer-Japanese Research, published through Pergamon Press, which contains a collection of translated papers from Japan. The publication tends to emphasize basic heat transfer research. An editorial board in Japan has identified this periodical as being of particular significance. The significance of this publication is not only that it contains translated papers, but that these papers are screened by a board. Researchers in several fields emphasized that merely translating articles is insufficient because researchers are discouraged by the prospect of having to wade through all of the literature to find the useful publications. Researchers commented that screening is essential to ensure the effective use of the translated information by the U.S. research community.

Several other recent publications review international work and include comprehensive coverage of activities in Japan. These include Previews of Heat and Mass Transfer and an annual survey of international work prepared by the Heat Transfer Group at the University of Minnesota. In Previews of Heat and Mass Transfer, approximately 300 journals addressing heat transfer research are scanned. This journal is published six times a year by the Rumford Publishing Company and provides coverage of six Japanese journals as well as twenty Russian publications. The Japanese journals reviewed include the following:

- Journal of Chemical Engineering, Japan
- Journal of the Society of Heating, Air Conditioning, and Sanitary Engineers of Japan
- Kagaku Kogaku Ronbunshu
- Memoirs of the Faculty of Engineering, Kyushu University
- Refrigeration
- Transactions of the Japan Society for Aeronautical and Space Sciences.

Based on the open Japanese literature, the Heat Transfer Group prepares an annual survey of international papers in the heat transfer area. This review article appears in the International Journal of Heat and Mass Transfer and discusses research developments in the field.

Researchers also identified several English language journals that present many significant publications from Japanese researchers. The two primary journals are International Journal of Heat and Mass Transfer and Journal of Heat Transfer. The International Journal of Heat and Mass Transfer contains papers of a theoretical nature and is intended to expand knowledge of the fundamental processes underlying the heat transfer mechanisms. Considered one of the more prestigious journals, it is printing increasing numbers of original Japanese papers. The Journal of Heat Transfer is similar, but focuses more on domestic work.

More topically-oriented publications were also identified, including Numerical Heat Transfer - An International Journal of Computation and Methodology, and Energy Developments in Japan. The former focuses on methodologies and computational solutions in heat transfer and has periodic submissions from Japan. The latter contains papers on energy developments in Japan in a broad range of energy generation and storage areas. The literature sources with information on research in Japan are summarized in Table 8.1.

TABLE 8.1. Literature Sources Containing Information on Heat Transfer Research in Japan

Literature	Primary	Secondary
ASHRAE Transactions		x
Energy Developments in Japan		x
Heat Transfer Engineering; An International Quarterly	x	
Heat Transfer-Japanese Research	x	
Heat Transfer Fluid Flow Service	x	
International Journal of Heat and Mass Transfer	x	
Journal of Heat Transfer		x
Numerical Heat Transfer- An International Journal of Computation and Methodology		x
Previews of Heat and Mass Transfer	x	

A second major component of information transfer is the interaction provided by conferences and seminars. Those identified are listed in Table 8.2. Researchers noted several well-attended major professional conferences and binational seminars. The most frequently noted of these conferences is the International Heat Transfer Conference, which is held every four years. At this conference prominent researchers from various countries are invited to discuss their research efforts. This conference has extensive Japanese participation and addresses all facets of heat transfer, including work on theoretical, experimental, and commercial applications.

A second, frequently noted conference was the Joint Thermal Engineering Conference. This conference was organized by the ASME and its Japanese counterpart, the JSME. The meeting, held in March, 1983, covered a broad spectrum of topics related to heat transfer and generated five volumes of proceedings. Additional binational meetings are planned.

TABLE 8.2. Conferences and Meetings with Papers Describing Heat Transfer Research in Japan

Conferences	Primary	Secondary
ASME Winter Annual Meeting-Heat Transfer Session		x
Annual Southeastern Seminar on Thermal Sciences, sponsored by the Clean Air Institute		x
International Heat Transfer Conference	x	
ASME/JSME Joint Thermal Engineering conference	x	

Other Meetings and Seminars
Two Phase Flow Dynamics- U.S.-Japan Joint Seminar, 1979
Heat Transfer in Energy- U.S.-Japan Joint Seminar, 1980

Smaller binational seminars sponsored by organizations such as the National Science Foundation (NSF) also provide a valuable contribution to the mutual understanding of research. Bergles co-organized such a seminar sponsored by NSF in 1979 which focused on two-phase flow dynamics. He noted that the seminar brought a lot of Japanese work to the attention of the U.S. scientific community. The papers are contained in a book titled Two-Phase Flow Dynamics, published by Hemisphere Publishing Corporation. A sequel to this meeting is planned for later this year. Rohsenow also commented that he had participated in an NSF joint seminar in Japan in 1981, in which researchers from both countries discussed their research in boiling and condensation. There was also a third seminar, sponsored by the NSF, related to heat transfer in energy technologies in 1980. The proceedings to this seminar were edited by Y. Mori and published by Hemisphere Publishing Corporation under the title Heat Transfer in Energy Problems: Proceedings of Japan-U.S. Joint Seminar, 1980.

Trip reports also provide the research community with useful summaries of different aspects of heat transfer R&D activity in Japan. An excellent report has recently been compiled by Dr. Simion Kuo for the Office of Naval Research. Dr. Kuo visited 20 research organizations in the universities and the industry.

The combination of these literature sources and opportunities for interaction have given most of the researchers interviewed the impression that they are aware of most of the research under way in Japan. Several researchers noted, however, that to develop a thorough and a timely understanding, onsite visits are still necessary. This is the only area in which suggestions for improving information transfer were offered. Otherwise, the mechanisms for information transfer from Japan to U.S. researchers appear to be operating effectively with little need for additional government support. If anything, this area might be looked upon as a model of effective information transfer for other fields to emulate.

8.3 SUMMARY OF PERSPECTIVES ON HEAT TRANSFER RESEARCH IN JAPAN

There was an unusually high level of agreement among researchers in the heat transfer field concerning the strengths of the Japanese research effort and the quality of the information transfer to the U.S. The strength of the research in Japan is perceived to be in the applied areas of heat transfer research. In the fundamental study of heat transfer, researchers felt the countries are at parity, with perhaps a slightly broader effort in the U.S. The quality of information transfer was noted to be extensive and reasonably timely, through a combination of the literature, conferences, seminars, and visits to organizations in Japan.

When discussing the comparative status of fundamental heat transfer research, the researchers interviewed either commented that the status of the two countries is comparable or that the U.S. might have an edge because of its broader program. Aung mentioned, for example, that U.S. researchers still develop more insightful analytic techniques. However, in the research of boiling, condensation, and conduction, the two nations are felt to be generally equal.

The strength of the research in Japan was clearly noted to be in the applied aspects of heat transfer research. These general areas of applied research (some of which overlap with the fundamental areas) include enhanced surfaces, boiling, condensation, high temperature, and heat transfer in electronic components. One of the stronger efforts in Japanese heat transfer research has been in the area of enhanced surfaces. Much of the innovative R&D that has occurred in this area has been conducted in Japan and West Germany. One example is the recent development of Hitachi's Thermoexel-E-surface, which has excellent nucleation boiling characteristics. In addition, there is significant heat transfer research in Japan addressing the areas of low-grade heat sources recovery (OTEC, geothermal, organic rankine power systems, etc.), more efficient operation of industrial and utility boilers, effective heat exchange in high-temperature systems (solar power generators, nuclear steelmaking, etc.), and electronic equipment cooling for the next generation of supercomputers.

Applied areas of research likely to be emphasized in the future include spray or mist cooling, flow models for boiling on porous surface, anti-fouling in boiling and condensation, and a unified approach for evaluating heat transfer enhancement techniques.

The most striking observation from the interviews resulted from researchers' comments regarding information transfer. There was a generally strong agreement that the mechanisms available are working effectively and comprehensively, with little room for improvement. Through a combination of journals, conferences, seminars, and visits to Japan, an effective system for information flow has been developed. The most relevant journal identified is Heat Transfer-Japanese Research, which translates and publishes Japanese articles that have been screened by an editorial board. The literature is complemented by several conferences well attended by both U.S. and Japanese researchers, such as the International Heat Transfer Conference and the Joint (Japan-U.S.) Thermal Engineering Conference. In addition to these large conferences, several binational seminars have been sponsored by the National Science Foundation. Because heat transfer is a critical area to many energy conversion, utilization, and storage processes, it seems essential to ensure that U.S. researchers continue to keep abreast of international developments to avoid falling into a position of comparative disadvantage.

8.4 RESEARCHERS CONTACTED REGARDING HEAT TRANSFER RESEARCH IN JAPAN

The following researchers offered comments on this field.

Win Aung - National Science Foundation

Dr. Aung is currently the director of the Thermal Systems and Engineering Program at the National Science Foundation. In addition, he is an adjunct Professor of Mechanical Engineering at Howard University and the University of Maryland and carries out independent research at both locations. Dr. Aung's research interests are very broad and encompass all aspects of heat transfer research. Within his program, approximately 200 projects are under way. Although Dr. Aung does not make a particular effort to follow research in Japan, he noted their publications in the literature and their presentations at major conferences, and keeps abreast of binational seminars. He has visited numerous research laboratories and presented several seminars in Japan.

Arthur Bergles - Iowa State University

Dr. Bergles is internationally known for his work in enhanced heat transfer and in two-phased flow. Fifteen projects are under way in his laboratory, covering such topics as enhanced surfaces for nuclear boiling, forced convection vaporization, and forced convection condensation.

