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IRM National Reference Series: Japan

An Evaluation of Government-Sponsored Energy Conservation Research and Development

C. D. Howard

July 1987

Prepared for
the U.S. Department of Energy
Conservation and Renewable Energy
Office of Energy Utilization Research
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
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PREFACE

This document is the first of a series of reports on energy conservation research and development activities in specific foreign countries. Prepared for the Office of Energy Utilization Research (EUR) in the U.S. Department of Energy (DOE), each report will outline the major forces shaping research in energy conservation, the leading organizations and research programs, funding levels, and a brief summary of the technical focus of key technologies. Each report will be accompanied by tables and figures highlighting key points. Certain tables may feature more detail than some readers need but are included in order to make the study a comprehensive starting point for more detailed analyses or for contacts between the two countries.

Japan represents a logical starting point for this series because of the breadth and depth of energy conservation research sponsored by the Japanese government. The technologies and programs covered in this report have been selected because they are either central to Japan's energy conservation efforts or closely related to energy conservation research and development sponsored by the U.S. government. A greater awareness of Japanese research in this area has tremendous potential to assist researchers, program managers, and policy makers in directing energy conservation research in the United States.

The recent major changes in the value of the yen relative to the dollar have made converting currencies a delicate task. This report presents data as they appear in the original source material: in yen, in U.S. dollars, or in both yen and U.S. dollars. The only conversions from one currency to the other appear in the tables, and there the assumed exchange rate is defined.

This series of reports is part of a larger effort by EUR to monitor foreign energy conservation research and development. The EUR supports the objectives of DOE in general and the DOE Conservation Program in particular through research and development in generic areas which underpin energy end-use sector technologies. In addition, EUR has lead responsibility within the Conservation Program for monitoring and evaluating the current status and future direction of energy conservation research in foreign countries. These objectives are accomplished through the International Research Monitoring (IRM) Program, established in 1985.

The IRM Program aids EUR and the entire Conservation Program in planning and managing their research programs. The results of the IRM Program will make it possible for program plans from the Conservation Program to be more cost-effective, because the amount of unnecessary or redundant research will be reduced, and to have a stronger technical foundation from the use of foreign research results. These benefits are expected to support primarily EUR goals and objectives. However, important side benefits are also likely to occur. For example, in the process of gathering information under the IRM Program, research results and related findings are expected to emerge that would be valuable for other DOE programs and technologies. Much of this information would likewise be useful for various industries as one means of improving their productivity and international competitiveness. Therefore, from a national perspective, the side benefits of the RIM Program will add significance to the research beyond the basic rationale of enhancing efficient energy conversion and utilization.

The IRM Program is conducted from the Pacific Northwest Laboratory (PNL), which is operated for the U.S. Department of Energy by the Battelle Memorial Institute.

SUMMARY

The purpose of this report is to provide an overview of government-sponsored energy conservation research in Japan. This report does not claim to provide a definitive analysis of the content and direction of energy conservation research in Japan. Rather, it forms a starting point for more detailed analyses of the key organizational and technical issues raised here. One obvious candidate for future investigation would be a fuller description of energy conservation research performed by the private sector without government support. Private sector efforts are mentioned in this study only as they pertain to government-sponsored research programs.

One important finding of this report is that despite the recent drop in world oil prices, the Japanese government is continuing to stress energy conservation. Because Japan relies on imports for 85% of its total energy requirements and virtually 100% of its petroleum, energy conservation is a high national priority. Total primary energy requirements per unit of gross national product (GNP) declined by 30% between 1973 and 1984. This decline accompanied an average annual real growth in GNP of almost 4%. Improvements in energy efficiency in Japan have apparently resulted more from conservation measures than from structural changes to the Japanese economy. The Japanese government will continue to promote energy conservation because of an anticipated tightening of world oil markets in the 1990s; the economic benefits of efficient, low-cost industries; and its positive effects on the environment.

An important difference between energy conservation research in Japan and the United States is the set of forces driving each effort. Japan stresses long-term developments and sees conservation as an integral part of its 50- to 100-year transition from fossil fuels to nuclear and renewable sources of energy. In addition, the Japanese government is targeting new materials, biotechnology, and electronics technologies as the foundation of Japan's economy in the 21st century. The choice of these technologies reflects Japan's reliance upon human resources and relative lack of mineral and energy resources. Success in developing these technologies depends considerably on Japan's ability to improve its basic research capabilities. Basic research is now a

frequent theme in government research and development (R&D) policy statements, and there is clear evidence of increased attention to this issue in both the public and private sectors.

Notwithstanding the recent emphasis on basic research, most government research programs in Japan are governed by aggressive timetables and fixed technical goals. They are usually guaranteed funding over a 5- to 10-year period. Consensus on goals is a hallmark of Japanese research; less well known is the degree of organizational competition that occurs. In some instances ministries contend with one another for leadership in researching an important technology, with overlap occurring most frequently at the level of feasibility studies.

Unlike the United States, Japan does not have a Department of Energy or network of national laboratories devoted specifically to energy research. Instead, several Japanese government organizations sponsor research programs which are related to energy conservation, but whose overriding goals are to improve industrial competitiveness and reduce dependence on imported oil. Of the major energy conservation research programs, the best known is the Moonlight Project, administered by the Ministry of International Trade and Industry (MITI). The Moonlight Project research tends to be oriented towards end-use technologies such as Stirling engines and advanced heat pumps. Parts of MITI's Basic Technologies for Future Industries Program involve research in new materials and bioreactors similar to programs in the U. S. Department of Energy's (DOE) Conservation Program. The Science and Technology Agency's Exploratory Research in Advanced Technologies (ERATO) Program is also investigating these technologies while emphasizing basic research. Other ministries supporting research related to energy conservation are the Ministry of Education, Science, and Culture and the Ministry of Construction.

Another important finding of this study is that the level of funding for energy conservation research in Japan is relatively high. For 1985, detailed program data published by the Japanese government indicate that government spending for energy conservation research was at least $50 million. Private sector funding of energy conservation research was approximately $500 million in 1984, according to the most recent government statistics. Nevertheless, because other estimates of Japanese spending on energy conservation R&D (based on different assumptions), differ from estimates provided in this report, the reader is encouraged to exercise caution when using such figures.

A brief outline of major programs and key participants is included for several of the most relevant technologies as a means of acquainting the reader with the scope of research currently underway. These technologies have been selected for their similarity to energy conservation research programs funded by the DOE.

It is hoped that the information contained in this report may facilitate a more comprehensive understanding of energy conservation research in Japan. An overview of Japan's experience in international scientific collaboration is also included. Since World War II, Japan has expanded its participation in cooperative research with other nations. Japan is now an important member of several International Energy Agency cooperative research programs in energy conservation and is the leading source of conservation-related technologies for the countries of Southeast Asia. Japan and the United States have collaborated successfully in many scientific fields. This history of collaboration should be borne in mind as future cooperative projects are pursued.

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I would like to thank Marvin E. Gunn, Jr. of the Office of Energy Utilization Research for his support and commitment to this program. From his research in Japan, Gerald Hane provided numerous primary source documents without which the project would not have been possible. Sean McDonald, Gerald Hane, and especially Justin Bloom provided valuable comments and suggestions; nevertheless, they cannot be held responsible for whatever flaws still remain. Finally, I would like to thank Dr. W. Bradford Ashton for his managerial support of this effort.

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FIGURES

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ACRONYMS

AIST - Agency of Industrial Science and Technology
ANRE - Agency of Natural Resources and Energy
CST - Council for Science and Technology
CY - calendar year
DOE - U.S. Department of Energy
EHD - electrohydrodynamic heat exchanger
ERATO - Exploratory Research in Advanced Technology
ETL - Electrotechnical Laboratory
EUR - Office of Energy Utilization Research
EUTWP - End Use Technology Working Party (IEA)
GIRI - Government Industrial Research Institute
GNP - gross national product
IC - integrated circuits
IEA - International Energy Agency
IRM - International Research Monitoring (Program)
ITIT - Institute for Transfer of Industrial Technology
JFY - Japanese fiscal year
JICST - Japan Information Center for Science and Technology
JOIS - JICST Online Information System
JRDC - Research Development Corporation of Japan
JSC - Science Council of Japan
JSPS - Japan Society for the Promotion of Science
LNG - liquid natural gas
MAFF - Ministry of Agriculture, Forestry, and Fisheries
MEL - Mechanical Engineering Laboratory
MESC - Ministry of Science, Education, and Culture
MHD - magnetohydrodynamic
MITI - Ministry of International Trade and Technology
MOC - Ministry of Construction
NEDO - New Energy Development Organization
NIST - National Information System for Science and Technology
PNL - Pacific Northwest Laboratory

R&D - research and development
RIKEN - Institute of Physical and Chemical Research
STA - Science and Technology Agency
Toyota CRDL - Toyota Central Research and Development Laboratories

1.0 BACKGROUND

Fundamentally, energy conservation research and development is conducted much differently in Japan than in the United States. The technical approaches to a given technology sometimes differ, as do the underlying assumptions, organizational structure, and definition of "conservation technologies." In order to appreciate how Japan views energy conservation, it will be necessary in places to examine how this research fits in the context of national priorities in science and technology. The result should be both a better understanding of the state of Japanese conservation research and development (R&D) and an appreciation of the factors helping to shape its future course.

Considering the importance of context, it would be helpful to provide some history of research in Japan, with emphasis on developments in energy conservation. Many of the most important research facilities in Japan were destroyed during World War II and had to be rebuilt. Immediate problems of food production, disease prevention, and runaway inflation dominated the Japanese research agenda through the 1950s. As a result, the major advances came in increasing crop yields, improving fertilizers, creating new strains of rice, and developing pharmaceuticals. The government enacted laws to ease the introduction of foreign technologies, and the process of quality control was introduced from the United States (U.S. Congress 1981).

Increasing affluence spurred consumer demand in durable goods and an expansion of the national transportation and communication systems during the 1960s. Products such as washing machines and "bullet" trains required iron and steel; as Japan increased its production capacity, it introduced the most advanced technologies into its mills. This experience with materials soon spilled over to synthetic fabrics and plastics. The other family of technologies developed during this period was electronics, from the mass production of transistors to the coaxial cable system. Private industry performed the vast majority of research and development, emphasizing only those technologies with clear market potential. The Japanese government gradually began to sponsor large-scale R&D programs, but these were likewise intended to produce commercial technologies for industry.

Just as Japan's technological prowess has important historical roots, so too does its current research in energy conservation. Like other industrialized nations, much of Japan's experience in conservation begins with the 1973-74 oil embargo. There was one notable exception, the Heat Control Law of 1951. In the process of rebuilding after World War II, Japan recognized the importance of using energy efficiently, especially coal, its primary indigenous fossil fuel. The major provision of the Law required all industrial plants consuming the energy equivalent of 1000 tons of coal per year or more to hire personnel specially trained in energy management (U.S. Congress 1981).

Japanese reaction to the oil embargo was swift and effective. In 1974 the Prime Minister created the Agency of Natural Resources and Energy (ANRE) to assure a stable supply of energy and promote energy conservation measures. The ANRE did not and does not support research in energy conservation. At the time of the embargo, ANRE took administrative steps such as closing gas stations on Sundays, curtailing use of neon lights, restricting elevator use, limiting automobile use and speeding, and programming a partial reduction in lighting. These measures reduced demand for energy substantially. When combined with heavy government borrowing of money, these demand management measures helped to mitigate, but not prevent, the ensuing economic recession.

During the late 1970s, the Japanese government became increasingly active in promoting energy conservation. In 1978 it enacted the Energy Conservation Law which essentially superseded the old Heat Control Law. This new law applied to all sectors, not just industry, and set forth standards and guidelines for conservation. For instance, in the case of plants that failed to take the necessary steps, the Law empowered officials to conduct on-the-spot inspections and order submission of reports on energy usage. The Law placed added emphasis on small- and medium-sized businesses, a sector thought to be generally energy inefficient (U.S. Congress 1981).

In addition to these measures the government initiated two important research programs: the Sunshine Project and the Moonlight Project. The Sunshine Project, started in 1974, is primarily aimed at developing alternative fuel sources such as solar, geothermal, hydrogen, and coal gasification and liquefaction. While most of the work more closely parallels U.S. research in renewable energy, some segments of the Sunshine Project touch on conservation. These segments will be discussed where applicable (AIST 1985).

The Moonlight Project, conceived in 1978, is the key government R&D program in energy conservation. The Moonlight Project is not a single project but a collection of Large-Scale Projects for Energy Conservation, smaller basic research projects, and some business assistance programs. The Project derives its name from the intent that even a tiny gleam of light will be used effectively. It is administered by the Agency of Industrial Science and Technology (AIST), which is part of the Ministry of International Trade and Industry (MITI).

Originally the Moonlight Project covered both basic research and programs geared towards developing specific technologies. Early topics in basic research included superconductivity, new batteries, new power sources, and heat-related phenomena. Although the Moonlight Project still includes some basic research, over 90% of the work is oriented towards applications (AIST 1982b; AIST 1984; AIST 1986).

The first Large-Scale Projects for Energy Conservation were the development of a waste heat utilization system and research into magnetohydrodynamic (MHD) power generation. Since then programs have been added in advanced gas turbines, advanced battery storage systems, fuel cells, Stirling engines, and heat pumps. Every project area except waste heat utilization and MHD power generation is currently active and will be described in more detail in the following sections.

Waste heat utilization, a 5-year project funded at approximately 4 billion yen, concentrated on creating components and systems for the recovery, exchange, transport, and storage of waste heat. From it came development of absorption heat pumps, computer models, and numerous patents. The MHD project, which received about 5 billion yen from 1976 to 1983,[a] culminated in the construction of the Mark VII experimental plant, with a power output of 100 kW (AIST 1984).

(a) The MHD research began before the Moonlight Project and was subsequently incorporated into it.

The Moonlight Project is the most visible program that is devoted to energy conservation research in Japan, but it is certainly not the only such program. The 1973-74 oil embargo and Japan's desire to become a major industrial power have created a national push aimed at a whole range of technologies that use energy more efficiently or use forms of energy other than petroleum. Government, academic, and industrial researchers have all devoted significant resources towards energy conservation in the last 10 to 15 years. Besides those projects already mentioned, research efforts have intensified in advanced materials, tribology, biocatalysis, and other fields paralleling DOE conservation research programs.

Such an accelerated rate of technological development could not have occurred without the commitment of organizations and individuals throughout the nation over an extended period of time. The overall structure of government-sponsored conservation R&D in Japan--the key institutions, researchers, and guiding policies--as well as the scientific approach, achievements, and obstacles characteristic of specific technical areas, is the major topic of this study. After reading this report, the reader should have a better sense of the state of Japanese R&D in energy conservation and the tools with which to estimate its future course.

Yet before examining the structure and scientific focus of this R&D, it is absolutely crucial to understand the forces shaping these efforts. Consensus, a hallmark of Japanese society, has been reached regarding fundamental questions of energy supply, Japan's role in the world economy, the country's natural and human resources, and the best way to conduct R&D. An understanding of these factors, an attempt to see the world as the Japanese do, will significantly improve the ability of U.S. researchers and policy makers to estimate the future direction of energy conservation R&D in Japan.

2.0 KEY FORCES SHAPING ENERGY CONSERVATION RESEARCH AND DEVELOPMENT

Many of the problems that are spurring energy conservation research in Japan are shared by the United States and other industrialized nations. Dwindling supplies of liquid fossil fuels and a shift towards high technology and service industries largely determine how Japan and the United States view future energy needs and the role of conservation.

Japan's relatively less abundant natural resources necessarily lead to a course that differs somewhat from the one taken in the United States. However, some aspects of the Japanese response could be appropriate for the United States because of some similarities in economic structure, level of technological sophistication, and direction of research programs related to energy conservation. A broader knowledge of Japanese programs could bring tangible benefits to U.S. programs and policies. The key factors shaping energy conservation R&D in Japan are summarized briefly below.

2.1 HOW THE JAPANESE VIEW ENERGY SUPPLY

Japanese policy makers view the present as an era of transition from petroleum to solar and nuclear energy. Figure A.1, taken from an official publication of the Moonlight Project, illustrates this perspective.

Energy conservation is a crucial link between energy eras and is intended to play a major role in Japanese energy policy from roughly 1970 to 2050. By the middle of the 21st century, the importance of conservation will diminish as an age of almost limitless energy supply begins. The development of solar, nuclear fission, and nuclear fusion technologies is seen as paramount and is being accelerated in Japan because of the long lead time to commercialization (AIST 1984).

2.2 THE NATURAL AND HUMAN RESOURCES OF JAPAN

Natural and human resources are major determinants of how Japan views its future energy supply and economic destiny. Japan relies on imports for about

85% of its total energy requirements and virtually 100% of its petroleum. Production of coal, the country's primary indigenous fossil fuel, has declined consistently over the last 10 years. Given its limited energy resources, the Japanese are understandably committed to improving the energy yield of coal, developing renewable energy sources, and encouraging energy conservation (Anderson 1984; Choy 1985).

Table A.1 indicates Japan's current energy supply picture and suggests possible trends for the future. Energy conservation is expected to play an increasingly important role in the future. The energy required per unit of industrial output is expected to decline 15% during the 1980s and approximately 25% during the 1990s (from both structural changes in the economy and efficiency improvements). In keeping with this emphasis on decreased energy dependence, energy conservation research is focusing on developing technologies with fuel flexibility, e.g., heat pumps and Stirling engines (Anderson 1984; Choy 1985).

Similar constraints exist with other natural resources. Of particular relevance to energy conservation technologies is Japan's relative lack of rare and precious minerals. As a result, the Japanese emphasize applying sophisticated technologies to common elements such as carbon, silicon, and nitrogen. Ceramics technology is a clear example of this approach.

Japan's human resources compensate for the lack of natural resources. The middle class is large and highly skilled, with the highest literacy rate in the world. The country's education system places heavy emphasis on mathematics and the sciences. Japan graduates twice as many engineers per capita as the United States and annually sends thousands of students to the United States for postgraduate education in engineering and the sciences. These factors and the intense competition of the domestic economy have been major determinants of Japan's advances in technology and economic growth (NSF 1985; Anderson 1984).[a]

2.3 THE IMPORTANCE OF ENERGY CONSERVATION

Japan's energy conservation efforts have produced impressive results since the 1973-74 oil embargo. Total primary energy requirements per unit of GNP have declined by 30% between 1973 and 1984. This decline accompanied an average annual real growth in the gross national product (GNP) of almost 4%. As with the United States, part of this increase in energy efficiency can be explained by structural changes in the economy away from energy-intensive industries. A recent Japanese study of energy consumption changes in industry during the period from 1979 to 1984 indicates, however, that energy conservation measures have been more important than these structural changes (Keizai Koho Center 1986; Energy Conservation Center 1986).

Government support for energy conservation comes in many forms. Besides research programs and financial incentives, the Japanese government recognizes the importance of energy conservation through information and publicity activities. February, the coldest month of the year, is "Energy Conservation Month." The first day of each month is "Energy Conservation Day" and the first day of December is "General Check-Up Day for Energy Conservation." Though symbolic in function, these measures serve to keep energy conservation in the public eye throughout the year.

Despite the recent drop in world oil prices, the Japanese government is continuing to stress energy conservation. According to a recent summary of government policy, "...the present relaxation in oil markets results from

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(a) It is important to remember, however, the majority of Japanese workers are not employed for life in large, technologically advanced companies. Ten percent of the labor force owns and controls the nation's wealth; 30% constitute the "labor aristocracy" who enjoy job security, good wages, and company health insurance; and the remaining 60% work for small- or medium-size companies, or work only part-time. This latter group is not guaranteed lifetime employment, receives lower wages, and often finds health care inadequate. In many ways this group makes the success of larger firms possible, particularly by performing subcontract work at low rates.

energy conservation efforts and the development and application of alternative energy..." (Energy Conservation Center 1986, p. 24). Besides its past success in helping to reduce demand and lower oil prices, conservation is being emphasized because of an anticipated tightening of world oil markets in the 1990s; the economic benefits of high-efficiency, low-cost industries; and its positive impact on the environment (Energy Conservation Center 1986).

2.4 THE ROLE OF TECHNOLOGY IN THE JAPANESE ECONOMY

Just as Japan believes itself to be at a turning point in the evolution of energy, it also views the 1980s as the beginning of another technological revolution. According to MITI Vice-Minister Konaga, "If you look at history, you can see that a new technological revolution occurs every 50 to 60 years. We think that the 1980s is the time to nurture the buds of technologies that will blossom in the 21st century. In particular, the technologies in question are electronics, biotechnology, and new materials." (Bell, Johnstone, and Nakaki 1985, p. 32). The shift from basic manufacturing to high technology is captured in the Japanese phrase "*ju-ko-cho-dai kara dei-haka-tan-sho made*," which translates as "from heavy-thick-long-large to light-thin-short-small" (Bell, Johnstone, and Nakaki 1985, p. 33).

Japan's willingness to concentrate heavily on advanced technology comes from its previous reliance upon technology as the engine of postwar economic growth and prosperity. Table A.2 shows how significant these contributions have been (Ishizaka 1983).

At the same time, Japan's new industrial competitors in Southeast Asia are accelerating Japan's shift to high-technology industries as they capture many of the basic manufacturing industries, such as steel, once controlled by Japan.

The United States is entering many of the same markets, but is not anticipating a future economy based as heavily on advanced technologies as Japan. The greater abundance of natural resources, the large agricultural sector, and the commitment to preserve certain industries in the name of national security or economic self-sufficiency in the United States help to explain this difference.

2.5 TIME FRAME

One striking feature evident in Figure A.1 is the extent to which the Japanese make plans and commitments for the future. Although it is not unusual for economists and policy makers to develop models that "predict" events decades away, in Japan government research projects are planned and funded much further into the future than is customary in the United States. Large-Scale Projects in the Moonlight Project usually have plans and funding for 5 to 10 years, and funding is guaranteed, although levels vary from year to year (AIST 1984).

Large commitments are not made easily; research projects typically pass through two preliminary stages before they are considered as major projects. If a technology is likely to have wide application and support from industry, the project is undertaken (Anderson 1984). This commitment to specific long-range research programs in energy conservation has no parallel in the United States. However, several western European countries have moved towards multi-year funding commitments.

2.6 THE IMPORTANCE OF BASIC RESEARCH

One of the chief criticisms of Japanese research is that it rests on a foundation of creative, basic research performed elsewhere, primarily in the United States. This criticism is valid for the period from World War II through the early 1970s. If one looks at the balance of trade in patent license payments, one will observe that Japan paid almost 12 billion yen to other countries in 1955 and took in only 0.1 billion yen. In 1984 patent payments still exceeded receipts (though barely) by 281 billion to 278 billion yen.

This statistic is misleading, however, because these payments tend to reflect breakthroughs made years earlier. For new patent payments only, Japan's receipts exceeded payments starting in 1972. Even more than the balance of trade between the United States and Japan, this balance of patent payments indicates the vitality of Japan's technological and economic infrastructure (Management and Coordination Agency 1985; Shishido 1983).

Nevertheless, if Japan is to advance it must become proficient in basic research, and the Japanese government and business community realize this. Private industries, led primarily by electronics firms such as Hitachi, Sanyo, Matsushita, and NEC are building laboratories dedicated to basic research. NEC's laboratory is especially noteworthy: since it opened in 1982 the staff has grown to 70 scientists and the budget for the 1984 Japanese fiscal year[a] (JFY 1984) was $7.8 million (Bell, Johnstone, and Nakaki 1985).

It is interesting to observe that the Japanese government seems to be lagging behind private industry in emphasizing basic research. In 1984, the Science and Technology White Paper, which is the government's annual policy statement, stressed the need for more basic research and acknowledged the initiatives taken by companies. How this new emphasis on basic research will translate into specific research programs is unclear. One basic constraint is the budget: a mounting national debt, equaling more than 50% of Japan's GNP in 1984 (see Table C.1), is placing increased pressure on research programs to show tangible results in the near term. Furthermore, the Japanese must continue to seek ways to apply the results of the basic research conducted at the national universities and laboratories (Chiba 1985).

2.7 HOW RESEARCH IS CONDUCTED

One important barrier to conducting basic research in Japan is the traditional organization of government research programs. Small teams of researchers, committed to consensus and driven by rigid deadlines and specific technical objectives, are not conducive to fundamental scientific research.

The Japanese government is starting to address this problem. In a dramatic departure from past practices, Japan's Science and Technology Agency (STA) is funding eight "blue sky" research projects known collectively as the Exploratory Research in Advanced Technologies (ERATO) project. So far, ERATO has been a pilot program that receives only a small fraction of the STA budget. Each research team is headed by and named after a distinguished scientist; each

(a) The JFY runs from April to March. Thus, JFY 1984 began in April 1984 and ended in March 1985.

has a loosely defined starting point rather than specific objectives. Project leaders are allowed to recruit their own teams and are encouraged to invite foreign researchers. Each project has a 5-year mission. Although ERATO is more highly structured than comparable U.S. programs, it represents a definite break with Japanese tradition (Bell, Johnstone, and Nakaki 1985; STA 1985).

Parallel changes in private industry can also be observed. NGK Spark Plugs, a leader in fine ceramics research, has recently begun appointing the most capable scientists as project leaders, regardless of age. The status of these "key persons," as they are called, directly contradicts the traditional system by which the most senior scientists automatically become project managers (Bell, Johnstone, and Nakaki 1985).

2.8 CONCLUSION

One of the great barriers to understanding the present shape and future course of Japanese technology is the significant change that is currently underway. The Age of Petroleum is giving way to a long transition period in which energy conservation is vital. Newly industrialized countries are capturing parts of the same basic manufacturing industries that Japan captured from the United States during the 1960s and 1970s. New research topics are being explored and new modes of organization developed. Japanese scientists and policy makers realize that change is needed in order to maintain the nation's rate of technological development and economic growth.

These changes are not difficult to track. The Japanese are explicit about future plans; the frequent statement of objectives is necessary to develop a public consensus. An understanding of where Japan is headed, supplemented by an awareness of the factors that define that direction, will enable United States researchers and policy makers to follow Japan as it charts new scientific and technological waters, and not some years after.

3.0 MAJOR ORGANIZATIONS AND PROGRAMS

Unlike the United States, Japan has no Department of Energy and no network of national laboratories specifically devoted to energy research. Instead, research is supported by several Japanese government organizations that are striving to improve industrial competitiveness and reduce dependence on imported oil. Because these goals are relatively stable over the long term, government R&D programs that conserve energy can therefore be guaranteed funding over long periods of time.

Given the remarkable degree of consensus on research priorities in Japan, it would seem logical to assume that the organizations responsible for implementing Japanese energy conservation policy would be highly centralized with discrete areas of authority and separate R&D projects. In fact, conservation research is sponsored by several government ministries who sometimes compete with one another for the most promising programs; duplication in funding of feasibility studies is not uncommon. Both the number of organizations and the degree of competition among them may be unfamiliar to researchers in the United States.

One of the primary objectives of this study is to identify the key players in government-sponsored conservation research in Japan--their overall objectives, major programs, and principal investigators. The major organizations concerned with energy conservation, as shown in Figure B.1, will be described one by one, starting at the highest policy level and will include specific institutes and universities.

Numerous private organizations also engage in energy conservation research. This research is usually geared towards improving productivity and economic competitiveness. This study includes research conducted in the private sector when it is done in conjunction with government research programs.

3.1 THE COUNCIL FOR SCIENCE AND TECHNOLOGY

The Council for Science and Technology (CST), established in 1959, appears to be the highest-ranking body for determining national science and technology policy. In fact its primary function is to promote policies and research programs established by STA. The CST is chaired by the Prime Minister and includes

- the Minister of Finance
- the Minister of State for Science and Technology
- the president of the Science Council of Japan
- five members with expertise in science and technology who are appointed by the Prime Minister
- other ministers chosen at the discretion of the Prime Minister.

Under the CST are panels concerning general affairs, research objectives, life sciences, energy sciences, promotion, and liaison with the Science Council of Japan. Each panel is chaired by a member of the CST, and includes other members of the Council as well as 30 to 40 specialists in the field. The CST meets three or four times a year; panels meet as often as necessary.

The CST is responsible for ensuring that R&D programs in Japan are consistent with the following science and technology goals:

- reduce dependence of foreign energy by improving energy efficiency and developing new energy sources, principally nuclear power
- reduce dependence on other imports by exploiting ocean resources and by moving towards high-technology industries that require less raw material
- stimulate research in key areas of technology
- improve innovation by breaking down interdisciplinary barriers, facilitating cooperation among research organizations, and increasing the amount of basic research.

The CST coordinates government research by formulating policies and goals and by funding certain projects through the Science and Technology Promotion

Coordination Fund. These projects are aimed at basic research and facilitate research conducted among several institutions and research that requires international cooperation. Each project lasts for 3 years. Although in absolute amounts the Fund is small, it is targeted at priority research issues. Since 1980, funding has been allocated for research in recombinant DNA, superconductivity, advanced materials, earthquake prediction, sensors, and laser systems (Anderson 1984, Lewis 1985).

3.2 THE SCIENCE COUNCIL OF JAPAN

The Science Council of Japan (JSC), often referred to as the "Parliament of Scientists," has two duties: to discuss important matters concerning science and to coordinate scientific research. Members are elected democratically and represent Japan's intellectual elite. The organization has seven sections and represents the humanities and social sciences as well as the hard sciences and engineering.

Traditionally, the JSC has exerted a major influence in policy formulation. Its president is a permanent member of the CST. Its reports and recommendations were given strong consideration by the Prime Minister. Decisions over which research areas to fund and which new institutes to build were regularly determined by the JSC.

Until recently, the JSC's authority has been diminishing. The Ministry of Science, Education, and Culture (MESC), concerned with its lack of influence in funding decisions, established its own Science Council in the early 1960s. The MESC Science Council's influence has grown over time, and may have equaled that of the JSC. The JSC also encountered difficulties when it began taking political stances that opposed those of the national government (Anderson 1984). Recently however, the JSC has moved to limit the political content of its recommendations in an effort to regain influence in the setting of research priorities. A list of potential JSC members is now submitted to the Prime Minister who then "nominates" those who are acceptable to the government.

3.3 THE SCIENCE AND TECHNOLOGY AGENCY

The STA is the primary organization responsible for coordinating research programs in Japan and ensuring consistency with national science and technology objectives. It is a part of the Prime Minister's Office. The STA Director-General is also the Minister of State for Science and Technology. The STA's primary duties are to frame national research plans, conduct long-term projects, and coordinate research conducted by other ministries. In addition, STA oversees research in space development, ocean resource development, and aviation technology (STA 1983; STA 1985).