As part of a contract he has with DOE, Dr. Bergles is tracking the international literature on heat transfer. He also has extensive contacts with Japanese researchers, receiving perhaps a dozen visitors a year. He also visits Japan about every other year. Dr. Bergles was involved in a joint activities seminar in 1979, which was organized by the National Science Foundation. This meeting focused on the topic of two-phased flow and involved both American and Japanese researchers preparing survey papers. Dr. Bergles is regarded as one of the most knowledgable researchers on Japanese developments.

Ernst Eckert - University of Minnesota

Dr. Eckert is the head of the Heat Transfer Division in the Mechanical Engineering Department. This division supports one of the largest heat transfer research efforts in the United States. More than ten projects are currently under way. Dr. Eckert's interests are in cooling and combined heat and mass transfer in porous unsaturated media. Dr. Eckert noted that his program is visited frequently by researchers from Japan. In 1982 he also spent three months in Japan. During that visit he gave lectures and visited the five leading universities working in heat transfer, government research labs, and several industrial labs.

Keith Ellingsworth - Office of Naval Research

Mr. Ellingsworth's research involves convection as applied to heat exchangers. He is currently investigating swirl and turbulence in complex heat exchanger geometries. To follow international developments, he relies on his U.S. contractors who scan the literature and attend international conferences. He recently sent a researcher to Japan to review heat transfer research at 20 organizations.

Warren Rohsenow - Massachusetts Institute of Technology

Dr. Rohsenow is the head of the Heat Transfer Laboratory and co-editor of the Heat Transfer Handbook. His research interests include boiling, boilers, turbines, and heat transfer in a wide variety of applications. Current projects involve fluidized bed heat transfer, post-dryout boiling in nuclear reactor tubes, moisture migration in insulated buildings, and heat transfer in buildings.

Dr. Rohsenow follows Japanese work in his field of interest: boiling and condensation. He finds the most effective means of keeping abreast of developments in Japan to be conferences and meetings. He also participated in a seminar sponsored by the National Science Foundation in which researchers from the U.S. and Japan met in Japan and presented papers on boiling and condensation.

Jerry Taborek - Heat Transfer Research Institute

Dr. Taborek is a Technical Director at the Heat Transfer Research Institute (HTRI), which has a broad research program covering heat transfer enhancement and heat exchanger design. Dr. Taborek serves on the Advisory Board to several publications and his primary research interest is in heat transfer related to industrial requirements such as petro-chemicals and refrigeration.

Dr. Taborek has, through the HTRI, developed very close ties with Japanese organizations. He visits these organizations in Japan and directly observes their research. About 35 Japanese organizations are members of the HTRI cooperative research activity. As a measure of the trust he has developed with Japanese firms, he has been given access to confidential research information.

William Thielbahr - U.S. D.O.E, Idaho Operations

Dr. Thielbahr is Director of the Conservation Technologies Division. Dr. Thielbahr relies on his network of contacts in Japan as a primary means of keeping abreast of developments there. A researcher from Japan has visited the Idaho facility. Dr. Thielbahr also views conferences, meetings, and seminars as very valuable forums for technical information exchange. To supplement the literature, he periodically has literature reviews and patent searches performed.

9.0 HIGH-TEMPERATURE SENSORS

Energy and materials in industrial processes are increasingly used more efficiently by the more precise and automated control of the process. A key component of this trend is the development of sensor technology to monitor process conditions. Advances in computer technologies have created tremendous potential for the widespread use of sensors. The use of sensors in manufacturing and production processes has received substantial publicity over the past few years. However, the use of sensors in many processes is limited by environmental concerns, such as high temperatures, which are common in many energy conversion processes. This chapter focuses on U.S. researchers' perceptions of the status of high-temperature sensor technology in Japan.

Researchers and engineers who contributed to this discussion include the following:

Alex Clark	Leeds and Northrup Company
Ray Dils	Acu-Fiber Corporation
Richard Gagg	Land Instruments
Mike Gusinow	Sandia National Laboratory
M. B. Herskovitz	Oak Ridge National Laboratory
Kenneth Kreider	National Bureau of Standards

The following sections contain discussions of these researchers' perceptions of notable aspects of research and technology development in Japan and the quality of technical information transfer to the U.S.

9.1 NOTABLE ASPECTS OF HIGH-TEMPERATURE SENSOR RESEARCH IN JAPAN

Conversations with several researchers revealed the perception that only minor activity is under way in this field in Japan. Although significant activity is under way in developing optical sensors and controls for manufacturing processes, researchers do not feel that this same level of interest exists in high-temperature sensors. However, the information network for keeping abreast of developments in Japan is generally poor, requiring researchers to rely primarily upon the contacts they have in Japan.

Researchers noted that the sponsored work that they were aware of in Japan typically occurs in the industry. Therefore, unless a business relationship is established with a company, monitoring activities in this field is very difficult. The general comments concerned the emphasis on manufacturing and applications of sensors, and on developments in fiber optic sensors, non-intrusive combustion species measurements, and infrared temperature measurement.

Several researchers commented that the current strength of the program in Japan is not in any particular high-temperature sensor technology, but in the manufacture of the sensor hardware and in the industrial application of the technology. Clark, Dils, Herskovitz, and Kreider commented on Japan's effectiveness in these commercial aspects of the technology. Clark noted the emphasis on applications in process technology, such as the basic oxygen furnace, and Kreider noted the strong interest in using sensors for conserving fuels and improving process yields.

Dils observed that there appears to be increasing interest in Japan in developing optical fiber thermometers. This trend may be worth monitoring because fiber optics is considered an important element of Japan's high-technology future. However, Dils and Kreider commented that the work in Japan is currently still catching up to work in the U.S. In particular, Dils noted that the work at the National Bureau of Standards is still leading the field.

Non-intrusive combustion analysis instruments are a second notable application for high-temperature sensors in Japanese research. Although there is increased interest in fundamental combustion studies, as evidenced by a MITI-supported effort in advanced combustion technology, this is also considered an area in which the U.S. leads. Gusinow noted that in the most advanced instruments, such as coherent anti-Stokes Raman scattering, Japan does not appear to have facilities comparable to some in the U.S.

Gagg commented that in infrared sensor technology development, the U.S. still appears to be well ahead. Although Minolta Camera Company has recently produced a portable radiation thermometry unit that has an operating range of 1100 to 5500°F, with an accuracy of 0.5%, he stated that much of the technology was borrowed from previous developments. His experience indicates Japanese technology to be several years behind U.S. developments.

Several researchers noted that thermocouples are also very important high-temperature sensors, but this technology is generally considered mature and at a comparable level of development in the two countries.

Beyond these general comments, researchers were restricted in their comparisons by the limited information available on developments in Japan. Although conclusions can only be tentative, given the sparse information available, the U.S. seems to be more significantly challenged in other sensor technologies, such as those being developed for manufacturing systems.

9.2 QUALITY OF INFORMATION TRANSFER

Although several researchers noted that literature is abundant in the sensors field, it was also noted that literature describing work in Japan is far less well represented. It was further remarked that information on high-temperature sensor activity is even less well described. As a supplement to this literature, researchers rely heavily upon contacts they had established with peers in Japan.

In general, coverage of Japanese research efforts in high-temperature sensors is very spotty. The literature sources identified are listed on Table 9.1. Note that each source is considered secondary. The work that is available is dispersed throughout a broad number of journals, which contain articles in three categories: 1) articles on advances in sensors and instrumentation, 2) applications-oriented articles in such topical areas as combustion, and 3) research papers that address the materials properties or underlying physics of sensors. Examples of the first category include the ISA Transactions, International Instruments and Control, Review of Scientific Instruments, Sensors and Actuators, and the National Technical Information Service's Tech Notes-Testing and Actuators. This last publication provides summaries of new applications for technology as developed by nine different federal agencies and their contractors. Journals in the second category include such materials as the Gas Turbine Yearbook and Laser Focus. Finally, the last category includes the Journal of Applied Physics, Journal of Metals, and the Journal of Applied Optics.

TABLE 9.1. Literature Sources Containing Information on High-Temperature Sensors Research in Japan

Source	Primary	Secondary
AIAA Journal		x
ASTM: Symposium on Infrared Instrument Measurement		x
Ceramics Age		x
Gas Turbine Yearbook		x
IEEE Transactions on Industrial Electronics and Control Instrumentation		x
ISA Transactions		x
In Tech		x
International Instruments and Controls		x
Japan Society of Precision Engineering		x
Journal of Applied Optics		x
Journal of Applied Physics		x
Journal of Dynamic Systems: Measurement and Control		x
Journal of Metals		x
Key Abstracts-- Electrical Measurement and Instrumentation, IEEE		x
Laser Focus		x
NTIS Tech Notes- Testing and Instrumentation		x
Optics Letters		x
Review of Scientific Instruments		x
Sensors and Actuators		x
Transactions of Power		x

The conferences identified also are considered secondary information sources. These are summarized in Table 9.2. The most notable conferences are the International Symposia on Aerospace Instrumentation and the High Temperature Symposium (held every five years).

TABLE 9.2. Conferences and Meetings With Papers Describing High-Temperature Sensor Research in Japan

Conference	Primary	Secondary
AIME Spring Meeting (emphasizes materials)		x
ASTM Symposium on Infrared Instrument Measurement		x
Aerospace Sciences Meeting		x
American Vacuum Society		x
Electrochemical Society Biannual Meeting		x
ISA Annual Meeting		x
International Conference on Solid State Transducers		x
International Symposium of Aerospace Instrumentation		x
Materials Research Society		x
SAE Aerospace Meeting		x

In general, there appears to be a striking lack of sources that might provide a comprehensive understanding of overall sensor or high-temperature sensor activities. Dils noted that information can be found on activities at the universities and government laboratories, but further added that a great deal of significant activity is underway in private laboratories, and that little of this information is released.