Recently, STA has gained recognition for its support of the ERATO program (discussed briefly in Section 2.7). An umbrella program consisting of several basic research projects, ERATO is a pilot effort to redirect the ways in which the Japanese government conducts research. Individual initiative and a lack of firm objectives are appearing where consensus and the typically grueling timetable once ruled (Johnstone 1983).

Beyond the organizational uniqueness of the ERATO program, the specific research projects themselves merit attention. The ERATO program began in 1981 with four core areas of research: ultrafine particles, amorphous and intercalation compounds, fine polymers, and perfect crystals. Since then ERATO has added at least one new project per year. Bioholonics, bioinformation transfer, "superbugs," nano-mechanisms, and solid surface modification now constitute the remainder of ERATO.[a] Each project lasts for a period of 5 years with a total funding of approximately 2 billion yen supporting between 20 and 30 researchers. All projects are explicitly designed to help lay the scientific groundwork in the new materials, biotechnology, and electronics needed to support Japan's economy in the 21st century (JRDC 1986; Johnstone 1983; Results 1986). Refer to Table B.1 for further detail.

(a) Three projects began in October of 1986. The first investigates molecular dynamic assemblies and the ways organisms function in changing environments. The second examines ways in which microorganisms absorb and emit photons. The last new project focuses on quantum magneta flux in cryogenic environments as a possible basis for a radically new supercomputer.

Responsibility for ERATO rests with the Research Development Corporation of Japan (JRDC), a semi-public organization that receives half of its funding from the STA and half from the private sector. In addition to supporting ERATO, JRDC is the government's premier organization devoted to technology transfer. It serves as the liaison between national research institutes and universities and companies interested in commercializing new technologies. The JRDC also locates companies in other countries which may be interested in forming licensing agreements and helps private inventors in Japan locate local companies that may be interested in developing their inventions (JRDC 1986; STA 1985).

Perhaps the most important feature of this technology transfer process is the government's acceptance of financial risk: companies that have received funding from JRDC to commercialize a technology are only obligated to repay the loan if their venture succeeds. If, after 3 years, the venture is a success, the loan is repaid at below-market interest rates. Failure does not necessarily mean financial ruin for these ventures, though they may find JRDC funding more difficult to secure for any subsequent efforts. In this manner the Japanese government encourages innovation and risk-taking while mitigating the costs of indiscriminate commercialization (Johnstone 1983; JRDC 1986).

The STA also plays an important role in information services by operating the National Information System for Science and Technology (NIST). The NIST expands the range of Japanese databases and provides a comprehensive network that can be accessed anywhere in the country. The best known organization carrying out these functions is the Japan Information Center for Science and Technology (JICST) with its JICST Online Information System (JOIS) (Anderson 1984). The JOIS is the main database of Japanese science and technology and may be accessed in the United States through the National Technical Information Service (although all titles and abstracts appear only in Japanese).

The last major function of STA is its coordination of international scientific collaboration within the Japanese government. International collaboration has received increasing emphasis in recent statements of Japanese science and technology policy; the 1981 White Paper on International Trade, for example, encouraged technological cooperation as an important means of keeping foreign markets open to Japanese goods (Hills 1983).

Japan has formal cooperative agreements with the United States, most of the major Western industrialized nations, and a significant number of Warsaw Pact countries. Japan is also the hub of scientific knowledge in Asia and works with many of the developing nations in the region to modernize their technology base and improve their energy situation.

Japan's STA oversees several public or "special" corporations which are technically different than research institutes supported by MITI. They are funded by special accounts in the government's budget and operate almost independently of government control. Almost all involve significant private sector support. Those with conservation-related research programs are described in some detail in Table B.2.

3.4 THE MINISTRY OF INTERNATIONAL TRADE AND INDUSTRY

No institution in Japan inspires as much awe or receives as much condemnation from the West as MITI. Thought by many to have near total control of the Japanese economy, MITI is better understood as an organization whose power has waned over the last 10 to 15 years and has consequently sought to regain its prestige through managing the development of advanced technologies.

During the 1960s and 197Ds, MITI played a direct role in promoting and protecting industries considered important to the nation's economy through administrative guidance, licensing permits, and control of foreign exchange. Private businessmen eventually came to see this kind of assistance as unnecessary and even burdensome. In 1979 this power was taken away. Since then, MITI has moved aggressively to support research in new materials, biotechnology, and electronics. This shift in emphasis has led to a growing rivalry between MITI and STA and to competition for some of the same research projects, which has resulted in some duplication of research and occasional confusion over which organization is leading Japan into the 21st century (Anderson 1984; AIST 1982a; Bell, Johnstone, and Nakaki 1985).

Within MITI, AIST is responsible for coordinating the activities of 16 national laboratories and research institutes. The AIST operates the Sunshine Project and Moonlight Project; supports basic research for future industrial technologies; subsidizes research in the private sector; conducts large-scale industrial research projects; promotes industrial standardization; and coordinates some collaborative research with other countries (AIST 1985).

3.4.1 The Sunshine Project

Initiated in July 1974 in response to the oil embargo, the Sunshine Project is devoted to lessening the dependence on imported oil by developing alternative energy sources. The current goal is for alternative sources to provide 2.5% of Japan's energy by 1990 and 8% by the year 2000 (Anderson 1984; Choy 1985).

Research is being conducted in geothermal, solar, and hydrogen energy. Research is being directed towards finding methods to accomplish coal liquefaction and gasification. Sunshine Project researchers are also experimenting with wind energy, ocean thermal energy, methods for producing fuel from biomass, and methods of leveling electric loads (AIST 1985).

While all of these projects were initiated by AIST, only the technologies requiring significant additional research, such as hydrogen and ocean thermal energy, remain there today. The other projects have been transferred to the New Energy Development Organization (NEDO), a semi-public association partially funded by MITI.

The NEDO was formed in 1980 to help commercialize alternative energy technologies. The private sector and the government jointly administer and fund the organization. Most of NEDO's activities coincide with renewable energy research programs in the United States.

The NEDO also seems to support portions of the Moonlight Project research in energy storage technologies, advanced heat pumps, and Stirling engines as they near commercialization. A more complete discussion of these technologies appears in Section 5.0.

3.4.2 The Moonlight Project

Created to complement the Sunshine Project, the Moonlight Project is Japan's primary energy conservation research program. The Moonlight Project has a somewhat more limited technical focus than programs supported by the U.S. Department of Energy (DOE). The main Large-Scale Projects for Energy Conservation tend to promote increased energy efficiency in industry, more efficient methods of generating energy, and better energy storage systems. All projects are budgeted for 5 to 10 years (Table B.3).

The Moonlight Project also supports some fundamental research in energy conservation (Table B.4), but funding is limited. The total funding in 1985 for 11 basic research projects was less than one quarter of the smallest Large-Scale Project.

The Moonlight Project supports the development of energy conservation technologies in other ways besides research. A small percentage of the budget is allocated for subsidies to private companies who wish to commercialize conservation technologies. The AIST helps Japanese businesses by conducting technology assessments and sponsoring informational seminars at the research institutes on the status of energy conservation technologies. Industrial rights to patents or designs generated by AIST-funded projects are distributed to applicants from industry. Finally, within the Moonlight Project there are funds for promoting standardization and rating the energy efficiency of construction materials, industrial ceramic furnaces, and residential appliances (AIST 1985).

3.4.3 Basic Technologies for Future Industries

One of the most exciting aspects of MITI's involvement in advanced technologies is its research on fundamental problems of biotechnology, new materials, and electronic devices. The Basic Technologies for Future Industries program, scheduled to run from 1981 to 1991, is a cooperative effort by business and government to accelerate the rate of technological progress in these key industries (Tables B.5 and B.6). The Japanese government usually funds only 20% to 30% of the total research costs (AIST 1984b; AIST 1985).

The MITI has further recognized the importance of new materials by sponsoring the new Key Technology Research Center, which started in October 1985. The new center is capitalized at $50 million: 50% from the government, 25% from the Japan Development Bank, and 25% from private industry. The Center will fund up to 70% of research costs whenever two or more companies join to investigate new materials. Like JRDC loans, these loans are repaid only if the technology is commercialized successfully. The initial plans call for constructing two new testing and evaluation centers for fine ceramics and advanced metal materials. Although the Center may eventually support R&D in biotechnology and electronic devices, current emphasis is on new materials (Eager 1985).

The government is also working to lower financial and legal barriers to investment in new materials, biotechnology, and electronics. Companies engaged in research and development in these areas receive an additional 7% investment tax credit, thus increasing the maximum deduction to 15% (Eager 1985). In response to a proposal from MITI, the national Diet (legislature) passed a law in May 1986 that allows private companies to use facilities at the national laboratories.

3.4.4 Conducting Energy Conservation Research

To the outside world, the Japanese government's conservation research appears as a mass of large programs, each funded for years and all somehow targeted at the most sophisticated and most promising technologies. These programs, while clearly important, are the result of a long winnowing out process in which the technology must exhibit strong potential at progressively higher levels of government funding.

The first level of scientific research in Japan is referred to as "ordinary research." One or two scientists are given $4,00D to $8,000 for the materials and services needed for their project. Should their work look promising, they are given more researchers and more money to undertake a "special research" project. A typical project of this nature has four or five researchers and a budget of $40,000 to $80,000. If the work still looks promising and private industry shows interest, the government supports "designated research." The ERATO project and the Moonlight Project are considered designated research projects. Research at this level involves cooperation among several national laboratories and industrial sponsors, and frequently with academic researchers as well (Eager 1985).

3.4.5 MITI Research Institutes and Laboratories

The MITI administers 16 of the nation's top research institutes and laboratories, many of which conduct research in conservation-related areas. Table B.7 summarizes the research that they conduct. Tables B.8 and B.9 give more detail about two of the most important research organizations working in energy conservation, the Mechanical Engineering Laboratory (MEL) and the Fermentation Research Institute.

3.5 THE MINISTRY OF EDUCATION, SCIENCE, AND CULTURE

Paralleling the scientific infrastructure of government research institutes and laboratories is the Japanese university system. Japan has three types of universities: national universities, administered by MESC; the regional or prefectural universities; and private universities. The quality of these institutions varies greatly, and only a handful, primarily the national universities, are recognized as truly outstanding research institutions. Consequently, competition for admission to the top schools is intense, and high school graduates frequently spend 1 to 2 years preparing for the entrance examinations. Although a number of private universities are considered the equal of any in the country, the national universities are generally better equipped for conducting scientific research (Anderson 1984).

Research conducted by Japan's national universities is organized differently than in the United States. One of the fundamental differences is the distinction made between basic and applied science. Programs in applied microbiology, for instance, are available through the agriculture or engineering school, totally separate from basic research in microbiology. Professors in applied sciences maintain close ties with private industry, serving as advisors on research projects and providing graduate students for these firms. The professors are not paid directly by private industry for their services; companies pay into a general MESC fund which is used for equipment or supplies needed by all national universities. Professors' salaries are paid only by MESC (Eager 1985).

Professors in the basic sciences also interact with the private sector, but at a greater distance, and traditionally have had the right to refuse industry suggestions for research topics (Anderson 1984; Eager 1985).

Another major difference is the educational path of Japanese scientists and engineers. Although Japan trains more scientists and engineers per capita than any country in the world, few students pursue a Ph.D. They tend to exit with a bachelor's or master's degree, feeling that further study would hinder their entrance into an industry laboratory and delay career advancement. Large companies believe that they can provide experience equivalent to a Ph.D., and it is possible to use research conducted in a corporate laboratory for a doctorate degree (Eager 1985).

One of the most distinctive characteristics of scientific research in Japanese universities is the *koza* system. Each *koza* is a research unit consisting of one professor, one or two associate professors, two or more graduate students, and occasionally a small technical staff. The professors have the status of civil servants. Each *koza* works on a specific research topic and receives separate funding (Eager 1985).

This structure ensures the freedom of each *koza* to conduct independent research. It often leads, however, to a lack of communication and information exchange among *kozas* and the inability of one group to justify the purchase of expensive equipment. Until recently, this problem has been aggravated by equal distribution of funds to all *kozas* in a given faculty, regardless of specific needs. The MESC is now taking steps to increase the funding of selected *kozas* in order to bring their facilities up to an international standard.

The MESC Science Council plays an important role in setting Japan's overall research priorities, especially regarding university research. The Council, which consists of 27 eminent scholars and scientists appointed by MESC, makes policy recommendations and administers a large grant-in-aid program for scientific research. The committee that administers the grants has more than

800 members, primarily academics, who are divided by discipline into numerous advisory committees. Although most of these grants are spread among thousands of applicants, a small but highly visible portion (5%) goes to a few groups for rapidly upgrading their research to an international caliber (Anderson 1984).

3.6 THE MINISTRY OF CONSTRUCTION

The Ministry of Construction (MOC) is charged with encouraging Japan's domestic construction industry, which accounts for 20% of GNP. The MOC's capabilities range from the R&D of new building materials to urban planning and construction economics. This diversity creates difficulty in isolating projects and expenditures that relate specifically to energy conservation. For example, the MOC currently sponsors considerable R&D in new materials and in building design, but this research is intended primarily to improve resistance to earthquakes and fires. Table B.10 gives more detail about MOC projects (NSF 1985b).

The MOC operates three laboratories: the Public Works Research Institute, the Geographical Survey Institute, and the Building Research Institute. Of these only the Building Research Institute conducts research related to conservation. Other research sponsored by the MOC is performed by private companies.

Because of the large size of many Japanese construction and engineering firms, the vast majority of buildings R&D related to conservation is funded and conducted by the private sector. Energy efficiency is a major point of competition among these firms; the majority of effort is geared towards new materials, waste heat recovery, and microprocessor controls (Sackett 1986).

3.7 OTHER MINISTRIES

Little government-sponsored conservation research occurs outside STA, MITI, MESC, and MOC. The Ministry of Agriculture, Forestry, and Fisheries (MAFF) has the fourth largest government research budget (after MESC, STA, and MITI) and oversees a total of 32 research institutes. The only area of overlap with energy conservation comes in biotechnology, but MAFF tends to concentrate on cell cultivation as opposed to bioreactors and enzymes (Anderson 1984; Eager 1985).

The Ministry of Posts and Telecommunications cofunds the Key Technology Research Center with MITI. Its interests are in advanced materials for electronics applications and in fiber optics. The Defense Agency conducts some research on ceramics and advanced materials, but this research is generally unrelated to conservation. No other ministry or government agency performs research that relates to energy conservation (Anderson 1984; Eager 1985).

3.8 TSUKUBA SCIENCE CITY

Forty miles north of Tokyo, in what used to be 40 square miles of marginal farm land, lies the intended source of Japan's technological strength for the 21st century, Tsukuba Science City. Planned in the early 1960s, Tsukuba took 17 years to complete. By 1984, 45 national research institutes had relocated to Tsukuba and two new universities had been built. Tsukuba is only the second city in the world created specifically for science (the first was Akademogorodok in the U.S.S.R., built after World War II). Cost estimates for the entire project vary; $5 to $6 billion for construction and relocation would be a conservative estimate (AIST 1982a; Science City 1983).