To keep abreast of private sector efforts, several researchers noted that a business relationship must be established with Japanese firms. In specific high-temperature sensor technologies, several researchers said they were comfortable with the information they were receiving through their interactions with associates in Japan. However, although personal contacts may provide information flow between companies involved in a certain specialty, the lack of an overall picture of the research activities still remains a problem.

Several suggestions were offered to lessen this information transfer problem. Kreider and Dils pointed to the need to accurately assess the amount of information published only in Japan. International workshops and exchanges of researchers were also mentioned as vehicles for enhancing the interaction between Japan and the U.S.

9.3 SUMMARY OF PERSPECTIVES ON HIGH-TEMPERATURE SENSOR RESEARCH IN JAPAN

The general lack of information on research in Japan on high-temperature sensors prevented an overall comparative assessment of this technology by the researchers interviewed. No literature or conferences were identified as primary or significant sources of information on Japanese work. Most of the researchers and engineers interviewed rely on contacts with associates in Japan as the primary means of monitoring relevant technology developments.

Although overall evaluations of the activities in Japan could not be made, several researchers did offer their perceptions of activities within their specialties. Several noted that Japanese researchers are very effective in manufacturing and applying high-temperature sensor technology. The ability to apply these sensors appears superior to that typically found in the U.S. An increasing interest in high-temperature fiber optic sensors in Japan was also noted. This interest is most likely related to the overall acceleration of fiber optics technology in Japan. However, researchers commented that the U.S. still leads in this area. Comments were also offered on highly sophisticated combustion instrumentation (such as coherent anti-Stokes Raman spectroscopy) and infrared sensors: the opinion of the researchers interviewed in these areas is that the U.S. has superior technology. Technology development in the two countries is considered to be comparable in thermocouple development, a very mature technology.

For researchers and engineers dealing in specific product areas, it was commented that the current exchange of information with colleagues in Japan is adequate. For other researchers whose interests span across several technologies, or whose jobs involve pursuing work at the leading edge of the technology, the current level of information exchange is considered insufficient.

Researchers noted that much more activity appears to be under way than is indicated in the sources available, and it was suggested that some type of overall review be performed to better define the scope and focus of Japanese efforts. Other suggestions offered for improving information transfer included translating key documents published in Japanese into English and encouraging scientific exchanges.

9.4 RESEARCHERS CONTACTED REGARDING HIGH TEMPERATURE SENSOR RESEARCH IN JAPAN

The following researchers offered comments on this field.

Alex Clark - Leeds and Northrup Company

Mr. Clark is a member of the ASTM's Radiation Thermometry Committee and a recognized authority in the field of high-temperature measurement. Leeds and Northrup is a major producer of high-temperature measurement equipment, including optical pyrometers, infrared radiation devices, thermocouples, and resistance thermometers. Mr. Clark noted that the High Temperature Symposium, held every five years, is the primary conference with active Japanese participation. His primary method of keeping abreast of work in Japan is through his marketing agents in Japan.

Ray Dils - Acu-Fiber Corporation

Mr. Dils' primary interest has been in the research of high-temperature measurement. While at the National Bureau of Standards, Mr. Dils invented a high-temperature optical fiber thermometer that he is now manufacturing. Mr. Dils actively follows the literature in the field but notes that his primary means of keeping abreast of developments in Japan is through his business interactions with Japanese firms.

Richard Gagg - Land Instruments

Mr. Gagg is the manager of U.S. operations of Land Instruments, a major producer of radiation thermometry equipment. He noted that sales to Japan represents a significant amount of their business. To keep abreast of developments in Japan, Mr. Gagg relies heavily on their marketing offices in Japan.

Mike Gusinow - Sandia National Laboratories

Dr. Gusinow is a Supervisor in the Combustion Technology program, in which non-intrusive measurement techniques are an integral part. He noted that his group is pioneering the development of coherent anti-Stokes Raman spectroscopy. He follows developments in Japan through combustion meetings, scanning the combustion literature, and meeting with visitors from Japan.

Dr. M. B. Herskovitz - Oak Ridge National Laboratory

Dr. Herskovitz is developing leading-edge sensor technology for use in pressurized water reactors. One of his major projects associated with this technology is an international effort with the participation of West Germany and Japan. He has primarily used recent trips to Japan to monitor technology developments. On his visits, he interacts with sensors researchers in the private sector. He finds the journals to be only a secondary source.

Kenneth Kreider - National Bureau of Standards

Dr. Kreider is associated with the development of a variety of high-temperature sensing technologies, including high-temperature measurements in gas turbine and internal combustion engines, thin-film sensors for turbine blades, precision sensors for process control, and a high-temperature optical fiber thermometer with very high accuracy. Dr. Kreider noted that they have frequent visits from researchers in Japan. He finds these contacts and his conversations with U.S. peers to be the most valuable means of keeping abreast of technology in Japan. He also finds the literature and conferences to be of some value.

10.0 THERMAL AND CHEMICAL ENERGY STORAGE

The cyclic energy demands required in many industrial, utility, solar thermal and building processes typically result in an inefficient use of power generation capacity, and contribute to the inefficient conversion of energy. To improve this situation, researchers have increasingly looked to the possibility of storing energy in times of excess capacity and releasing the energy later to meet peak energy demands. Two methods of energy storage being researched in both the U.S. and Japan are thermal energy storage and chemical energy storage.

In Japan, the need to efficiently use energy is amplified by the nation's large dependence on imported sources. Although energy storage technologies have not traditionally been a high-priority research area, indications are that significant technical work is increasingly under way. The purpose of this chapter is to investigate the U.S. researchers' perceptions of the status of R&D in this technology in Japan and the quality of information on Japanese activities available to U.S. researchers.

Researchers who contributed to this discussion include the following:

Robert Copeland	Solar Energy Research Institute
Anthony Gorski	Argonne National Laboratory
R. J. Petri	Institute of Gas Technology
Lee Radosevich	Sandia National Laboratories
John Tomlinson	Oak Ridge National Laboratory

The following sections summarize their comments.

10.1 NOTABLE ASPECTS OF THERMAL STORAGE RESEARCH IN JAPAN

Interviews with several U.S. researchers in this field revealed that little appears to be known about the developments in Japan and that little effort is made to keep abreast of developments there. As a result, strong perceptions of the status of technology development in this area could not be offered.

However, through information obtained from Japanese participation at international conferences and contacts researchers have with peers in Japan, several researchers were able to offer general perceptions of major aspects of Japanese R&D in this field.

Researchers perceived activities in Japan to be generally similar to those in the U.S. Japanese researchers are investigating both the direct means of thermal energy storage, such as sensible and latent heat recovery, and the indirect means of storage, such as the concentration difference of solutions, adsorption-desorption isotherms, reversible chemical reactions, and photochemical reactions. Petri noted that until 1979 or 1980 he perceived little interest in this technology on the part of the Japanese. In recent years, he noted that they have made tremendous progress, and from scanning of the patent literature, feel that they are in rough parity with the U.S. This perception of approximate parity is shared by Tomlinson and Copeland. It was also commented that the work that is published appears to be methodically performed and well-executed.

The researchers indicated that the Japanese seem to be pushing phase-change technology, clathrates for low-temperature energy storage, and metal hydrides. Copeland commented that in discussions with his U.S. peers, it has been noted that Japan is developing advanced technology in phase-change energy storage. Hasatani, in his article "Thermal Storage: Japanese Research," (Hasatani and Matsuda 1983) noted that organizations such as the Electrotechnical Laboratory have explored a variety of materials as candidates for latent heat systems, with one of the more promising developments occurring with form stable high-density polyethylene. In this technology, high-density polyethylene is treated with an ion plasma bombardment to form surface-crosslinkage that would prevent degradation into the heating medium of the device.

Clathrate development in Japan for low-temperature energy storage was also noted. Petri and Tomlinson commented that the Japanese appear to be very interested in using low-temperature energy storage for space cooling in residential and commercial buildings. Hasatani (Hasatani and Matsuda 1983) confirms this interest, noting that the general area of chemical energy storage is considered one of the most promising future thermal storage techniques. He also noted the interest in gas clathrate compounds such as Freon 11 and Freon 12, which are decomposed and/or reformed with a relatively large quantity of heat in the temperature region between 0 and 15°C. Current technical issues being studied include enhancing the rate of heat transfer as well as the rate of phase change in a clathrate slurry. Tomlinson observed that Mitsubishi is planning to develop a clathrate storage facility in conjunction with the building of a cool storage facility.

Petri also noted an interest in Japan in developing metal hydrides and in high-temperature thermal chemical energy storage. Hasatani (Hasatani and Matsuda 1983) also commented on this interest, noting that this is considered another one of the most highly promising areas for thermal energy storage. Hasatani pointed out that a particular attraction of metal hydrides is the wide range of potential temperatures for operation. He notes that equilibrium diagrams of reactions between hydrogen and various metals show temperatures ranging from -20°C to 1000°C. A related technology of interest is the chemical heat pump using metal hydrides and chemical heat pipes. This latter technology involves the catalytic reaction of the hydrogenation/dehydrogenation of benzene/cyclohexane within a heat pipe. Current research is examining the various catalysts that would most effectively support the reaction. Work on metal hydride thermal storage, chemical heat pumps, and chemical heat pipes is currently under way at the National Chemical Laboratory for Industry.

In other areas of thermal energy storage, Copeland noted that Japanese researchers occasionally develop unusual end uses. For example, he noted the development of an automobile using thermal storage techniques, which would have apparent overall efficiencies of less that 1%.[a]

Radosevich commented that his perceptions of Japan's storage research were limited to the systems installed in the Sunshine Project. One system used pressurized water that was stored until needed; the other was a two-stage system involving pressurized water and a phase-change salt. Radosevich is unaware of any significant results from this research.

(a) Hasatani (Hasatani and Matsuda 1983) notes the recent proposal of such a gas clathrate engine.

Due to the lack of available information, comparing the overall status of the effort in Japan with work in the U.S. is difficult. Several researchers commented that Japan may be ahead in applications of thermal and chemical energy storage in the industry and in buildings. In general, researchers commented that the work they are aware of in Japan is thorough, committed, quickly performed, and of overall high quality.

10.2 QUALITY OF INFORMATION TRANSFER

The researchers interviewed indicated that information about thermal storage R&D activities in Japan is generally sparse. No significant publications or conferences were identified as being particularly good about reporting developments in Japan. The information sources available only contain occasional or irregular articles on R&D in Japan. None of the researchers interviewed felt that the information available provides a comprehensive view of Japanese work in this area nor that it allows them to follow any one area very closely.

The journals and conferences that were mentioned as containing some submissions by researchers from Japan are listed on Table 10.1. The Intersociety Energy Conversion Engineering Conference was the only source mentioned by more than one researcher as being somewhat useful for its Japanese participation.

Researchers did note, however, that Japanese patents that are available in English can provide useful information. Even the patents filed only in Japan, as compared with patents filed in Japan and in the U.S., could potentially provide information on targeted commercial applications for specific technologies. Further study is thus also needed to explore patents as a potential source of information in this field.

Because of the significant lack of information on work under way in Japan, the researchers interviewed could not comment on specific information gaps. In some ways, the entire field can be viewed as an information gap. Given the perceived level of thermal storage research activity in Japan, and the perception of significant technical advances being made in several areas of thermal energy storage, the field seems to be clearly in need of some preliminary

TABLE 10.1. Sources Containing Information on Thermal Energy Storage Research in Japan

Sources	Primary	Secondary
ASME Winter Annual Meeting		x
Chemical Energy Magazine		x
Energy Digest		x
Intersociety Energy Conversion Engineering Conference		x
Journal of Heat Transfer		x
Journal of ASME		x
Journal of ASCHE		x
Journal of Solar Energy Engineering		x
Popular Science		x
Solar Energy		x

study. The study is needed to clarify issues of comparative position and technical focus that cannot be answered by information currently available to U.S. researchers.

10.3 SUMMARY OF PERSPECTIVES ON THERMAL AND CHEMICAL ENERGY STORAGE IN JAPAN

Interviews with several major researchers in the thermal and chemical energy storage field revealed that little information is available in the U.S. regarding Japanese research efforts in this field. The researchers interviewed rely primarily on contacts in Japan, and supplement these contacts with the information sources available and the Japanese papers in the international literature and at conferences. None of the literature or conferences is considered a major source of information about activities in Japan. With this shortcoming in the information flow, researchers had difficulty providing overall assessments of the comparative status of technology development.

In general, researchers did not detect many differences between the work they have perceived in Japan and the U.S. programs. It was noted that before the late 1970s, Japan did not seem very interested in thermal and chemical energy storage. However, the level of activity has recently been perceived to have notably increased. Areas that Japanese researchers seem to be pursuing at a significant pace include phase-change technology, clathrates for low-temperature energy storage, and metal hydrides. In each of these areas, there is some sense that Japanese technology has rapidly achieved parity with and may be surpassing technology in the U.S. In particular, Japanese efforts in low-temperature space conditioning of buildings with clathrates was noted as an area in which they have probably advanced beyond U.S. development. The research of hydrides for a wide range of temperature applications also appears to be receiving increasing attention.

Developing a comprehensive understanding of the extent and status of thermal and chemical energy storage in Japan is severely hampered by the lack of information on Japanese work available in the U.S. Because of the evidence of recent, significant work in Japan in this field and given the track record of rapid Japanese technology development in other fields, it is recommended that a study be conducted to define the major activities under way and determine the actual size of the information gap.

10.4 RESEARCHERS INTERVIEWED REGARDING JAPANESE RESEARCH IN THERMAL ENERGY STORAGE

The following researchers offered comments on this field.

Robert Copeland - Solar Energy Research Institute

Dr. Copeland's present research is based on a project on advanced, high-temperature molten-salt storage. As such, his group is addressing long-term research questions and is working on technology that will probably not be available for application until the 1990s. Dr. Copeland follows activities in Japan through information presented in journals and at conferences.

Anthony Gorski - Argonne National Laboratory

Dr. Gorski's current research includes work in seasonal ice storage technology. He primarily relies on conversations with colleagues from Japan to keep abreast of developments in his field.

Lee Radosevich - Sandia National Laboratories

Dr. Radosevich noted that Sandia is involved in developing several solar thermal storage systems, including a molten nitrate salt system and a solid particle system. Both are sensible heat systems. Dr. Radosevich follows activities in Japan through information presented in journals and international workshops on central receiver projects.

John Tomlinson - Oak Ridge National Laboratory

Dr. Tomlinson's current research includes phase-change energy storage at low temperatures. He noted that they keep track of activities as they appear and have found information in sources that include the literature, patent applications, and occasional conversations with technical people from Japan.

R. J. Petri - Institute of Gas Technology

Mr. Petri is involved in work on high-temperature phase-change thermal storage for industrial, solar thermal, electric utility load, and solar dynamic power space applications. As part of his monitoring of the field, Mr. Petri reviews Japanese patents available in English, as well as journals and conferences.

11.0 TRIBOLOGY

Although the field of tribology is less than twenty years old, research in Japan into the processes of friction, wear and lubrication has spanned many decades. Research into the wear of materials in Japan has been traced back to the late nineteenth century, when the government began to develop the national railway system. Studies were conducted on the anti-wear properties of rails and tires as well as on bearings, gears, brakes and anti-wear materials. Organization of wear research was assisted by the formation of a research committee on the mechanism of wear by the Japanese Society for the Promotion of Science in 1937, and the organization of the Japanese Society of Lubrication Engineers in 1956. Although research has been active in the country for decades, research activities have not been well known internationally, largely because important journals such as the Journal of the Japanese Society of Lubrication Engineering, the Transactions of the Japanese Society of Mechanical Engineers, the Journal of the Japanese Institute of Metals, and the Journal of Precision Engineering are all written in Japanese.

The information presented here is based primarily on interviews with the researchers are listed below:

Don Buckley	NASA-Lewis Research Center
Herb Cheng	Northwestern University
William Glaeser	Battelle-Columbus Laboratories
Robert Harmon	Consultant
Manfred Kaminsky	Argonne National Laboratory
Elmer Klaus	Pennsylvania State University
Ken Ludema	University of Michigan
Marshall Peterson	Wear Sciences
Dave Rigney	Ohio State University
Lou Sibley	Tribology Consultants
Tom Thomas	Pacific Northwest Laboratory
Don Wilcock	Mechanical Technology Inc.
Charles Yust	Oak Ridge National Laboratory

The following sections include discussions of the researchers' perceptions of notable aspects of tribology research in Japan and of the quality of technical information transfer to U.S. researchers.

11.1 NOTABLE ASPECTS OF TRIBOLOGY RESEARCH IN JAPAN

Researchers interviewed about tribology research in Japan had a wide diversity of opinions on the strengths and comparative status of research in Japan. When asked about the comparative position of research in the two countries, two very different perspectives emerged. One group suggested that Japanese researchers excelled in certain aspects, and that the overall effort was at least comparable, if not better than that in the U.S. A second group suggested that Japanese researchers are largely still trying to catch up to U.S. researchers and that there are few signs of their work threatening the competitive position of U.S. R&D. The following discussion will explore some of the bases for this seemingly large difference of opinion.

In discussing notable features of research in Japan, researchers' comments touched on 1) general aspects of the organization and structure of research, 2) specific examples of advanced capabilities, and 3) specific facilities and their capabilities for performing research. In the following discussion, the comments offered will be grouped according to these three categories. After the comments are summarized, the basis for the general difference in opinion on tribology work in Japan and the U.S. will be examined.

11.1.1 General Aspects of the Organization and Structure of Research

Research into the chemical components of tribology, referred to hereafter as chemical tribology, was identified by several researchers as a field that is better developed in Japan than in the U.S. Researchers such as Klaus, Ludema, and Cheng pointed out that tribology researchers in the U.S. have traditionally emphasized the research of the mechanical aspects of friction and wear. As a result, the U.S. has developed a very sophisticated capability in this area. However, the chemical component of tribology has not received similar attention. Chemical tribology includes the chemical component of lubrication and changes in chemistry at the lubricant-solid interface, chemical corrosion, and chemical reaction seizure. Dr. Klaus pointed out that in certain engine processes, 90% of component wear can be attributed to chemical processes and only 10% to mechanical processes. Examples of this superiority in the chemical component of tribology can already be seen in industry. Nippon Mining, which operates petroleum refineries, has had sophisticated equipment for chemical and surface analysis since the mid-1970s, equipment that U.S. companies are only now trying to procure. The high quality of automobile engines from a Japanese manufacturer, as conceded by a technical manager from a U.S. auto company, has been attributed at least partly to chemical tribology. Further, the manufacturers of some of the best diagnostic equipment, including scanning electron microscopes and scanning transmission microscopes, are Japanese.