The proponents of Tsukuba had several objectives in mind. First, locating many of the nation's research institutes in one place would facilitate interdisciplinary research and create the critical mass necessary for truly innovative R&D. Foreign scientists would be invited more often to engage in cooperative research, thus creating an intellectually dynamic environment. Moreover, Tsukuba would serve as a magnet, drawing private companies that wished to capitalize on the breadth and depth of scientific and engineering knowledge concentrated in one area. Tsukuba would also start to draw people and scientific talent away from the Tokyo-Osaka corridor, an area believed to have too much of both (AIST 1982a; Gregory 1986).

Tsukuba must still be considered an experiment. Fewer than 150,000 out of an anticipated 200,000 people live in Tsukuba, and about 110,000 of these are long-time residents. Of the 40,000 who have moved to Tsukuba, no more than a quarter of them are scientists or engineers. For many, Tsukuba is a place to work but not to live. While foreign scientists do indeed work there, especially in areas requiring innovation like the ERATO program, their visits are usually short (Bell, Johnstone, and Nakaki 1985; Science City 1983; Yukuta et al. 1985). By 1983, 91 public and private organizations were located in Tsukuba, including all the government facilities (Private Sector 1983). The primary benefit of Tsukuba has been the ability to rebuild research facilities and update equipment that had in many instances become obsolete.

3.9 THE ROLE OF PRIVATE INDUSTRY

The existence of Tsukuba raises the question of how private companies in Japan are able to benefit from government research. Technology transfer in Japan takes place through well-established channels. The government has designated certain organizations to link technologies with potential industry users. The JRDC is the best example of this approach. Another option, one frequently suggested for implementation in the United States, is the formation of research associations of private companies.

Japanese research associations are established by the private sector but initiated and chartered by MITI. They are governed by the Research Association Law of 1961 that structures cooperative research agreements so that they do not violate antitrust laws. Associations must be nonprofit and cannot hold patents, which are the property of the government (Lewis 1985b).

Because of these restrictions, especially concerning patent rights, large corporations sometimes decline MITI's invitation to join the research association. As a result, these associations do not necessarily include the most technically advanced companies in a given area and may not present as much a threat to businesses in the West as might be assumed (Lewis 1985b).

Research associations currently exist for metals and composites, ceramics, polymer materials, biotechnology, and numerous other areas. In conservation technologies these associations correspond to MITI's Basic Technologies for Future Industries program, and in fact support 70% to 80% of the research. More detail on these associations may help to clarify the general structure and point up the strengths and weaknesses of this approach to technology transfer.

Government attention to biotechnology first surfaced in 1971 when STA proclaimed the need for more biotechnology research. Little research was undertaken, however, primarily because STA did not allocate any funds. All this changed around 1980 when the U.S. Supreme Court ruled that microorganisms could be patented. This ruling and the resulting frenzy on Wall Street over Genentech and similar ventures made the Japanese realize that the United States might soon dominate the biotechnology market. In 1981, MITI responded by forming a research association in biotechnology. Of the 14 companies involved, all were established chemical businesses with previous experience in biotechnology. Half of the members received invitations; the other half volunteered. Several large companies declined to join,[a] but it is unlikely any of the current members will withdraw for fear of losing prestige (Lewis 1985a; Lewis 1985b).

The association is organized exactly along the lines of MITI's own biotechnology program: one division each in bioreactors, large-cell cultivation, and recombinant DNA. Table B.11 shows how companies are aligned with specific research areas.

Although this arrangement is supposed to promote cooperative research and raise the level of scientific knowledge, at least two factors work against these goals. First, member companies are almost always performing independent research and hesitate to exchange some of their research results. Only Denki Kagaku Kogyo KK and Mitsui Petrochemical Industries are actually working together in the same laboratory, and even so it is at the neutral site of the government's Fermentation Research Institute. The second factor is that while many companies with experience in biotechnology are participating, they seldom engage in research in areas where they have the greatest expertise. For example, a company adept at bioreactor development will join the recombinant DNA group in the expectation that it can develop a new business area. As a result, research associations may be doing less to add to the state of the art and more to enable companies to achieve a competitive edge in the global market for biotechnology products (Lewis 1985a; Lewis 1985b).

(a) Tanabe Seiyaku, considered the leader in bioreactor research, was one of those to decline.

Section 2.0 mentioned new laboratories being formed by private companies, primarily in the electronics industry, for the conduct of basic research. While this trend has not yet spread to companies developing energy conservation technologies, some large corporations in this area do maintain separate facilities for advanced R&D projects. The Toyota Central Research and Development Laboratories, Inc. (Toyota CRDL) is a case in point. Established in 1960, the Toyota CRDL has approximately 800 employees and an annual budget of 10 billion yen. It serves as a "think tank" for the entire Toyota family of companies. Research cuts across a spectrum of energy conservation technologies, from combustion and heat transfer to ceramics and composite materials (see Table B.12). Although the laboratory is organized into six divisions, each conducting proprietary research, interdisciplinary teams of researchers are formed on an as-needed basis (Toyota CRDL 1984).

Toyota CRDL has made a number of advancements in energy conservation. The Toyota diffusion coating process applies a layer of vanadium carbide and other materials to metal to provide resistance against corrosion, wear, seizure, and oxidation. A second innovation is "CELOAM", a lightweight insulating material made from automotive glass used in the bottoms of liquid natural gas (LNG) tanks. Toyota CRDL has also developed a single-cylinder engine, which allows direct, nonintrusive observation of the interior of the chamber during combustion research (Toyota CRDL 1984).

Research associations and central laboratories are two organizations of importance when examining conservation R&D conducted by private companies in Japan. Section 5.0 presents more details about research conducted by private industry in conjunction with government programs.

4.0 FUNDING

Estimating expenditures for energy conservation research in Japan is not easy and requires detailed explanation of what is meant by "energy conservation." This report will approach the question of funding from two directions: through a comparison of overall resources devoted to science and technology in Japan and in the United States; and through a detailed breakdown of Japan's national conservation research budget by program. At the highest level of aggregation, R&D figures are roughly comparable and indicate general research trends and priorities. With specific program information, the reader can gain a clear sense of funding for programs that correspond generally to conservation programs in the United States.

4.1 AGGREGATE R&D INDICATORS

In examining the government's commitment to research it is important to remember that Japan is facing impressive annual budget deficits and an imposing total national debt.[a] As shown in Table C.1, Japan's 1984 deficit as a percentage of the government budget was larger than that of the United States and totaled over $50 billion. While in absolute dollars the total U.S. debt exceeds that of Japan, it remains a smaller percentage of GNP than in Japan (Keizai Koho Center 1986).

Although the national debt has not (yet) received the same level of public attention in Japan as in the United States, government research expenditures have started to level off. Moreover, researchers are feeling public pressure to orient their research more towards applications and away from projects with unquantifiable benefits. The juxtaposition of budget constraints and a

(a) Much of Japan's current fiscal problems can be traced back to the oil embargo of 1973-74. The Japanese government spent heavily in order to prevent a deep recession similar to ones experienced throughout the industrialized world. In the short run, the strategy proved successful; however, the government did not compensate later on with either new taxes or major budget reductions.

national call to perform more large-scale, basic research is one of the central tensions affecting Japanese science and technology and will likely remain so in the future.

In terms of absolute levels of R&D funding, the U.S. lead over Japan is diminishing (see Table C.2). The United States outspent Japan by a factor of 3 in 1975, but that ratio closed to 2.5 by 1983. Japan has also increased its funding margin over important European nations like West Germany and France (NSF 1985a).

When adjusted for GNP, Japan's commitment to R&D becomes even more impressive (Table C.3). Total R&D expenditures as a percentage of GNP in the United States increased only slightly during 1971-1983, from 2.48% to 2.62%. In Japan the ratio went from 1.85% to 2.58%, effectively equaling the figure for the United States by 1983 (NSF 1985a).

When funding for defense-related research is excluded, Japan is no longer the equal of the United States; it is far ahead. In fact, the Japanese have devoted a larger portion of their GNP to nondefense R&D than the United States since at least the early 1970s (see Table C.3). As an indication (albeit only partial) of relative resources aimed at energy conservation research, the disparity in nondefense R&D expenditures offers cause for concern among the U.S. research community.

One characteristic of research in Japan is the strong role played by industry in both funding and performing research. As Table C.4 shows, businesses in Japan perform approximately two-thirds of all R&D, a figure comparable with other Western industrialized nations. What sets Japan apart is the degree to which corporations fund research. While in the United States about 50% of all research is funded by the private sector, the figure in Japan is closer to 70% (Anderson 1984).

Before moving to a more detailed examination of funding levels for Japanese conservation programs, brief mention should be made of conservation's place within the overall budget for energy in Japan. The dominant component of Japan's energy strategy is the development of nuclear energy. Over 75% of Japan's energy research budget in 1985 went to nonbreeder, breeder, and fusion technologies. Table C.5 illustrates that coal, renewable energy, oil and gas, and energy storage and transmission compose virtually all of the remaining budget (IEA 1986).

4.2 GOVERNMENT FUNDING OF CONSERVATION RESEARCH

As reported in the 1985 International Energy Agency (IEA) review of energy policies and programs in member countries (Table C.6), the Japanese government's budget for conservation research declined precipitously from 1978 through 1982, with only minor gains since. By 1985, the reported budget was $12.3 million (IEA 1986).

According to data provided by Japan to the IEA, conservation R&D accounts for less than 1% of the government's total energy R&D budget (Table C.5). How is it then that a country with a stated commitment to conservation, one reflected in a number of long-term research programs, can spend so little? Can the Japanese government actually have spent less on conservation R&D in 1985 than its counterparts in Spain, Italy, or the Netherlands?

Japan's figures may seem low when compared with those of other nations for a number of reasons. There may be definitional problems over what constitutes energy conservation. Some distortion may arise over how the IEA adjusts for differences in fiscal years among the countries. Distortion could also occur if the Japanese reported conservation research funded by the "general account" budget only and not the larger portion that is funded by other "special accounts".[a]

In addition to using the IEA data, there are at least three other ways of determining the level of government funding for energy conservation in Japan. Each method uses only Japanese government documents. One simple approach would be to count just MITI's Moonlight Project, referred to repeatedly in government documents as the central energy conservation research program in Japan. In 1985, the Moonlight Project budget was approximately 11.2 billion yen or over

(a) "General account" funds come from the government's overall base of revenues. "Special account" funds for energy conservation come from taxes placed on oil and electricity consumption.

$50 million (see Table C.7) (AIST 1984a; AIST 1986). This figure exceeds the conservation R&D budgets reported to the IEA by Sweden, West Germany, and the United Kingdom and seems a more reasonable estimate than the $12 million reported by the IEA.

Table C.8 presents a second definition of conservation more in line with programs sponsored by DOE. Research programs added because they parallel DOE conservation research programs include advanced materials and bioreactor projects from MITI's Basic Technologies for Future Industries program; alcohol fuels projects from NEDO; MESC funding of combustion and laser diagnostics research; and the ERATO projects in advanced materials and bioreactors. These programs received over $76 million in government funding in 1985 (AIST 1985; Landgrebe 1986; Committee on Laser Diagnostics and Prediction of Combustion 1986; "ERATO Looks to Other Countries" 1985). This figure is still low since it fails to account for MESC-funded projects at the national universities in such areas as heat transfer and advanced materials (not broken out in the MESC budget). It also excludes an indeterminate portion of the MOC's research budget related to conservation in buildings. A figure of $80 million may probably be a fair and realistic estimate using this approach.

A third estimate is provided by the Japanese government's Indicators of Science and Technology. According to this source, Japanese research institutes and universities spent over 106 billion yen on energy conservation R&D in 1984 (Management and Coordination Agency 1985). At an 1984 exchange rate of 237.5 yen to the dollar this is the equivalent of $448 million. This estimate is clearly much larger than the other two methods. It is very difficult to explain the difference in the estimates, especially since all came from data published by the Japanese government. Therefore, U.S. policy makers should take extra care when using funding comparisons as a definitive measure of U.S. and Japanese conservation research programs.

What is lost in any of these "snapshot" approaches is a sense of the continuity of funding for Japanese research. All of the government's major conservation research programs are funded for anywhere from 5 to 10 years. As a result, scientists can plan their projects more efficiently and achieve better results than if they annually face budget reduction, termination, or even increase. The leverage that such assurance gives is not readily quantifiable, but still quite real. The major point is that the effective level of government expenditures, stated in terms of research activity purchased, is larger than the single-year figure would indicate. This advantage has nothing to do with the quality of Japan's researchers compared with those in the United States or elsewhere. It does, however, have everything to do with the nature of research program planning.

4.3 PRIVATE SECTOR FUNDING OF CONSERVATION RESEARCH

The most recent government statistics for private sector research and development in energy conservation indicate substantial activity. According to Indicators in Science and Technology, Japanese companies spent almost 140 billion yen on conservation research in 1984. At an exchange rate of 237.5 yen to the dollar, this is the equivalent of $587 million. Of this 140 billion yen, 61 billion ($257 million) went to the transportation sector, 41 billion ($173 million) to industry, 17 billion ($72 million) to buildings, 13 billion ($54 million) to electric power conversion and storage, and 7 billion ($32 million) to other uses. Only about 12% (or approximately $75 million) of this amount appears to be related to government-sponsored research programs (Management and Coordination Agency 1985).[a] Tables C.9, C.10, and C.11 provide additional detail about funding trends.

4.4 CONCLUSION

Despite the difficulty in determining the precise level of government support for conservation research, even the low estimate of $50 million is four times the $12.3 million figure reported to the IEA for 1985. It could be higher. Estimating private sector funding for energy conservation is easier,

(a) This estimate is based on a few reasonable assumptions. Companies fund a small fraction of the Moonlight Project, all for prototypes or demonstrations. Companies fund roughly 70% to 80% of MITI's Basic Technologies for Future Industries Program. Currently, a little industry support may be going to ERATO. No private funds can be earmarked for specific university research projects sponsored by MESC. Using these rules of thumb and Table C.8 gives a figure of 15 to 20 billion yen, or about 12% of the total.

if only because there appears to be only one source of data. Companies spent almost $600 million on energy conservation in 1984, primarily on research and development projects unrelated to government programs. In both the public and private sectors in Japan, support for energy conservation research and development is strong.

As the preceding chapter indicated, conservation R&D in Japan is broad-based and involves several ministries, each with important research programs. These efforts are also well-funded, not only in absolute numbers but also given the size of Japan's population and GNP. Now that the breadth of Japan's efforts has been established, the next chapter will add depth through a closer look at the specific technical areas being investigated, including key individuals, specific projects, and a general evaluation of research strengths and weaknesses.

5.0 SPECIFIC AREAS OF CONSERVATION RESEARCH

This section presents an overview of current knowledge of Japanese energy conservation technologies: major R&D programs and their objectives, key institutions and researchers, technical approach, and strengths and weaknesses. These technologies have been selected either because they are considered energy conservation technologies in Japan or because they parallel research programs funded by DOE Conservation.

For those who are familiar with a specific Japanese technology, this approach has the benefit of setting forth the status of related programs and technologies. For others, this summary provides an introduction and orientation to the entire range of conservation technologies.

5.1 CERAMICS

Entire books can and have been written about the status of ceramics research in Japan. The following summary is a radical distillation of current knowledge. A good starting point for those desiring more information would be the National Research Council's recent report, High-Technology Ceramics in Japan.