The significance of this chemical tribology research is further enhanced by coordination with the mechanical investigations. Workers in Japan, some researchers mentioned, seem less restricted by disciplines. More cross-training in both the chemical and mechanical areas and in the use of surface science tools was noted to occur. It was further noted that Japanese research in chemical tribology is highly innovative and not just patterned after work performed elsewhere. This is quite different from Japanese research in the mechanical aspects of tribology, which is not noted for its creativity.

Researchers including Rigney, Ludema, and, in particular, Cheng have noted that another strength of the program in Japan is the depth of the manpower and the breadth of the coordination. Ludema commented that in the research of wear, understanding in the U.S. and Japan are currently comparable. He added, however, that a stronger, long-term effort is under way in Japan within university groups who are doing significant studies of wear and lubrication.

Dr. Cheng further commented that the well-known researchers at top-flight universities in Japan are very credible, and furthermore, the depth of researchers doing substantive work in tribology is also significant. Dr. Cheng noted that the well-known researchers at the top-rated universities are usually supported by a substantial staff of research associates. In addition, very good tribology research can be found at second- and third-rated schools as well. In addition, much of the work of the research associates at the top-rated schools and of researchers at the lesser-known schools is usually only published in Japanese.

A related capability perceived by many of the researchers is the strong tie between the government and industry in Japan. Cheng notes that any university tribology group lacking strong ties to industry is considered secondary. Klaus further noted that the top consultants to Toyota in tribology are Sakurai, from the Tokyo Institute of Technology, in the mechanical aspects and Soda, recently retired from the University of Tokyo, in the chemical aspects. He commented that it is not just these principal researchers who are actively involved with the industry, but also their research associates and students.

University professors in the U.S. have also noticed a recent renewal in the interest of industry employees and younger professors from Japan in studying at U.S. schools. Rigney noted in the late 1960s and early 1970s there was a strong interest in having technical people from Japan study in the U.S., but in the mid- to late-1970s this subsided for no clear reason. Within the past few years, he and his colleagues have noticed a definite resurgence in interest. Ludema remarked that he is virtually inundated with requests from prospective Japanese students, particularly young professors or mid-career technical people, to join his program.

Facility equipment also indicates the status of research. While this would seem to be an area in which consensus could be easily achieved, clear differences of opinion were again expressed. Researchers, including Cheng, Buckley, Klaus, Ludema and Rigney, noted that the facilities in Japan are generally comparable to U.S. laboratories, with perhaps more depth and in some cases greater sophistication. Yust, on the other hand, recently viewed several university facilities in Japan and noted that the laboratory equipment was generally old and gave the impression of limited financial support. These differences in opinion will be explained further in a review of facilities later in this chapter.

11.1.2 Specific Examples of Advanced Capabilities

In addition to the general characteristics mentioned above, researchers noted several aspects of the work in Japan that are considered significant. These comments identified significant technical developments, and noted the development of a sophisticated national tribology laboratory. This tribology research facility and several examples of these technical developments are described below.

National Mechanical Engineering Laboratory, Tribology Facility - Those researchers familiar with this facility agreed that it represents one of the most sophisticated tribology laboratories in the world, surpassing any facility in the U.S. Dr. Tsuya, who is in charge of the laboratory, has a staff of nine full-time researchers and their work is described as first-rate. Dr. Tsuya also has much of the latest research equipment at her disposal. For example, both Yust and Buckley noted the availability of an acoustic microscope for observing subsurface cracking. Yust noted that this facility is particularly well equipped for the study of the tribology of ceramics, in both monolithic forms and as coatings. He noted, for example, that they have developed a technique to measure the adhesion of coatings by observing the onset of cracking between pairs of indentations. Rigney noted that their work on solid lubricants is very good and feels they have generated good independent ideas on mechanisms of friction. Both Yust and Rigney commented that the laboratory is mounting a strong effort in establishing a data base.

Coating Research - Kaminsky observed that significant coatings research is under way in Japan. In particular, he noted the work in hard coatings for extreme conditions of temperature, high pressure, chemically active environments, and hot corrosive environments. The coating work is performed under a variety of programs in a variety of organizations. For example, in the private sector, Kyocera, NGK, and Toshiba are quite active in this area. In the national laboratories, the Institute for Inorganic Materials is active as well as the Institute for Metals, which is researching titanium diboride and titanium carbide coatings. The Japan Atomic Energy Research Institute (JAERI) is also researching titanium carbide and titanium nitride coatings. At the university level, there are several groups at the University of Tokyo. In addition, Professor Morozumi leads a significant effort at Tohoku University, and Dr. Yamashita, at the University of Hokkaido, has a group pursuing titanium carbide and titanium nitride coatings. Kaminsky noted that these are just examples of a substantial overall effort that he feels is further enhanced by some overall coordination. He added that some of the results of the hard coatings research can already be seen in commercial products with superior durability, such as drill bits and piston rings.

Ceramic bearings - Several researchers, including Sibley, Yust, Peterson and Buckley, have noted that a significant effort is under way in developing ceramic bearings. Sibley noted, however, that much of this work is being conducted in the private sector (e.g. Kyocera, Toshiba, etc.), and that most of the work is in the manufacturing of the bearings, with some basic research in the sintering mechanisms and some developmental work in near net-shape processing.

Lubricants and oil additives - Dr. Buckley observed that significant work is being produced in this area in Japan. This may be due to the greater overall emphasis on the chemical aspects of tribology.

Tribology modeling - Thomas commented that he has seen significant research in tribology modeling in Japan.

Gear lubrication - Wilcock noted that very interesting work has been performed in Japan in gear lubrication. In particular, Wilcock pointed to research that examines the influence of surface lay direction on wear.

Interpretation of microstructural effects in wear processes - Glaeser commented that Japanese researchers have developed a strong capability in this skill.

Machining investigations - Wilcock also noted that Japanese researchers have produced some very interesting work in machining.

11.1.3 Specific Facilities and Their Capabilities

Several researchers also offered impressions of the research being performed at specific universities and institutions. These comments are summarized here because they provide some indication of the nature of tribology research activity in Japan. It is also interesting to note that researchers' perceptions of work conducted at an institution can be quite different. In these cases, both opinions will be presented and possible reasons for the differences discussed.

Tohoku University - Cheng noted that there are several active groups at Tohoku University. One group is lead by Professor Tamai, a chemist specializing in boundary lubrication. Professor Kato leads another effort in the investigation of wear, particularly sliding wear. Rigney visited Kato recently and noted that Kato's work is of a similar scale to wear research efforts in the U.S. He pointed out that Kato emphasizes the mechanical aspects of tribology, including system dynamics, crack initiation and propagation, abrasion, fretting, debris analysis, effects of different gas pressures, and asperity contact. A third group focuses on gear lubrication. The work at Tohoku is substantial in both its scope and depth.

Tokyo Institute of Technology - Professor Sasada's work at the Institute is published internationally. He is well known to U.S. researchers for his wear investigations. Sasada and his staff act as principal tribology consultants to Toyota. Cheng noted that the significant advantage of Sasada's work is the depth of his staff. Assisting him in his work are four to five assistant professors and other doctoral students. Cheng added that Professor Okabe, a chemical engineer at the Institute, complements the wear work of Sasada through his work in surface films. Okabe also has a support staff of 13 to 15 doctoral candidates. Rigney has recently visited Sasada's laboratory to discuss wear research. He noted that Sasada has developed a good understanding of basic mechanisms for wear. Rigney noted Sasada's use of electron beam instruments for materials characterization and commented that his work is generally independent and imaginative. He thought that the facilities he viewed are comparable to U.S. facilities and noted that Sasada has very well-qualified associates and assistants on his staff. Yust also visited Sasada at the Institute and cited the emphasis on wear research and debris particle formation in particular. The laboratory, he noted, includes pin-on-disc arrangements, and a special apparatus for evaluating the effects of a magnetic field in the wear of materials. In general, however, Yust observed that the facilities appeared to be old but well maintained.

University of Tokyo, Main Campus - Cheng noted that work at the main campus tends to be more academic than at the research campus. Tribology work at both campuses, he commented, is supported with significant government funding. Principal researchers at the main campus include Professor Hori and Professor Someya. Professor Hori has provided good, although somewhat academic, studies of polymer bearings and rotodynamics. Professor Someya specializes in the research of journal bearings.

University of Tokyo, Research Campus - Cheng commented that the government provides substantial support to the tribology research at the Research Campus with more than $1 million annually. This effort was led by Professor Soda, who has an international reputation. Currently, Professor Kimura, one of Soda's students, is particularly active. The work tends to be very broad, with strengths in elastohydrodynamic lubrication (EHL), contact fatigue, and wear. Rigney described Kimura as somewhat a maverick in the field because he challenges conventional ideas. Yust also visited Kimura's laboratory and commented that these university facilities also appeared to be old, but were well maintained and functional. The principal instruments are 4-head rolling disc machines, a vacuum wear test system, and several pin-on-disc systems.

In addition to this government support, Cheng noted that there are significant ties to the industry, which supports research through activities such as purchasing equipment. He added that any group without strong industry ties is considered secondary.

Agricultural University of Tokyo - Cheng noted that the effort here is led by a relatively young professor, Professor Yamamoto, who specializes in contact fatigue and wear.

Electrocommunication College in Tokyo - Cheng commented that Professor Naruse leads a strong effort in the research of gear lubrication.

Tokyo Area - Cheng observed that about 10 industrial laboratories are also working on tribology research. The size of the staffs in these facilities range from one to five researchers. In addition, there is considerable work under way at seven to eight lesser-known colleges. As an example, Cheng recalled meeting Professor Wada from a private university in Tokyo. Through their conversation he discovered Professor Wada had read most of Cheng's papers and was performing some very good research in elastohydrodynamics. Cheng further discovered that Wada only publishes in Japanese.

Nagoya University - Several researchers described this university as a center of active tribology work. However, the details of the work are obscure, and the strength of the program could not be identified.

Kyoto University - Cheng noted that active leaders in the work at this university include Professor Mori in fluid films, lubrication and gas lubrication, and Professor Aendo in erosion and corrosion.

Osaka University - Yust recently visited the Department of Precision Engineering with Dr. Ohmae, who is well known for his tribology research. While there, he viewed projects in 1) reactive ion plating, 2) the use of field ion microscopy for studying surface defects induced by solid contact, 3) the use of a tribometer for the study of the dynamic aspects of friction testing, and 4) dry sliding studies of ceramics involving the measurement of wear and friction. Yust also commented on electron microscope facilities available on the Osaka campus. Of particular interest was the recent installation of a JEOL 400-keV electron microscope with microanalytic capability. The system will have a 1.5 A resolution and image magnification at the viewing screen of 1 million. Atom imaging microscopy is performed with the system. The system is also equipped with EDAX and EELS capability. Rigney also noted the sophisticated surface analysis capability of Ohmae's laboratory.

Hiroshima University - Cheng observed that the strength of this effort is in contact fatigue.

Kyushu University - Cheng commented that this group was led, until recently, by Professor Hirano, who has a very prestigious reputation in Japan but does not travel abroad. The effort here is perceived as being very broad, with three principal groups covering topics that include chemical considerations, surface films, and scuffing.

Active tribology research is also under way at the Government Industrial Research Institutes (GIRI) in Nagoya, Osaka, and Kyushu.

GIRI, Nagoya - At the GIRI at Nagoya, tribology research topics related to production engineering, advanced measuring techniques and high-pressure technology are being investigated. In production engineering, metal cutting and grinding processes are of particular interest. In measurement technology, a new type of dynamic wire fatigue testing device is being developed, and research is being conducted into the boronizing of steel to obtain a very hard and wear-resistant surface for use in high-temperature and high-pressure environments.

GIRI, Osaka - Yust noted that attention here is being directed to investigating mechanisms of dry sliding wear in ceramics of interest for heat engine applications. In touring the facility, Yust observed several wear test systems suitable for wear investigations, if not especially advanced or sophisticated. He also noted that the staff, who were relatively new to the field, were technically well prepared.

GIRI, Kyushu - Research is under way in developing new cutting tool materials for cutting titanium-boride based cements and high-performance grinding with super-fine grain grindstones.

In addition to this university- and government-based research, researchers pointed out that significant activity is under way in many major private sector firms, especially directed toward ceramic bearings.

This summary of technical highlights and research strengths is only intended to provide an indication of the level of tribological work under way in Japan. Conclusions must be drawn very carefully because the descriptions are necessarily qualitative. Researchers presented a very wide range of opinions based on very different levels of familiarity with work in Japan. Although those researchers who are more familiar with Japan could offer more information, this experience factor was otherwise not used to screen comments. It should be noted, however, that several researchers described this experience factor as critical. Researchers warned that the reticence of Japanese researchers can make them seem poorly informed, and that the operation of Japanese laboratories can often give the illusion of inactivity. Evaluating research in a country, several researchers suggested, cannot be done without a thorough understanding of operational and cultural factors.

11.2 QUALITY OF INFORMATION TRANSFER

In this section, literature sources and interactions among researchers in both countries are discussed.

11.2.1 Literature Sources

Only a few English language journals and magazines contain papers authored by Japanese researchers in tribology. Opportunities for U.S. researchers to interact with researchers in Japan are equally limited, with only one biennial conference and one biennial joint society meeting providing the primary grounds for interaction. While researchers agreed on these points, they did not agree on whether this limited information is nonetheless adequate.

The principal sources of written information about tribology research in Japan are the American Society of Lubrication Engineers (ASLE) Journal of Lubrication, the Japanese Society of Lubrication Engineers (JSLE) International Edition, and the journal Wear. Abstracts from the monthly JSLE journal are translated into English and published in the ASLE Journal of Lubrication. Researchers interviewed revealed that this is the most commonly used source of information on Japanese research. JSLE also publishes a quarterly international edition in English. Because this edition has only been available for a few years, it is not used very widely by researchers. Several researchers also mentioned that papers from Japan are frequently published in Wear magazine. Rigney felt that although the English publications may only represent one of every five papers published in Japan, they tend to be the better papers and thus can provide a reasonable indication of the status of research in Japan.

Having only a limited perspective of work in Japan, however, makes other researchers more uncomfortable. Ludema noted that Japanese students applying to his program at the University of Michigan are showing a larger number of publications in Japanese. He attributes this to the increasing prestige of domestic (Japanese) journals.

Klaus and Cheng also feel that U.S. researchers are only seeing the "tip of the iceberg," and Buckley pointed to the usefulness of screening and translating material in a more timely manner. The screening process is considered as important as the translating because several researchers pointed out that the review process in Japan is not as strict as it is in the U.S. As a result, many lower-quality articles seem to be mixed with the higher-quality articles. Researchers recalled that several years ago many Russian articles were translated. However, because the articles were not screened, the quality varied greatly and the need to sort through the material inhibited many researchers from using this resource.

Other publications that contain occasional information on tribology research in Japan include Tribology International, a magazine primarily containing British papers; the Journal of Tribology, the Journal of the American Ceramic Society; the Journal of Gas Turbine Society of Japan; the JSME Bulletin, which has sporadic articles on tribology; and Precision Engineering, published by the Tokyo Institute of Technology. It was also noted that related research in coatings could be found in the Journal of Thin Solid Films and the Journal of Nuclear Materials. In surface science, publications containing research in Japan include the Journal of Vacuum Science and Technology, which receives many submissions from Japan, Surface Science, Journal of Surface and Interface Analysis and the Journal of Applied Surface Science. All of these literature sources are listed in Table 11.1 and are categorized as either primary or secondary sources.

11.2.2 Interaction Among Researchers

Lack of interaction among researchers in the U.S. and Japan was identified as a major problem by most of the researchers contacted. Currently, researchers must rely on international conferences in the U.S. for the opportunity for interaction. The primary opportunities for U.S. researchers to interact with researchers from Japan are the International Conference on the Wear of Materials and the Joint ASLE-JSLE meetings listed in Table 11.2. While both are attended by prominent researchers from Japan, both occur only biennially. While most agreed that many of the more well known researchers in Japan tend to travel to the U.S., several drawbacks to relying on this mechanism were identified:

- International conferences only allow interaction with a few researchers who can arrange the travel. Many first-rate researchers in Japan can only make such visits infrequently, if at all.

TABLE 11.1. Publications Containing Information on Tribology Research in Japan

Publication	Primary	Secondary
ASLE Lubrication Journal abstracts from JSLE Journal	x	
JSLE International Edition	x	
Wear	x	
Tribology International		x
JSME Bulletin		x
Journal of the American Ceramic Society		x
Journal of the Gas Turbine Society of Japan		x
Precision Engineering		x
ASME Journal		x
Journal of Thin Films		x
Journal of Nuclear Materials		x
Surface Science		x
Journal of Vacuum Science and Technology		x
Journal of Surface and Interface Analysis		x
Journal of Applied Surface Science		x
Journal of Tribology		x

- Information on significant research is substantially enhanced by visiting the research facilities. Visits to the labs are therefore very important.
- Japanese researchers are sometimes isolated from much of the interaction at large conferences.

TABLE 11.2. Conferences and Meetings with Papers Describing Tribology Research in Japan

Conference	Primary	Secondary
International Conference on the Wear of Materials	x	
Joint ASLE-JSLE Meeting	x	
SAE Annual Congress		x

Researchers recommended a greater number of meetings in smaller groups, where introductions and information interaction occur more easily. Reducing some of the international travel restrictions for government projects was also highly recommended. It is interesting to note that several of the most prominent researchers in the U.S. had only been to Japan on very brief visits once or twice, or in some cases not at all.

11.3 SUMMARY OF PERSPECTIVES ON TRIBOLOGY RESEARCH IN JAPAN

When discussing the status of Japanese tribology research with researchers in the U.S., a very wide diversity of opinion is encountered. The differences are more marked in this field than in any of the others covered in this study. Responses vary from the assertion that the U.S. is still clearly ahead of Japan in tribology research and research capability, to the judgment that much of the tribology work is comparable, to the warning that Japan already has greater technical capability in tribology research than the U.S.

When first encountered, this variety of apparently contradictory opinions is perplexing. After all, it seems odd that established researchers who monitor international work in a single field express distinctly opposing impressions. Examining the basis for these differences reveals, however, that researchers base these opinions on different sets of limited information. Tribology is a very broad field involving research in the mechanical aspects of friction, wear and lubrication, the chemical aspects of friction, wear and lubrication, coatings, surface science, and advanced materials. One reason for the diverse opinions is that many researchers are referring only to their particular subfield. When considering all of the subfields of tribology, a picture emerges that shows that the comments of the researchers are actually consistent, and that together these observations offer a broad overview of tribology-related work in Japan.

Researchers generally agreed that articles published in English language journals and magazines indicate that U.S. research appears to be more significant than, or at least comparable with, research being conducted in Japan in the mechanical aspects of tribology. A few researchers commented that much of the work they have seen from Japan is often very similar to research previously completed in the U.S. Although the projects in Japan may be conducted more thoroughly or may examine more variables, the work is not generally noted for creativity. It is based on this evidence from English sources that several researchers assert the superiority of U.S. technical work.