The STA, MESC, and especially MITI each have major research efforts involving ceramics R&D. The MITI, in conjunction with the private Engineering Research Association for High-Performance Ceramics, is sponsoring a 10-year, 13-billion yen program in fine ceramics[a] as one of its Basic Technologies for Future Industries. Like the other long-term Japanese projects in conservation R&D, the ceramics project has a definite and ambitious timetable with performance objectives specified in detail (see Table D.1). Ceramics research is also important in MITI-sponsored research in gas turbines, MHD power generation, and battery storage (AIST 1985; National Research Council 1984).

(a) "Fine ceramics," according to the National Research Council report, are defined as "extremely pure, composition-controlled, ultra-minute particles formed, sintered, and treated under highly controlled conditions. These properties and procedures give the ceramics superior performance characteristics."

As part of the ERATO project within STA, researchers interested in ultrafine particles research, conducted as part of the ERATO project, are investigating the fundamental properties of particles of certain inorganic materials; nickel, iron, and gold have been examined to date. The resultant knowledge is intended to serve as the basis for ceramic coatings and high-performance catalysts (Results 1986).

The national universities under MESC have numerous smaller research projects and tend to focus more on fundamental issues than the national laboratories. Applications are not ignored, however. The JRDC is working with the national universities to transfer ceramic technologies to the private sector.

5.1.1 Approach

With so many active programs there is no one dominant approach to ceramics research in Japan. Overall, Japanese ceramics research emphasizes characterization and composition. These experiments are aided by high-quality instrumentation and sensors and frequent use of computers which permit accurate analysis of many kinds of data. Although basic research in general in Japan has been singled out for improvement, fundamental knowledge of the structure of ceramics is highly advanced. Finally, Japanese ceramics researchers are especially attuned to end uses, showing real ingenuity in adapting basic technologies to marketable products. Processing technology is therefore highly developed (Hane et al. 1985b).

Japan anticipates a rapidly growing world market for ceramic products, primarily in electrical and structural applications. In particular, cutting tools, substrates for microcircuitry, multilayered capacitors, packaging for electronic components, and gas turbine blades are applications requiring new ceramic materials and technologies. These markets are sometimes small, but customers are willing to pay a premium for high performance. The Japanese are currently active in a host of these market niches (Potts 1985).

Japan can adopt this "shotgun" approach to developing new technologies because the government takes a long-term approach to R&D and because private corporations are often large enough to absorb losses while experimenting with different applications. The collective goal, as in other Japanese high-technology markets, is to accumulate experience in a technology faster than any other nation.

5.1.2 Key Institutions and Researchers

Within MITI, the Government Industrial Research Institute (GIRI) laboratories at Nagoya, Kyushu, and Osaka, and the Mechanical Engineering Laboratory (MEL) are all very active. Though almost every major university conducts ceramics research, a few programs merit special mention. The University of Tokyo, Hiroshima University, the Tokyo Institute of Technology, Kyoto University, Tohoku University, and Osaka University are noted for the quality of their ceramics research. The other major government organizations conducting ceramics research are STA's National Institute for Research of Inorganic Materials and National Research Institute for Metals (Hane et al. 1985b; AIST 1985; Science and Technology in Japan 1986).

Companies conducting ceramics-related research abound. Their efforts outside government-sponsored programs are almost certainly many times greater in scope. The most important group working with the government is the Engineering Research Association for High-Performance Ceramics. These 15 companies together support approximately 70% to 80% of the Basic Technologies for Future Industries program in fine ceramics, making industry contributions equal about 50 billion yen over 10 years (National Research Council 1984). Association members and their areas of investigation are shown in Table D.2.

The most notable of these leading companies is Kyocera, with 70% of the market for ceramic packages used to carry electronic chips and a growing presence in the market for structural ceramics such as cutting tools and engine components (Potts 1985). The other major ceramics industry organization is the Japan Fine Ceramics Association, composed of over 170 companies who do not, however, conduct large cooperative research projects (National Research Council 1984).

5.1.3 Strengths and Weaknesses

Use of sophisticated equipment, the span of applications, superior performance characteristics, process engineering skills, large numbers of competent investigators, and a large commitment by the government have all been cited as generic strengths of Japan's ceramics research. Ceramic regenerator cores, cutting tools, electronic substrates, and heat engine components are specific applications in which Japan is a world leader (Hane et al. 1985a).

The main weaknesses relate to the relative lack of predictive design tools and to evident difficulties in constructing a "ceramic engine." Once touted as imminent, the ceramic engine is now being seriously questioned by Japanese automobile companies who are unable to develop the requisite components. Brittleness, high defect rates, high cost, and the declining price of oil have forced every major company except Isuzu to scale back their efforts and revise their development timetable. Even Isuzu concedes the need for a few breakthroughs before finding an economical material with high performance characteristics (Yoder 1986). These hurdles notwithstanding, the overall quality of ceramics R&D in Japan is excellent.

5.2 ADVANCED MATERIALS

There is also considerable government research activity in new materials other than ceramics, such as amorphous metals, synthetic metals, polymers, and composites. In amorphous metals, the guiding objectives are development of improved power transformer cores, magnetic recording heads, and solar cells. The MESC funded a Special Project for Research on Amorphous Materials which involved almost all of Japan's leading university scientists in the field. The Project ended in 1982 and cost the government $2.7 million (Hane et al. 1985a; Hane et al. 1985b).

Since then the Japan Society for the Promotion of Science (JSPS), also affiliated with MESC, has embarked on a 5-year program to disseminate the results of the Special Project to the private sector. Research related to power transformer cores is being coordinated by the JRDC but performed by Nippon Steel and Tohoku University.

The MITI's major program in amorphous metals is included in the program on Leading and Basic Technologies for Energy Conservation. Research on solar cell applications is also conducted by MITI through the Sunshine Project (AIST 1985).

A large fraction of the Basic Technologies for Future Industries project is devoted to the development of new materials. Research on synthetic metals, high performance plastics, advanced composites, and advanced alloys with controlled crystalline structures are scheduled to receive a total of 30 billion yen between 1981 and 1990 (AIST 1985; Science and Technology in Japan 1986).

5.2.1 Approach

Japan is gradually moving towards more basic research in amorphous metals. In 1983 and 1984, workshops were held on structural control, thermodynamics of supercooling, chemical short-range order, and magnetic thermal stability. Japanese researchers are also investigating corrosion processes and surface science, two areas that will be discussed later in conjunction with tribology R&D.

The new synthetic metals are designed to have improved electrical conductivity, stability, and shaping performance. Plastics of high rigidity through crosslinking of polymers and molecular conjugation are being developed, as are new molding techniques for creating two- and three-dimensional materials. For composite materials, the emphasis is on structural materials with high reliability. Lastly, stronger alloys are being developed through crystallization and grain refining (Hane et al. 1985b; Eager 1985).

5.2.2 Key Institutions and Researchers

Tohoku University operates one of the world's preeminent research facility for amorphous metals. Dr. Tsuyoshi Masumoto heads up this effort and has an outstanding international reputation. Also at Tohoku are Drs. Fujimori, Suzuki, and Fukamichi. The other important university research facilities can be found at Nagoya University, Osaka University, and Kyushu University (Hane et al. 1985b).

Among national laboratories, the Electrotechnical Laboratory (ETL) conducts most of MITI's research in this area. The Institute of Physical and

Chemical Research has recently announced formation of an International Frontier Research Organization which will conduct fundamental research in new materials (Institute of Physical and Chemical Research 1986).

5.2.3 Strengths and Weaknesses

One of the most important factors contributing to Japan's success in advanced materials is the high quality of research equipment. Although no facility can match the capabilities of the Lawrence Berkeley Laboratory, several Japanese facilities are only a notch below. Once again, developmental research, and in particular compositional studies, is a strength in this field. Japanese scientists frequently screen thousands of materials to find the desired properties. The transition to commercial production is also well-managed, and corrosion processes are very well understood. The main weakness would seem to be in some areas of fundamental research, especially magnetic properties (Eager 1985; Hane et al. 1985b).

5.3 ADVANCED GAS TURBINE

Research on advanced gas turbines was one of the first efforts undertaken by MITI's Moonlight Project. This program has a clear goal: creation of a 100-MW pilot plant with a combined thermal efficiency greater than 55%, and a turbine inlet temperature of 1300°C. Currently, gas turbines can achieve about a 30% efficiency level. A turbine with efficiency greater than 55% will have the advantages of increasing fuel flexibility, reducing demand for petroleum, decreasing emissions levels, and permitting flexible siting as demand for electricity rises (AIST 1984a; AIST 1986).

The initial work concentrated on developing sophisticated, heat-resistant materials for the combustors and turbine blades. Nickel and cobalt alloys, ceramics, and fiber-reinforced ceramics were all investigated. The pilot plant has been built and is now undergoing tests at Tokyo Electric Power's Sodegaura power station. In 1983, the pilot plant successfully completed no-load tests for a total of 30 hours. Funding for this project in 1985 was slightly over 1.2 billion yen (AIST 1986).

5.3.1 Approach

The primary scientific issues being addressed are development of advanced materials and cooling technologies.

5.3.2 Key Institutions and Researchers

Four national laboratories affiliated with MITI, two of the laboratories under STA, and the Engineering Research Association for Advanced Gas Turbines are cooperating in this project.

5.3.3 Strengths and Weaknesses

Emission standards are much tougher in Japan than in the United States, prompting the search for "clean" engines. Japan leads the United States in emissions control technology. The main hurdles in this project involve successful operation of the facility under actual conditions and then integrating its use into the power generating grid (AIST 1984a; Hane et al. 1985b).

5.4 ADVANCED HEAT PUMPS

Government-supported heat pump research started in 1984 and is the most recent addition to the Moonlight Project. The objectives are to develop the technologies needed for chemical heat pumps with heat storage (output temperature = 200°C), high output temperature (150°C), and high performance [coefficient of performance (COP) = 6-8]. Creation of pilot plants is expected to begin by 1991 (see Table D.3). Applications for this technology will be in air conditioning systems for urban communities and large buildings and in industries using exhaust process heat (AIST 1984a).

5.4.1 Approach

Initially, the program will focus on using chemical reactions to generate high-temperature output from low-grade exhausts and developing a compressor whose motor is encased in a heat exchanger to utilize the heat given off. Researchers will then work on developing a multistage counter-current type of heat exchanger. The final area of emphasis is development of a systemizing technology to optimize energy accumulation. Fuel flexibility will be stressed at each stage of development (AIST 1984a; Narita 1986).

5.4.2 Key Institutions and Researchers

The National Chemical Laboratory for Industry and Government Industrial Research Laboratory at Hokkaido conduct heat pump R&D for the Moonlight Project. An important focal point for industry research will be the Japan Heat Pump Center, soon to be formed by the Japan Industrial Refrigeration Association (Hane et al. 1985b).

5.4.3 Strengths and Weaknesses

An evaluation of Japanese heat pump efforts is difficult because of the relatively short history of the research and the lack of information from Japanese sources. All indications are that research in this area currently lags behind research in the United States. However, Japan is trying to close this gap rapidly through larger national programs and active collaboration with other nations (Hane et al. 1985b).

5.5 STIRLING ENGINES

In many ways the Moonlight Project research programs in heat pumps and Stirling engines are two halves of a whole. Stirling engines are first being developed for application in heat pumps, and then for application in small marine and automotive engines. In general, Stirling engines are being investigated because they promise fuel versatility, energy efficiency, and low emissions.

The current R&D program is scheduled to run from 1982 to 1987 (see Table D.3). Because Japan is developing Stirling engines for a wide range of uses, research is somewhat more generic or fundamental in this area than in other segments of the Moonlight Project. The goal of the program is to design an engine with a 10-year life span, a power range of 3 to 30 kW, and a 32% to 37% efficiency rate (AIST 1984a; AIST 1986).

5.5.1 Approach

The MITI has divided the project into four research groups: combustion, heat exchangers, working fluids, and power train and sealing. The project will later move to simulation of engine performance, design and construction of prototypes, and demonstration tests by 1987. The government has given priority to the kinematic Stirling engine rather than the free-piston approach used by the United States for heat pump applications.

Since much of the R&D is conducted at the large, multidisciplinary national laboratories, researchers often build on capabilities developed in other areas of energy conservation research. The MEL, for example, is investigating the heat transfer and the material design and development aspects of Stirling engine development. Fundamental research on combustion fluid dynamics is being conducted at the National Aerospace Laboratory (Hane et al. 1985b).

5.5.2 Key Institutions and Researchers

The MEL, National Aerospace Laboratory, and Pollution and National Resources Laboratory all participate as part of the Moonlight Project. The Ship Research Institute participated in the government's first Stirling engine research project in the 1970s concerning marine applications. An unspecified amount of the project is also handled by NEDO contractors such as Aisin (Toyota) (Hane et al. 1985b; Keller 1986).

The University of Tokyo, Nihon University, Meiji University, the Institute of Industrial Science, and Kanazawa University are known to be active. In general they are not as well equipped or staffed as the national laboratories, but that is not to say that the quality of their research is necessarily low (Hane et al. 1985b).

5.5.3 Strengths and Weaknesses

An evaluation of the strengths and weakness of the Stirling engine program is constrained for the same reasons as discussed in Section 5.4.3 concerning the heat pump program. More information on Japanese research should be forthcoming as a result of an IEA cooperative project on Stirling engines among Japan, Sweden, and the United States. As part of their contribution, Japan will translate documents relating to their research and make them available for the first time.

5.6 ENERGY STORAGE - BATTERIES

Japan considers improvements in battery technology an essential component of energy conservation research. The major government research program on batteries is part of MITI's Moonlight Project. The program's goal is to develop an electrical energy system with load leveling function using electrochemical reactions. The primary objective is to develop and demonstrate a 1-MW system and establish its feasibility by 1990 (see Table D.4) (AIST 1984a).

Five separate battery types are being developed, each with approximately the same funding level and number of researchers: sodium-sulfur, zinc-bromine, zinc-chlorine, redox, and advanced lead-acid. Funding for the program has increased over the past couple of years, from 1.2 billion yen in 1984 to 2.1 billion in 1985 and a request of 2.6 billion for fiscal year 1986 (AIST 1984a; McLarnon 1985).

5.6.1 Approach

In sodium-sulfur battery R&D, there are no plans to use fuses or circuit breakers as were used in the Ford Aerospace load-leveling battery. Scientists are now working on developing large Beta-alumina tubes, improving electrolyte durability and reliability, and improving fabrication techniques for mass production (Landgrebe 1986).

Only minor improvements are being pursued in zinc-bromine batteries: reduction of spacing between electrodes; increase in electrolyte conductivity; reduction in current density; prevention of complete discharge; prevention of degradation of carbon plastics by bromine; and improvement of energy density (Landgrebe 1986).

In zinc-chlorine battery research, the main focus is on reducing the concentration of chlorine in the electrolyte that corrodes the zinc electrode.

Researchers in the area of redox batteries are investigating the mechanical strength and manufacturing reliability of a large-scale bipolar plater and uneven electrolyte distribution within a stack of cells (Landgrebe 1986; Quinn 1985).

Finally, to improve the standard lead-acid battery, Japanese researchers are emphasizing miniaturization, weight reduction, and sealing technologies (Quinn 1985).

In related areas, Japan leads the United States in manganese dioxide, lithium-manganese, and lithium-CF_x battery technology research. Because of the recent drop in oil prices and improved gas efficiency of automobiles, little attention is being given to applications of battery technology to electric vehicles (McLarnon 1985; Hane et al. 1985b).

5.6.2 Key Institutions and Researchers

Most of the Moonlight Project work in advanced batteries is performed by a small group of companies. Yuasa Battery and NGK Spark Plug conduct the sodium-sulfur work. Meidensha Electric concentrates on zinc-bromine batteries, and Furukawa Denko Electric is responsible for zinc-chlorine development. Mitsui Engineering and Shipbuilding took over the redox battery work from the ETL when the technology reached the demonstration stage. Japan Storage Battery is the last major corporate participant and specializes in advanced lead-acid battery technology (Landgrebe 1986).

The GIRI at Osaka is the primary government facility responsible for conducting and coordinating advanced battery research. Contributions from the national universities are negligible (Hane et al. 1985b).

5.6.3 Strengths and Weaknesses

The common strength of each of the five major battery programs is the capability for quick scale-up. A fundamental knowledge of electrochemistry is generally lacking, although the Japanese are starting to show interest in the field. Hurdles specific to each battery are mentioned above in the discussion of approach. In general, the quality of the battery research work should be further increased as researchers tap into Japanese knowledge of ceramics technology (Hane 1985b).

5.7 ENERGY STORAGE - FUEL CELLS

Fuel cells, like battery storage, are seen as an important means of addressing future demand for electricity. Fuel cells promise improved efficiency in electric power generation and permit siting flexibility. They are more environmentally benign than most other sources of electricity.

The major national program in fuel cell R&O falls within the Moonlight Project. The objectives are to develop two 1-MW class generating plants using phosphoric acid fuel cells by 1986 and to create smaller stacks, in the 1- to 10-kW range, each of molten carbonate, solid oxide, and alkaline fuel cells (see Table D.5). Fuji Electric, Mitsubishi Electric, Hitachi, and Toshiba have cooperated in this project (AIST 1984a; AIST 1986).

By late 1985, industrial and government researchers successfully installed one 1-MW class phosphoric acid fuel cell plant at the Sakai-Ko power plant of the Kansai Electric Power Company and one at the Chita No. 2 power plant of the Chuba Electric Power Company. These will undergo operational testing through 1987 (Itoh 1986).

5.7.1 Approach

The approach to R&O in this area is similar to that used in battery R&D; several different fuel cell types are being investigated simultaneously. What distinguishes this work is the priority given to phosphoric acid fuel cells as the technology most likely to be commercialized in the near future. Both low-pressure and high-pressure phosphoric acid fuel cells are being developed for use in the generating plants. The other three types of fuel cells will undergo first fundamental study and then construction (AIST 1984a; AIST 1986).

5.7.2 Key Institutions and Researchers

The ETL and GIRI at Osaka have primary responsibility for the Moonlight Project fuel cell research (Hane et al. 1985b).

5.7.3 Strengths and Weaknesses

Because Japanese interest in fuel cells dates from the oil shortage in 1979, the overall level of technology lags behind that of the United States. Nevertheless, according to Kim Kinoshita, a fuel cell researcher at Lawrence Berkeley Laboratory, the Japanese and U.S. fuel cell programs are headed for approximate parity (Hane et al. 1985b).

5.8 COMBUSTION

Although most combustion research in Japan is performed by the major automobile manufacturers, the government sponsors some generic research through MESC and the national universities. The MESC devoted 190 million yen to research in laser diagnostics and fundamental combustion phenomena in 1985. This work is performed in conjunction with the Committee on Laser Diagnostics and Prediction of Combustion, a group of 36 private companies who are members of the Japan Society of Mechanical Engineers. The private contribution to funding in this program amounted to only 10.8 million yen in 1985 (Committee on Laser Diagnostics and Prediction of Combustion 1986).

Another major national effort in combustion research is MITI's program in Leading and Basic Technologies for Energy Conservation. The stated objectives are development of optical diagnostic techniques and a burner control system capable of maintaining complete combustion with minimal excess air. Additional information is hard to come by since this project is one of eleven areas within the MITI program, which are usually referred to as a unit. Because funding for the entire program was only 227 million yen in JFY 1985, the share allocated to combustion cannot have been too large (AIST 1986).

5.8.1 Approach

Reducing their dependence on oil, increasing fuel flexibility, and improving the efficiency and environmental impact of coal are the driving forces behind combustion research in Japan. One important technology that addresses all of these concerns is the adiabatic diesel engine, whose development will also be hastened by developments in ceramics.

In fundamental research, Japanese researchers seem to be concentrating on gaseous injection at high pressures; the mechanisms of fuel dispersal in engines; fuel injection; fuel spray; droplet formation; combustion chamber design; turbochargers; alternative concepts for spark ignition and diesel engines; unstable combustion; emissions control; and fluidized-bed combustion of coal and other solid fuels. The development of diagnostic equipment is integral to conducting this work.

More applied research is being conducted in the development of catalytic burners and of lighter weight, more efficient pistons. The use of microprocessors to control combustion is a noted strong point of combustion research in general (Hane et al. 1985b).

5.8.2 Key Institutions and Researchers

Members of The Committee on Laser Diagnostics and Prediction of Combustion include many of the leading combustion researchers from the universities. See Table D.6 for their affiliations and current research projects. Among the universities, Tokyo University and Keio University have the strongest reputations (Committee on Laser Diagnostics and Prediction of Combustion 1986; Hane et al. 1985b).

5.8.3 Strengths and Weaknesses

A survey of U.S. experts conducted by Hane et al. (1985b) revealed remarkable unanimity in assessing the strengths and weaknesses of Japanese combustion research. Most of these experts agreed that while U.S. research is more broadly based, Japanese research is more focused towards end uses.

In many areas Japanese efforts are the equal of any in the world. Significant strengths include the adiabatic diesel engine, emissions control, coal combustion, microprocessor controls, and general combustion phenomena. However, opinion is divided on the quality of laser diagnostics and combustion modeling work (Hane et al. 1985b). In sum, Japan appears to be catching up rapidly or surpassing the United States along the whole range of combustion R&D; future efforts should be expected in fundamentally new areas of inquiry.

5.9 HEAT TRANSFER

The two primary goals of heat transfer research in Japan are to harness abundant low-grade energy more effectively and to improve the reliability of many high-technology products that require high heat transfer rates.

Research on the harnessing of low-grade energy is fairly generic and usually conducted by the national universities. An exception is MEL, which is developing an advanced electrohydrodynamic (EHD) heat exchanger for improved waste-heat recovery. This project is part of the Basic and Leading Technologies for Energy Conservation program under MITI. For reasons already mentioned, funding for this project cannot be that high (see Section 5.8).

Private companies in the electronics or appliance industries conduct much of the R&D to improve the reliability of high-technology products (Hane et al. 1985b).

5.9.1 Approach

The major areas under investigation in heat transfer are boiling, condensation, enhanced surfaces, high-temperature heat exchangers, and heat transfer in electronic components. Boiling and condensation relate specifically to improved usage of ocean thermal and geothermal energy, and potentially to boilers in nuclear power plants. Investigations often combine two or more of these technical areas, as in the development of enhanced surfaces that facilitate boiling (Hane et al. 1985b; Kuo 1983).

5.9.2 Key Institutions and Researchers

As of late 1982, the major universities involved in heat transfer research were the University of Tokyo, Tokyo Institute of Technology, Kyushu University, Kyoto University, Tohoku University, and Nagoya University. Key researchers and their general fields of expertise are given in Table D.7 (Kuo 1983).

5.9.3 Strengths and Weaknesses

The Japanese have demonstrated a remarkable ability to move heat transfer technologies into production. The quality of both fundamental and applied research appears to be generally on par with that of the United States.

Kuo (1983) identified several areas of possible future research: spray or mist cooling, analytic flow models for boiling heat transfer from porous surfaces, anti-fouling characteristics of selected boiling and condensation surfaces, and a method for ranking the large number of heat-transfer techniques proposed.

5.10 BIOTECHNOLOGY

Within MITI, biotechnology research is part of the Basic Technologies for Future Industries program. It is scheduled to receive over 25 billion yen between 1981 and 1991. The major areas under investigation are bioreactors, large-scale cell cultivation, and recombinant DNA. A program in monoclonal antibodies was also considered but scrapped for budgetary reasons. The research schedule is presented in Table D.8 (Lewis 1985a).

The use of biotechnology in the development of new fuel sources is MITI's other major area of activity. Much of the work in this area is conducted by the NEDO and features a number of cooperative projects with other nations. Through the ERATO project, STA is also active in this field. Since 1982, work has begun on bioholonics, bioinformation transfer, and the development of "superbugs."

Private companies in Japan have greatly increased their research into biotechnology since the success of Genentech and other U.S. firms. Table D.9 offers further detail on the bioreactor research of private companies participating in the Research Association for Biotechnology (Lewis 1985a; Lewis 1985b).

Refer to the discussion in Section 3.8 on research associations for further detail on government-industry collaboration in biotechnology R&D.[a]

5.10.1 Approach

Bioreactor research is related to energy conservation when applied to industries such as chemicals and pulp and paper. The traditional Japanese approach is to decide what reaction is desired, project what general class of microorganisms might have the desired properties, and then screen the resulting field (sometimes numbering in the thousands) one by one.[b] This methodology contrasts sharply with that used in the United States which tends to investigate fundamental characteristics and then design the needed microorganism (Hane et al. 1985b; Lewis 1985a).

The major areas under investigation include enzyme sensors, enzyme immobilization, ethanol production, cellulose hydrolysis, and the development of advanced bioreactors (Hane et al. 1985b).

(a) A related topic that merits attention is the Human Frontier Science Program, initiated by the Japanese government. This program is a potentially massive attempt at fostering interdisciplinary research on an international scale. Although details are lacking, the Program seems to be designed to combine research in artificial intelligence with studies of the functions of living organisms. The Institute of Physical and Chemical Research (RIKEN) has announced a 15-year, $220 million research program covering the biological background of homeostasis, advanced materials, and a planned project in designing an artificial brain. The entire program could reach a funding level of 1 trillion yen over 20 years, with 50% coming from Japan and 50% from other nations (Institute of Physical and Chemical Research 1986).

(b) The process of systematic screening probably has its roots in oriental religion and philosophy. Nature is believed to have supplied all the variance that is necessary and useful; it is the scientist's responsibility to find the existing organism rather than to tamper with nature. Exclusive reliance upon this approach is slowly disappearing, most notably in the field of recombinant DNA, but it is still the dominant approach in bioreactor R&D (Lewis 1985b).

5.10.2 Key Institutions and Researchers

A listing of the major government laboratories, universities, and companies conducting bioreactor R&D can be found in Table D.10. The most important government research organizations are the Fermentation Research Institute and Tokyo University (Lewis 1985b).

5.10.3 Strengths and Weaknesses

Japanese biotechnology R&D is more empirically based and clearly more oriented towards end uses than in the United States. This advantage over other nations in fermentation technology has resulted in a strong understanding of process engineering. The major shortcoming of Japanese biotechnology R&D is in the understanding of fundamental chemical and physical phenomena related to microorganisms (Hane et al. 1985b).

5.11 TRIBOLOGY

Japanese interest in the mechanisms of friction, wear, and lubrication dates back to the late 19th century when the government began studying the wear properties of rails, tires, brakes, bearings, and gears. Although there is no national research program in tribology, considerable research is performed by several national laboratories, a number of universities, and manufacturers of automotive engines and industrial coatings (Hane et al. 1985b).

5.11.1 Approach

While researchers in the United States have tended to concentrate on mechanical tribology, their Japanese counterparts devote much more time to chemical tribology. This is not an exclusive division--Japan does some research in the mechanical aspects and seems adept at combining it with projects relating to chemical phenomena. Among the many subfields of tribology, Japan is especially active in coatings and the development of ceramic bearings, both of which contribute to the national effort in new materials. Almost all of the research benefits from very sophisticated equipment and modern laboratory facilities (Hane et al. 1985b).

5.11.2 Key Institutions and Researchers

The identity and technical focus of government and university researchers in tribology are fairly well known and are summarized in Table D.11. The most important factors to note are the recent addition of a laboratory dedicated to fundamental research at the MEL and the prevalence of competent scientists even at second- and third-tier universities. Less is known about corporate participation, through Toyota, NGK Spark Plugs, Toshiba, and Kyocera are clearly active in this research (Hane et al. 1985b).

5.11.3 Strengths and Weaknesses

Taken as a whole, tribology R&D is highly advanced in Japan. The quality of tribology research results from close cooperation among researchers, the sheer number of scientists and engineers involved, and the quality of researchers at all levels. Japanese understanding of chemical tribology is excellent.

Specific areas of Japanese strength include coatings, ceramic bearings, lubricants and oil additives, gear lubrication, machining investigations, modeling, and interpretation of microstructural effects in wear processes.

Although Japan seems to be trailing the United States in mechanical tribology and fundamental knowledge in this area, the gap is clearly narrowing (Hane et al. 1985b).

6.0 INTERNATIONAL COLLABORATION

Japan's history of formal collaboration with other nations in science and technology has occurred in three stages (see Table E.1 for a listing of all agreements). The first stage occurred during the 1960s and early 1970s, when collaboration on specific topics focused on agriculture, medical research, and the life sciences. As indicated in Section 1.0, research in these areas helped solve the crucial problems of postwar Japan.

A second stage of collaborative arrangements followed the 1973-74 oil embargo. For the first time, Japan (as well as other Western nations) began to cooperate in energy conservation research, as in the agreements struck between Japan and France, and Japan and West Germany in 1974. During this second period Japan signed a series of agreements with Warsaw Pact nations, began collaborating in nuclear power research, and participated in the IEA Working Party in Renewable Energy.

The third and current stage was triggered by an the oil shortage of 1979-80.[a] Two important consequences resulted from this second oil shortage. First, Japan became an active member of the IEA End-Use Technology Working Party (EUTWP), the largest forum for cooperative energy conservation research in the world. Japan currently participates in the Combustion Processes, Alcohol and Alcohol Blends as Motor Fuels, Pulp and Paper Industry, and Advanced Heat Pump Technology implementing agreements. Second, Japan emerged as the source of advanced energy and conservation technologies for Southeast Asian countries. The general pattern has been for Japan to develop a technology that capitalizes upon its partner's abundant energy resources. Japan's Fermentation Research Institute, for example, is currently working with Thailand, Malaysia, and the Philippines to produce ethanol from biomass using native supplies of casaba (Lewis 1985a).

(a) The pressures Japan was and is still feeling from its major Western trading partners to open its domestic markets also contributed to a renewed interest in collaborative research. Official Japanese White Papers on Science and Technology have explicitly encouraged cooperation as a means of sustaining Japan's access to overseas markets (Hills 1983).

A similar trend can be discerned in collaborative projects in the efficient use of coal. Japan is developing coal gasification and liquefaction technologies in conjunction with Australia and Canada as one method of assuring a reliable supply of coal from those countries.[a]

6.1 PARTICIPATION IN IEA AGREEMENTS

Japan's participation in the IEA over the last 5 years reveals a number of important patterns. One of the more surprising facts of Japan's history of collaborative R&D is the failure of cooperation to keep pace with Japan's ascent as a leader in energy conservation R&D. In the IEA EUTWP, for example, Japan has participated in roughly one-quarter of all research annexes.[b] Their level of participation is surpassed by countries such as Belgium, Switzerland, and Italy.