However, other researchers noted that the literature in English permits only a very limited perspective of Japanese tribology research. These researchers note that 1) there are few high-quality English language journals in tribology in which the Japanese publish, 2) the articles tend to cover only the mechanical aspects of tribology, and 3) many articles are published only in Japanese language literature. Consequently, several significant aspects of the work in Japan are inadequately presented by the English literature, including 1) the greater Japanese emphasis on the chemical component of tribology, 2) developments in major subfields of tribology, such as tribological coatings and ceramic bearings, 3) the significant depth of the university research staffs in Japan, and 4) the recent commitment to studying more of the fundamentals of tribology, as witnessed by the new tribology laboratory at the National Mechanical Engineering Laboratory at Tsukuba.

Several researchers, including Klaus, Cheng, and Ludema, noted that research in the U.S. has tended to emphasize the mechanical components of tribology. They added that there is a significant chemical contribution to tribology that Japan and Russia have long recognized that has not been fully appreciated in the U.S. The chemical component generally refers to changes in the chemistry of the lubricant in the boundary layer at the solid interface. In certain engine processes, for example, the chemical component of tribology can be responsible for up to 90% of the material wear, with the mechanical component contributing only 10%. The investigation of this chemical component and the balance between chemical and mechanical work are areas in which Japanese technical capability has exceeded that of the U.S.

Kaminsky further commented that while visiting Japan on a senior research fellowship, he witnessed very significant and technically advanced research in coatings (e.g., TiBoride, TiNitride, TiCarbide). Kaminsky noted that coating research is being performed in a variety of organizations, including the Japan Atomic Energy Research Institute, universities, and private research laboratories. He further commented that there seems to be some overall coordination among the programs. Sibley commented that significant commercial activity is under way in developing ceramic bearings. This work, he noted, extends to fundamental research into the sintering and forming mechanisms. Because only a few researchers in Japan publish in the U.S., several researchers warned that we are only seeing the "tip of the iceberg."

The third aspect of Japanese research considered significant is the depth of the research capability. While U.S. researchers may be aware of the presence of established researchers at the well-known organizations and universities (e.g., national institutes, major public universities, etc.), significant work is still being accomplished at the second- and third-level universities. These researchers, it was noted, typically publish most, if not all, of their papers in Japan. One researcher felt that much of the work is intentionally published only in Japanese, thereby restricting foreign access.

A fourth point noted by several researchers is that although their general perception is that much of the past research in Japan has been empirical and perhaps lagged behind U.S. research, this situation has changed in the past year. There is evidence of a new movement toward more fundamental studies, including the investment made in the tribology facility at the National Mechanical Engineering Laboratory. Researchers, including Buckley and Yust, feel that this facility has more advanced tribology research equipment than any single U.S. facility. Buckley further noted that he has recently been asked to write an article on the U.S. approach to long-term research planning for a Japanese language journal. Results of this new emphasis, researchers noted, will not be seen in the literature for several years.

Therefore, while it is generally agreed that the English language literature indicates that U.S. research compares favorably with work in Japan, this is only a partial perspective. Significant developments have been noted in chemical tribology, tribological coatings, and ceramic bearings. The quality of tribology researchers in Japan, who publish predominantly in Japanese journals, was also cited, as well as the apparent shift toward increased fundamental studies.

As indicated earlier, a major cause of the difference in opinion about Japanese research is the incomplete system of information transfer. In the literature, most researchers must rely on Japanese researchers publishing in the U.S. or in international literature. The more significant publications include the ASLE Journal of Lubrication, Wear magazine, and the quarterly printing of the Japanese Society of Lubrication Engineering (JSLE) International Edition. The first two sources contain only occasional papers from Japan, and the third is fairly recent and yet to be widely used. ASLE also prints English abstracts of the regular JSLE journal. Researchers are restricted to these sources for access to Japanese publications, and several researchers commented that this is only a small portion of the work published in Japan. Opportunities for interaction are similarly limited, with a predominant reliance on Japanese attendance at U.S. and international conferences.

To improve information transfer, researchers recommended identifying and screening the literature published in Japanese and encouraging more frequent interaction of researchers through mechanisms such as seminars and workshops.

11.4 RESEARCHERS CONTACTED REGARDING TRIBOLOGY RESEARCH IN JAPAN

The following researchers offered comments on this field.

Don Buckley - NASA-Lewis Research Center

Dr. Buckley leads the tribology research group at NASA-Lewis, which is considered one of the primary centers for tribology research in the country. Dr. Buckley serves on the committee that reviews papers exchanged by the ASLE and the JSLE and has also made several trips to Japan.

At NASA-Lewis Dr. Buckley regularly receives visitors from Japan. Currently, three professors on sabbatical leave from Japanese universities are performing research at NASA-Lewis sponsored by National Research Council Fellowship programs. Dr. Buckley is one of the most knowledgeable U.S. researchers on tribology efforts in Japan.

Herb Cheng - Northwestern University

Dr. Cheng leads the tribology laboratory in the Department of Mechanical Engineering at Northwestern. He has recently received a planning grant from the National Science Foundation to establish a Center for Engineering Tribology. Dr. Cheng's technical speciality is elastohydrodynamics, although a variety of other fields are being researched at his lab.

Dr. Cheng spent 6 months on a research fellowship at the Tokyo Institute of Technology in 1978. As a result, he established and continues to maintain relationships with researchers at a wide variety of institutions in Japan. Dr. Cheng is one of the most knowledgeable U.S. researchers on tribology efforts in Japan.

William Glaeser - Battelle-Columbus Laboratories

Dr. Glaeser has an international reputation in the research of wear. He is an editor of Wear magazine and chaired the 1983 International Conference on the Wear of Materials. Dr. Glaeser follows work in Japan through his position as editor of Wear and receives visitors from Japan at his laboratory.

Robert Harmon - Consultant

Dr. Harmon is a private consultant who specializes in gas turbine technology developments. He attended the 1983 Gas Turbine Conference in Hakone and has toured several industrial facilities on a visit arranged by the Technology Transfer Institute.

Manfred Kaminsky - Argonne National Laboratory

Dr. Kaminsky specializes in the research of surface coatings and has been appointed technical program manager of the ECUT Tribology Program. In 1982 Dr. Kaminsky performed research in Japan as a visiting fellow on a senior research award offered by the Japanese government. During this period he was exposed to the coatings work in the government institutes, universities, and private laboratories.

Elmer Klaus - Pennsylvania State University

Dr. Klaus specializes in research of the chemical components of tribology. In 1975, Dr. Klaus was one of three non-Japanese organizers of a conference on wear in Tokyo.

Dr. Klaus maintains close relations with peers in Japan. When Professor Sakurai of the Tokyo Institute of Technology retired, he sent Dr. Klaus copies of all of his works. The tribology program at Penn State receives regular visitors from Japan. Dr. Klaus is one of the most knowledgeable researchers in the U.S. on tribology efforts in Japan.

Ken Ludema - University of Michigan

Dr. Ludema specializes in the research of wear. He is the editor and co-founder of the International Conference on Wear Materials. He regularly receives researchers from Japan on sabbatical leave and follows Japanese developments in wear and surface lubrication.

Marshall Peterson - Wear Sciences

Dr. Peterson is currently President of Wear Sciences. He was the project manager of the study on corrosion sponsored by the Office of Technology Assessment. Although he considers himself most knowledgeable on research in Russia and China, he reviews Japanese articles published in English language journals.

Dave Rigney - Ohio State University

Dr. Rigney specializes in research on materials aspects of wear. Although he considers himself more knowledgeable about work in China (he recently performed a study of wear research in China for the National Science Foundation), he has visited the Tokyo Institute of Technology, and Tohoku University in Japan to discuss wear research. Dr. Rigney follows Japanese work in English language publications such as Wear and by discussions with visiting Japanese tribologists.

Lou Sibley - Tribology Consultants

Dr. Sibley is President of Tribology Consultants. He has worked with Japanese firms that are developing ceramic bearings.

Tom Thomas - Pacific Northwest Laboratory

Dr. Thomas has an international reputation for his research in surface science. He has attended many international conferences, including the Rapidly Quenched Materials Conference in Japan in 1982, and is familiar with Japanese research involving surface science applied to tribology.

Don Wilcock - Mechanical Technology Inc.

Dr. Wilcock has an international reputation for his research in tribology. He co-authored the study Energy Conservation Through Tribology in 1978, which remains the most thorough analysis of the role of tribology in the U.S. economy. He visited Japan on a couple of occasions in the late 1970s and follows work in Japan through publications in English language journals.

Charles Yust - Oak Ridge National Laboratory

Mr. Yust specializes in the research of sliding wear. In October, 1983, Dr. Yust attended the International Symposium on Ceramic Components for Engines in Hakone and also visited several university and government tribology laboratories in Japan.

12.0 INFORMATION SERVICES

In the preceding chapters, comments on the mechanisms of information transfer indicated that researchers consider the English language literature and information flow in general to be incomplete. This view was echoed in the hearings of the House Subcommittee on Science, Technology and Research on March 6 and 7, 1984, which were described in the introduction. It was noted that only 19% of the Japanese applied science journals are available with English translations. However, several information services are available that cover various, limited elements of the Japanese literature and Japanese developments.

In the following section, various information services that report on aspects of technology development in Japan are briefly described. Types of available services range from very broad data bases containing international references, to international publications, to topically specific newsletters that focus on developments in Japan. These services are a mixture of government-sponsored and commercial ventures.