Not surprisingly, each implementing agreement in which Japan does participate corresponds to a long-range research project. Research in advanced heat pumps ties in directly with the Moonlight Project, combustion with both the advanced turbine and heat pump R&D of the Moonlight Project, and alcohol fuels with the Sunshine Project. Less clear ties can be seen between the pulp and paper agreement and a major Japanese energy program, which probably explains Japan's lack of activity in this area.[c] In the future, it would seem

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(a) It is possible that the newly formed Human Frontier Science Program signals the start of a fourth stage of international collaboration. If the objectives of the program are realized, it would be remarkable for its size, scope, emphasis on fundamental research, and degree of Japanese initiative. See Section 5.10 for further details.

(b) See Table E.2, E.3, E.4, for summaries of Japan's current involvement in IEA EUTWP Implementing Agreements.

(c) Japan's present status in this agreement is somewhat in doubt. The Executive Chairman sent a letter to the Japanese representative in late 1985 asking for Japan's future plans in light of recent inactivity. Japan's only participation came in the completed annex on Developing an Energy Accounting Method (annex #2). Despite the emphasis Japan places on heat pumps, it is not a participant in the ongoing annex regarding Industrial Heat Pumps (annex #5). This may be because of its participation in a similar project in conjunction with the Implementing Agreement on Advanced Heat Pumps.

reasonable to expect Japanese participation only when projects coincide with established, multi-year programs and not to subjects still under investigation.

There are also patterns to the ways in which Japan participates once in a given IEA implementing agreement. As Tables E.2, E.3, and E.4 show, Japan has no bias against either cost-shared or task-shared arrangements.[a] Japan does not always wait until an agreement has a few proven successes before joining; it has participated from the start in the combustion, advanced heat pumps, and alcohol fuels agreements. What is unusual about Japan's record is the apparent absence of Japanese participation as operating agents for any research annexes. In the IEA Working Party on Renewable Energy, on the other hand, Japan has served as operating agent for at least two annexes.

6.2 PARTICIPATION BY UNIVERSITIES

Outside of international cooperative R&D via the IEA or formal bilateral agreements are a whole series of exchanges and collaborative projects undertaken by Japanese universities. The vast majority of these are administered by the JSPS, a semiautonomous organization connected with MESC. An examination of the most recent data (see Table E.5) reinforces previous characterizations of Japanese R&D collaboration in energy conservation. Many of the projects, especially with technologically advanced nations, center on new materials or biocatalysis. Also impressive are the number of projects involving neighboring Asian countries, and the recurrence of alcohol fuels as a topic of investigation. As with its bilateral agreements, Japan is combining its technology with

(a) During 1982 and 1983, Japan and Sweden participated in an IEA implementing Agreement and conducted task shared research on new energy saving processes for the manufacture of iron and steel. Three Japanese steel companies working through the Japan Iron and Steel Federation, Nippon Steel, Nippon Kokan K. K., and Kobe Steel, evaluated the economic and technical viability of smelting reduction using a molten iron bath. The process seemed to offer lower capital costs and the opportunity to use lower-grade coal, with commercialization envisioned in the next 10 to 20 years. The Swedish team, working through the National Swedish Board for Technical Development, undertook a feasibility study on coal gasification using a molten iron bath. Experiments were carried out with both laboratory-sized and a 6-ton experimental furnace. This implementing agreement is no longer functioning.

the natural resources of countries such as Thailand and Indonesia. What distinguishes these examples of R&D collaboration from the more formal and broader agreements is the greater frequency of work on generic technologies, particularly combustion and heat transfer research (JSPS 1985).

6.3 COLLABORATION WITH THE UNITED STATES

As the tables in Appendix E indicate, Japan is not now dependent on the United States for establishing cooperative research efforts, but this was not always the case. Immediately after World War II, Japan relied almost exclusively on the United States for technical assistance, both because it was an integral part of reconstruction efforts undertaken by U.S. occupation forces and because Europe had to devote all of its energies to its own reconstruction. For obvious reasons, Japan gradually worked to lessen this dependence and engage other industrialized nations in cooperative agreements.

Japan also looked elsewhere for research partners because some of its scientific arrangements with the United States were not always successful. Therefore, particular attention will be paid to instances in which amicable cooperation has been strained, in order to explain past difficulties and illuminate obstacles to future joint research. Conversely, areas of proven successful cooperation will also be highlighted. If researchers or policy makers wish to understand how and where future collaboration between the two countries could occur, or why less has happened in the past than one might expect, a quick review of the chronology of scientific collaboration with the United States should prove instructive.

One of the first agreements with technical content struck between the two countries involved the transfer of nuclear materials and technologies from the United States to Japan. The agreement was one of several undertaken by the United States to regulate the dissemination of nuclear capabilities to countries interested in civilian applications. Japan was the first nation to be covered by this agreement and has since relied almost exclusively on the United States to build their extensive nuclear power program.

Tensions arose, however, over restrictions on the kinds of technologies subject to transfer. The United States balked in the late 1960s over transferring the capability to reprocess spent fuel. Japan subsequently turned to France and by 1977 had an operating reprocessing facility near Tokai Mura. The United States still refused to allow spent fuel from U.S. reactors to be reprocessed there on the grounds that Japan could not safeguard against the diversion of plutonium. The ensuing debate caused considerable strain between the two countries; this strain still persists to some degree.

Better results have come from the bilateral agreement covering a broad range of basic sciences signed by President Kennedy in 1961. Coordinated by the National Science Foundation and the Japan Society for the Promotion of Science, the program has expanded beyond basic science to include several large technical projects and now involves scientists from other nations. Japanese researchers have been allowed to use the research vessel Glomar Challenger for experiments in ocean exploration. Engineers from the United States have studied the effects of earthquakes upon buildings at the Building Research Institute at Tsukuba. Both sides seem convinced of the benefits of the program, pointing to the regular contact among researchers and exposure to alternative methods for solving common problems as evidence.

Three years after this agreement Japan and the United States began formal cooperation in the area of natural resources with emphasis on marine resources. This program has been less formal than most. It involves conferences and the presentation of papers rather than cooperative research projects. No proprietary technology or research is involved, thereby diminishing the competition and increasing information exchange.

Given the importance of marine resources to Japan and the absence of sensitive material to protect, it is not surprising that the Japanese government supports the program fairly strongly, even designating a separate line item in the budget (in contrast to the United States, where funding comes from a myriad of existing programs). Nevertheless, benefits have accrued to both sides and the participants have worked diligently to see that their findings are available to the general technical community.

Even more than in natural resources, cooperation in the field of medicine has probably provided the best example of mutually beneficial, pathbreaking scientific research. Support for the program has been strong, with each country contributing approximately $12 million annually. Collaboration began in 1965 and was extended in the early 1970s to include cancer research. Most of the early projects focused on diseases common in the Third World and made significant contributions to control cholera and tuberculosis. Cooperation in the field of cancer research has been facilitated by the opportunity to study why given form of cancer exhibits subtle but important differences in each country. It should be noted that where problems occur in this agreement, they have often been the result of interagency squabbling in Japan. As mentioned earlier in the context of MITI's contest with STA to direct Japan's leading R&D programs, cooperation between Japanese agencies frequently succumbs to bureaucratic red tape or very rigorous notions of competition.

Collaboration in environmental protection, which started in the mid-1970s, has had a rather mixed history. Major benefits to the United States have come from the transfer of Japanese technology in sewage treatment, solid waste management, and stationary source pollution control. Japan also allowed U.S. researchers to study air pollution control in their steel plants, the most sophisticated in the world (although U.S. firms did little with the knowledge they gained).

On the other hand, Japan has not been willing to consider environment-related trade issues raised by the United States. From an institutional perspective, cooperation has been hampered by the inability of Japan's Environment Agency to adopt the practice of environmental impact assessment, by the involvement of numerous Japanese agencies, and by the internal political turmoil of the U.S. Environmental Protection Agency during the early 1980s.

Two other areas of cooperation should be mentioned. They receive only brief mention because cooperation has been restricted to unilateral transfers of technology.

In the area of transportation, Japan has shared its most sophisticated railway technology with the United States, resulting in substantial improvements in signalling, roadbed maintenance, and dispatching in the Northeast.

In the area of space technology, the knowledge has flowed in the opposite direction. Japan has enjoyed a greater degree of access to U.S. space technology than any other country, including the ability to purchase launch vehicle technology and satellites from U.S. companies. There were and are strings attached, but the program has clearly aided Japan in developing a space program and improving its communications systems. Unfortunately, neither program teaches any useful lessons about building and sustaining a successful, mutually beneficial program of collaborative R&D with Japan.

In the wake of the 1973-74 oil embargo, Japan began to include energy R&D in its bilateral agreements with other nations, including the United States. The 1974 agreement between the two countries was entirely devoted to the development of new and renewable energy sources, as well as conservation. During the mid-1970s, few issues in energy received as much public attention in Japan and the United States as renewable energy and energy conservation. Why then was this cooperative program such a failure? Justin Bloom, the U.S. science attache at the U.S. Embassy in Tokyo during much of this period, has pointed to a fundamental mismatch in the size of the two countries' non-nuclear energy R&D programs. In particular, funding for the Sunshine Project in renewable energy has paled in comparison with that for similar research in the U.S. (Bloom 1984).

After this agreement had produced little or no progress for several years, Prime Minister Fukuda suggested a new bilateral agreement covering nuclear fusion and photosynthesis R&D. This episode was historic in that it was the first such joint effort initiated by Japan. The United States agreed under the condition that Japan would also invest heavily in DOE's coal conversion program. After much internal debate, Japan approved the program.

The 1979 agreement soon proved to be the low point of the U.S.-Japan science and technology relationship because of a number of factors. Research and development projects in geothermal energy and high-energy physics were added at the last minute. The United States did not offer up its most advanced fusion research but instead convinced Japan to invest in a smaller system. Photosynthesis was gradually relegated to a small joint program administered jointly by the National Science Foundation and the JSPS.

Most importantly, the United States persuaded Japan, and later West Germany to support the SRC II process for converting coal to synthetic crude oil. The Japanese commitment amounted to several hundred million dollars over 10 years and required a significant amount of internal politicking to secure. After the 1980 U.S. elections, however, plans for the SRC II were scrapped. Japanese government officials who had lobbied hard for funding quickly lost face and many faced dismissal as a result. Together with the dispute over nuclear fuel reprocessing, the SRC II incident stands as a painful reminder of U.S. "untrustworthiness" in the minds of the Japanese scientific and technical community.

During this same time period President Carter signed a new bilateral agreement with Japan that, from the U.S. point of view, was supposed to supercede all previous accords. Japan balked at this interpretation since it threatened to disrupt the many relationships between the two countries' administrative agencies. The other primary hitch in this relationship was the intended flow of technologies. The United States intended to redress a perceived imbalance in technology transfer by requiring Japan to provide significant funding and expertise for U.S. programs without an equal level of support for Japanese programs. Little has yet to come of this 1980 agreement.

Seen in its entirety, the history of U.S.-Japan scientific collaboration provides some lessons for the future. Factors which have facilitated cooperation in the past include: clear definition of objectives by both sides; research areas free from commercial or trade issues, such as medicine; close working relationships between individual researchers; establishment of one and only one Japanese organization as primary agent to prevent interagency squabbling; and political stability in the United States to assure the continuity of large-scale projects. On this last point the Japanese are especially sensitive. Most of these lessons apply equally to energy conservation R&D, the main difference being that the possibility of terminating a large project is not great since no conservation program requires anything like the support needed for nuclear fusion or coal conversion.

Efforts during the 1970s to cooperate in energy conservation failed in part because the Japanese government had not yet committed itself fully to developing these technologies. That is clearly no longer a problem. Both nations are currently facing imposing budget deficits and are seeking ways to leverage their research dollars (or yen). Japan is further motivated to cooperate in order to keep open its export markets. The United States sees many areas of technology, in conservation and elsewhere, in which Japan represents the state of the art. Many of the two nations' interests coincide. Many of their strengths are complementary. The lower price of oil notwithstanding, there seems no better time in the last 15 years than the present for increased cooperation between the United States and Japan in energy conservation research.

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APPENDIX A

KEY FORCES SHAPING ENERGY CONSERVATION R&D--SUPPORTING DATA FOR SECTION 2.0

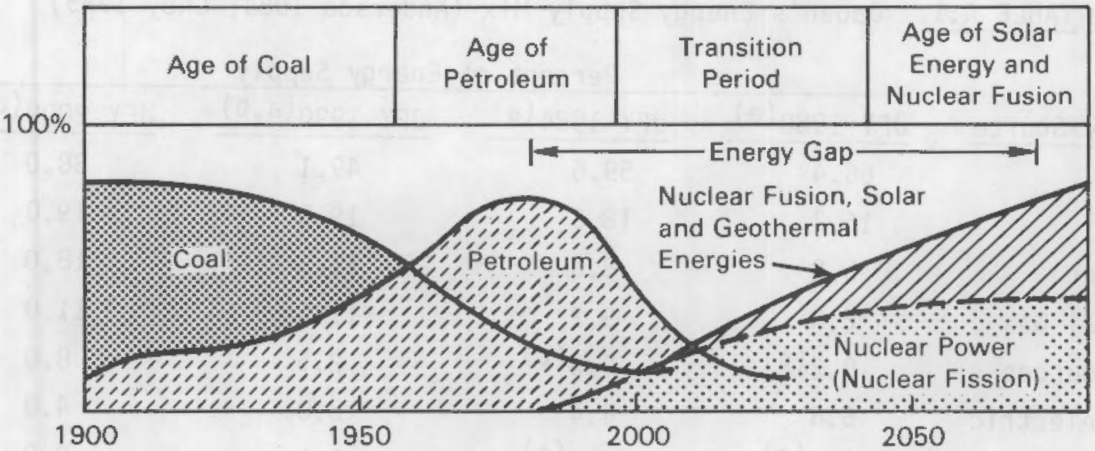

FIGURE A.1. Japanese View of Energy Supply (Adapted from AIST 1984)

TABLE A.1. Japan's Energy Supply Mix (Anderson 1984; Choy 1985)

Energy Source	Percent of Energy Supply			
	JFY 1980[a]	JFY 1984[a]	JFY 1990[a,b]	JFY 2000[a,b]
Oil	66.4	59.6	49.1	38.0
Coal	16.7	18.5	19.5	19.0
Nuclear	5.0	8.0	11.3	18.0
Natural Gas	6.0	9.2	11.5	11.0
New Sources	0.2[c]	0.3[c]	2.5	8.0
Hydroelectric	5.6	4.4	5.0	4.0
Geothermal	0.1[c]	0.1[c]	1.0	2.0
Total	100.0	100.0	100.0	100.0

(a) These figures have been rounded.
(b) Estimates for 1990 and 2000 were made in 1982. Actual figures for 1984 indicate where changes in Japan's energy supply mix are actually occuring. It should be noted that new sources of energy are not having an impact as rapidly as planned.
(c) Approximate values.