Among the broadly-based information services are NASA Scan, Current Contents, the Foreign Science and Technology Center service, and the Compendex data base of Engineering Information, Inc.. These services cover a breadth of international work in a wide range of technology areas. Other services are more topically focused and include the Chemical Abstracts Services, the Stirling Engine Newsletter, and the Current Awareness bulletins. These services also cover international developments. A small handful of services compose a third group of organizations that more specifically follow activities in Japan. These include the Biotechnology Newsservice and the Scientific Bulletin.

It is interesting to note that most of the U.S. government-sponsored activity in this area is funded through the Department of Defense (DOD). Defense-sponsored activities include the Foreign Science and Technology Center, the Current Awareness bulletins, the Scientific Bulletin, and the DOD classified Defense Technical Information Center. No significant government-sponsored services for use by the general scientific community were identified. NTIS had a minor effort under way in monitoring Japanese literature, but the program was curtailed because of funding constraints.

The information services available range from user-designed scans conducted through large data bases, to collections of conference reports and laboratory visits, to surveys of commercial activities and new technology announcements. Currently, the services specializing in Japan are of the latter two types. Although some services such as the Institute for Scientific Information's "Current Contents" does have sizable Japanese coverage, the material is not screened or translated. The lack of screening is also a barrier with the use of the Defense Technical Information Center service and the Foreign Science and Technology Center services.

The following section describes the information services identified by providing the following characteristics:

1. brief description
2. sponsoring organization
3. technical coverage
4. availability
5. cost.

Although the different services are useful to meet various specific needs, the services together still only provide U.S. research managers and the general research community with information on a fraction of the developments in Japan. Given the accelerating technological advances being made in Japan, improving the effectiveness and comprehensiveness of our information mechanisms should not be deferred much longer.

12.1 GENERAL INFORMATION SERVICES

- Biotechnology in Japan Newsservice
  Japan Pacific Associates
  441 California Avenue, Rm. 3
  Palo Alto, California 94306
  Tel: (415) 332-8441

  1. This newsservice provides a monthly issue that reviews product and program developments that affect the development of biotechnology in Japan. The service relies upon its office in Japan to monitor developments in this field.

2. Unsponsored.

3. Developments in biotechnology.

4. By subscription.

5. $215 per annum.

- Chemical Abstracts Services
  P.O. Box 3012
  Columbus, Ohio
  Tel: (614) 421-3600

1. This is the largest chemical information abstracting firm in the world outside the Soviet Union. They abstract from all of the major chemical journals published worldwide, including Japanese industrial information.

2. This is a nonprofit, self-supporting entity of the American Chemical Society.

3. All chemistry-related data.

4. By subscription. "Chemical Abstracts" is only one of the publications this organization distributes. It is published weekly, and includes some 8,000 to 9,000 citations annually.

5. "Chemical Abstracts" costs $7,500 per annum.

- Current Awareness Bulletin
  Metals & Ceramics Information Center
  P.O. Box 8128
  Columbus, Ohio

1. Currently, there are approximately 20 Information Analysis Centers dedicated to specific technical fields. Their mission is to collect, review, analyze, summarize, and store available information on highly specialized technical areas of concern. The synthesized information is then disseminated through Current Awareness bulletins, addressing such fields as metals & ceramics or manufacturing technology.

The Current Awareness newsletters are intended to keep the Centers' users appraised of the latest and most significant technological developments within the Center's field of interest.

2. Sponsored by the Defense Logistics Agency and the Defense Technical Information Center.

3. Information collected covers a variety of topics related to the Center's field of interest.

4. Cost varies depending upon the service requested.

- Current Contents
  Institute for Scientific Information
  3501 Market Street
  University City Science Center
  Philadelphia, Pennsylvania 19104

1. There are seven reports in the Current Contents series that list the Table of Contents from 6,300 journals. Of particular interest are the two series entitled "Engineering, Technology and Applied Sciences," and "Physical, Chemical, and Earth Sciences." Coverage does include selected Japanese journals.

2. Unsponsored.

3. Each journal covered by Current Contents is selected as one of the most important in its field. Journals are selected by an editorial review board.

4. Current Contents is a weekly publication.

5. The cost is $270 per annual subscription.

- Defense Technical Information Center (DTIC)
  Defense Logistics Agency
  Cameron Station
  Alexandria, Virginia 22314

1. DTIC is a component of the Department of Defense (DOD) scientific and technological program. It has an extensive data base that includes all the technical reports developed under DOD sponsorship. Products include 1) the "Technical Abstract

Bulletin," 2) a bi-weekly classified publication listing the research and development covered by DTIC, and 3) bibliographies in areas of interest.

2. Sponsored by the DOD.

3. Information collected addresses a myriad of topics.

4. The disseminated information consists of bi-weekly reports to subscribers and bibliographies generated in response to specific requests.

5. The cost varies depending upon the service.

- Engineering Information, Inc.
  345 East 47th Street
  New York, New York 10017
  Tel: (212) 705-7600

1. Engineering Information, Inc. (Ei) is a private, not-for-profit organization directed toward serving the information needs of engineering and related professions worldwide. It publishes the Engineering Index Annual, The Engineering Index Monthly, COMPENDEX, and Ei Engineering Meetings.

2. Unsponsored.

3. During 1982-83 Ei selectively indexed and abstracted approximately 8500 papers from 130 Japanese engineering periodicals. In 1982 and 1983 the Ei Engineering Meetings data base included approximately 1600 papers published in Japanese conference proceedings. Ei is currently proposing a Japanese Awareness Service that would provide access to information published in over 1000 important technical periodicals in Japan.

4. Information searches are issued in periodicals as well as individually.

5. Cost varies with service.

- Foreign Science & Technology Center
  220 7th Street, N.E.
  Charlottesville, Virginia 22901
  Tel: (804) 296-5171

1. Includes any topics of Army interest, except for information on missiles and medicine. Technologies related to this survey include coal gasification, solar power, alternate energy sources, batteries, combustion, etc.

2. Sponsored by the DOD.

3. Information collected addresses a myriad of topics. Available unclassified data consists primarily of translated material from foreign languages, including Japanese.

4. Recipients must be on registered list to receive material.

5. No cost involved if recipient is under government contract.

- Martini Engineering
  2303 Harris
  Richland, Washington 99352
  Tel: (509) 375-0115

1. Martini Engineering's president, Mr. W. R. Martini, publishes the Stirling Engine Newsletter, a quarterly publication devoted to new developments in Stirling engine technology. This information relates to the information developed on advanced heat engines.

2. By subscription only.

3. Relevant information on new developments in Stirling engine technology.

4. By subscription.

5. $25 per annum.

- NASA STI Facility
  P. O. Box 8757
  BWI Airport, Maryland 21240
  Tel: (301) 621-0153

1. The technologies covered in NASA STI's publication, NASA Scan, include 186 topics. The publication covers all technologies related to this statement of work.

2. Unsponsored.

3. Information collected includes a myriad of topics, all of which are related to NASA's overall mission.

4. Recipients must be registered with NASA STI as legitimate research organizations.

5. There is no charge for this publication.

- Scientific Bulletin
  Department of the Navy
  Office of Naval Research (ONR)
  Liaison Office, Far East
  APO San Francisco, 96503

1. The Scientific Bulletin is a quarterly publication presenting articles covering recent developments in Far Eastern scientific research, with an emphasis on Japan. The articles are written primarily by members of the staff of ONR Far East. Occasionally, a regional scientist is invited to submit an article covering his own work, if it is considered of special interest. The technologies covered address a wide spectrum of areas, with high technology emphasized.

2. The sponsor is the Office of Naval Research.

3. The information collected covers a myriad of topics, from the New Ceramics Fair to translation of State Department reports on Japanese high-technology strategy.

4. The information is disseminated through a quarterly journal.

5. There is no charge for this publication.

REFERENCES

Fuchida, K. et al. 1982. "Sodium Sulfur Battery Program in Japan." Presented at the 17th Intersociety Energy Conversion Engineering Conference, August 8-12, 1982, Los Angeles, California.

Hane, G. J., et al. 1985. Long-Term Research in Japan: Amorphous Metals, Metal Oxide Varistors, High-Power Semiconductors and Superconducting Generators. PNL-5376, Pacific Northwest Laboratory, Richland, Washington.

Hasatani, M. and H. Matsuda. 1983. Thermal Storage: Japanese Research. Nagoya University, Nagoya, Japan.

Japan Economic Institute (JEI). February 24, 1984. "Biotechnology in Japan," JEI Report. No. 8A, Japan Economic Institute, Washington, D.C.

Kenney, G. B. and H. K. Bowen. 1983. "High Tech Ceramics in Japan: Current and Future Markets." Ceramic Bulletin. 62(5).

National Research Council. 1984. High Technology Ceramics in Japan. National Materials Advisory Board, National Research Council, Washington, D.C.

National Science Foundation. 1983. Science Indicators-1982. National Science Foundation, Washington, D.C.

Norman, C. "American Dominates Biotechnology." Science, February 3, 1984.

Office of Technology Assessment (OTA). 1984. Commercial Biotechnology - An International Analysis. U.S. Government Printing Office, Washington, D.C.

Peck, M. J. and S. Tamura. 1976. Asia's New Giant. The Brookings Institution, Washington, D.C.

Science and Technology in Japan (STJ). 1983. "High-Performance Fine Ceramics in Japan." 2(8).

APPENDIX

RESEARCHERS INTERVIEWED

APPENDIX

RESEARCHERS INTERVIEWED

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