TABLE A.2. Impact of Technology on Economic Growth in Japan (Ishizaka 1983)

Time Period	Economic Growth Rate in Japan, %	Growth Rate Resulting from Technology, %
1955 to 1960	8.7	6.0
1960 to 1965	9.7	5.8
1965 to 1970	11.6	7.0
1970 to 1975	6.2	3.0
1975 to 1980	5.0	3.3

APPENDIX B

MAJOR ORGANIZATIONS AND PROGRAMS--SUPPORTING DATA FOR SECTION 3.0

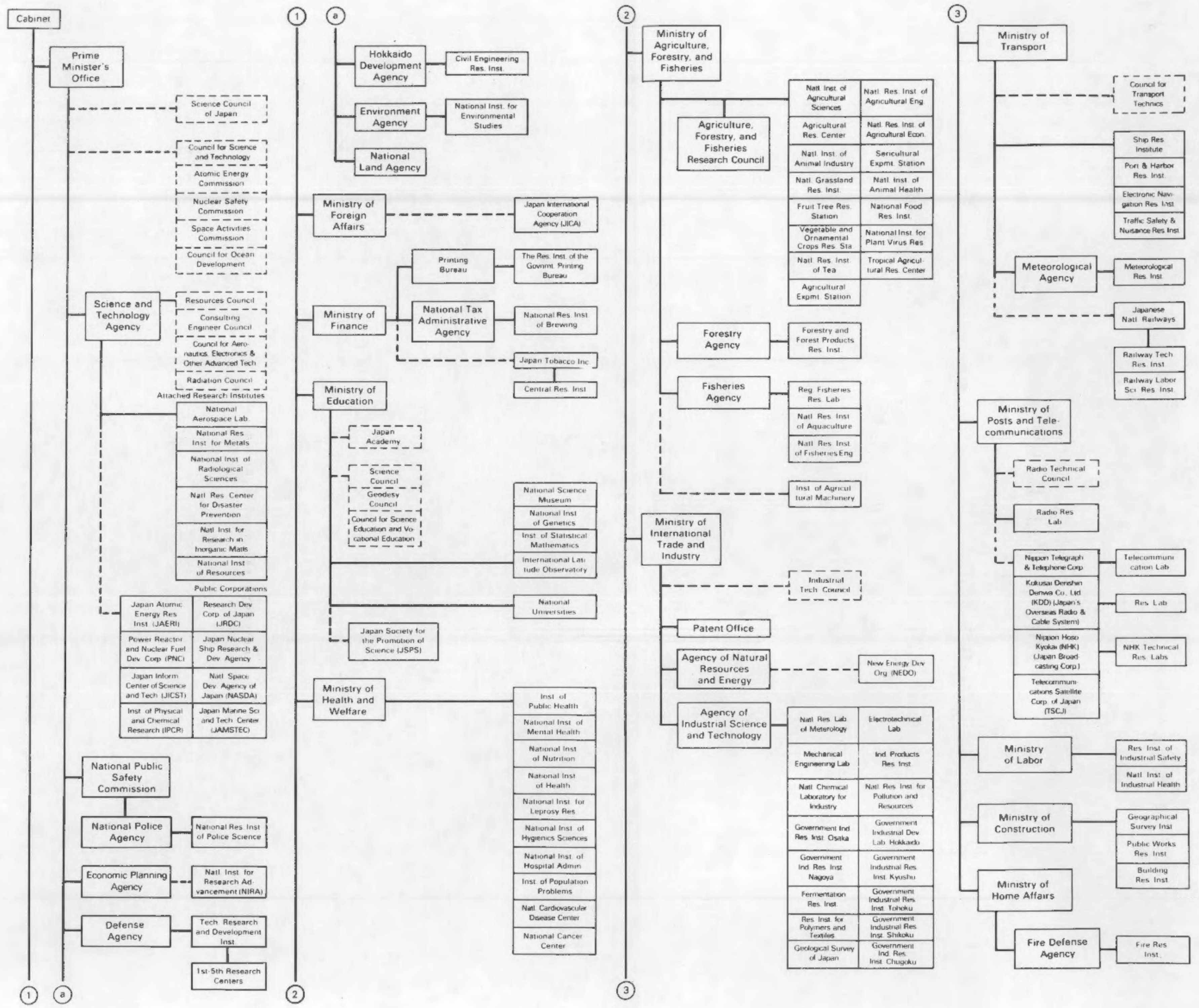

FIGURE B.1. Administrative Structure of Science and Technology in Japan

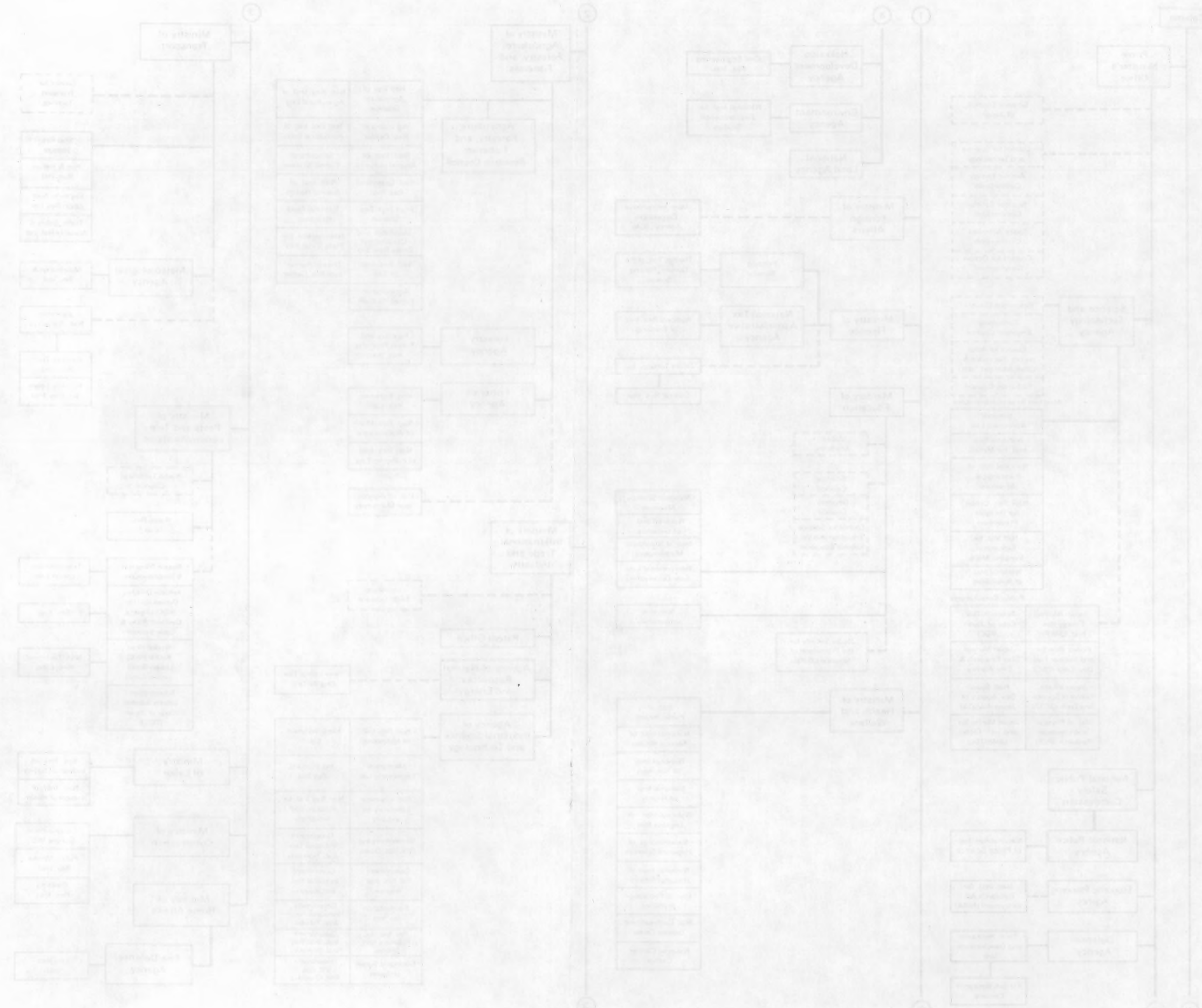

FIGURE 8.1. Administrative Structure of Science and Technology in Japan

TABLE B.1. The ERATO Projects of STA (from JRDC 1986)

Project	Lead Organizations	Activities
Ultrafine Particles	ULVAC Corporation (Dr. Chikara Hayashi); Meijo University; Stanley Electric Co.	Clarify the physical properties of ultrafine particles and evaluate their potential as industrial materials. Applications in recording media, light absorbers, catalysts, and ultrafine particle filters.
Amorphous and Intercalation Compounds	Institute for Iron, Steel, and Other Metals, Tohoku University (Dr. Tsuyoshi Masumoto); Research Institute of Electric and Magnetic Alloys; Otsuka Chemical Co.; Gakushuin University; Furukawa Electric Co.	Synthesize new materials for industrial use by drastically changing the atomic configuration and electronic structures of various materials. Harbor potential as electrical, optoelectrical, catalytic, and biological materials.
Fine Polymers	Sophia University (Dr. Naoya Ogata); Mitsubishi Chemical Industries; Matsushita Research Institute	Development of new generation of synthetic polymers, especially condensation polymers of high added value.
Perfect Crystals	Institute of Electrical Communication, Tohoku University (Dr. Jun'ichi Nishizawa); Semiconductor Research Foundation; Mitsubishi Electric; Mitsubishi Metal Industries; Hamamatsu Phototonics	Probe for leads toward developing a new generation of semiconductors by combining perfect crystal formation technology with static induction control technology.
Bioholonics	Teikyo University (Dr. Den'ichi Mizuno)	Understand the cooperative interaction between individual elements in a system and the system itself, especially in biological systems.

TABLE B.1. (contd)

Project	Lead Organizations	Activities
Bioinformation Transfer	Osaka Medical College (Dr. Osamu Hayaishi); Nippon Shinyaku Co.	Elucidate the mechanisms in intercellular and intracellular information transfer through studies on newly discovered neuroactive substances.
"Superbugs"	Institute of Physical and Chemical Research (Dr. Koki Horikoshi); Hamamatsu Phototonics	Search the world's most extreme environments for microorganisms that grow under conditions of strong pH, temperature, salinity, and pressure and introduce their unique properties into more "moderate" bacteria.
Nanomechanisms	Nippon-Kogaku K.K. (Mr. Shoichiro Yoshida); Tsukuba Research Consortium	Analyze physical actions and mechanical properties of materials in the nanometer region in order to construct new measuring machines.
Solid Surfaces	Tokyo University (Dr. Haruo Kuroda); Tsukuba Research Consortium; Toray Research Center	Search for methods for modifying solid surfaces by use of chemical or photochemical reactions or by physical processes under well-controlled situations.
Quantum Magneto Flux Logic	NA	Explore the possibility of creating an ultrafast computer using magnetic quanta as units of operation.
Molecular Dynamics Assembly	Kyoto University (Dr. Hirokazu Hotani)	Understand how living organisms function properly in a changing environment in order to create intelligent materials capable of changing their morphology in response to changes in the environment.

TABLE B.2. Science and Technology Agency Research Organizations (STA 1985)

Japan Information Center of Science and Technology (JIST)

Activities:	The JISCT is the central organ of scientific and technological information in Japan.
JFY85 Budget:	8.2 billion yen (4.7 billion yen from the government)
JFY85 Staff:	326
Year Established:	1957
Address:	5-2 Nagatacho 2-chome, Chiyoda-ku, Tokyo 100
Telephone:	03-581-6411

Research Development Corporation of Japan (JRDC)

Activities:	The JRDC promotes technology transfer, especially between Japan's universities and the private sector. It conducts basic research necessary for Japan's future industries, such as ERATO.
JFY85 Budget:	8.2 billion yen (4.2 billion yen from the government)
JFY85 Staff:	81
Year Established:	1961
Address:	5-2 Nagatacho 2-chome, Chiyoda-ku, Tokyo 100
Telephone:	03-581-6451

Institute of Physical and Chemical Research

Activities:	This independent public corporation recently set up an International Frontier Research Organization (tentative name) for the conduct of basic research in new materials. It also conducts significant biotechnology research, some of it on biocatalysis.
JFY85 Budget:	11.7 billion yen
JFY85 Staff:	620
Year Established:	1958
Address:	2-1, Hirosawa, Wako-shi, Saitama-ken 351
Telephone:	0484-62-1111

TABLE B.2. (contd)

National Research Institute for Metals

Activities:	This institute researches new metallurgical technologies, ceramic-metal bonding, ceramics dispersion, and new alloys.
JFY85 Budget:	3.8 billion yen
JFY85 Staff:	447
Year Established:	1956
Address:	2-3-12, Nakameguro Meguro-ku, Tokyo 133
Telephone:	03-719-2271

National Institute for Research in Inorganic Materials

Activities:	This institute researches advanced materials such as zinc oxide, silicon carbide, zirconium carbide, and zirconium phosphate. It also investigates the sintering of ceramics.
JFY85 Budget:	1.8 billion yen
JFY85 Staff:	166
Year Established:	1966
Address:	1-1, Namiki, Sakura-mura, Niihari-gun, Ibaraki-ken 305
Telephone:	0298-51-3351

National Aerospace Laboratory

Activities:	The National Aerospace Laboratory is the Japanese government's primary facility for aeronautical and space research and development. It performs some basic research in combustion as part of the Stirling engine R&D component of the Moonlight Project.
JFY85 Budget:	10.0 billion yen
JFY85 Staff:	456
Year Established:	1955
Address:	7-44-1 Jindaiji-Higashi-machi, Chofu, Tokyo 182
Telephone:	0422-47-5911

TABLE B.2. (contd)

STA Institutes Without Energy Conservation-Related Projects

National Space Development Agency of Japan

National Institute of Radiological Sciences

National Research Center for Disaster Prevention

National Institute of Resources

Japan Atomic Energy Research Institute

Power Reactor and Nuclear Fuel Development Corporation

Japan Marine Science and Technology Center

TABLE B.3. Large-Scale Projects for Energy Conservation (Moonlight Project) (AIST 1985)

Technology	Duration	Objectives
Advanced gas turbine	1978 to 1987	Construct a 100-MW pilot plant with a combined cycle thermal efficiency greater than 55%.
Advanced battery storage	1980 to 1990	Create a large-size battery system with load-leveling functions. Develop 1-kW, 10-kW, and 1,000-kW class sodium-sulfur, zinc-chlorine, zinc-bromine, redox, and advanced lead-acid batteries.
Fuel cell power generation	1981 to 1986	Develop advanced phosphoric acid, molten carbonate, solid oxide, and alkaline fuel cells. Construct two 1,000-kW plants using phosphoric acid fuel cells, and smaller prototypes for the other technologies.
Stirling engines for wide use	1982 to 1987	Develop Stirling engines for use as small industrial power generators, residential air conditioning, and commercial air conditioning. Fuel flexibility.
Advanced heat pumps	1984 to 1991	Develop chemical heat pumps with heat storage system; COP[a] between 6 and 8; and a high-temperature compressor-driven heat pump.

(a) COP = coefficient of performance.

TABLE B.4. Leading and Basic Technology for Energy Conservation Projects (AIST 1984a)

Technology	Description
Large-scale electric power generation	Fundamental study on the system of superconducting power transmission cable and superconductive materials.
Amorphous magnetic materials	Technologies to produce high performance amorphous materials with low hysteresis and eddy-current loss using melt-quenching.
Potassium turbine power generation	Basic research on potassium-steam binary vapor cycle.
Latent heat energy storage	Effective use of thermal output from nuclear reactors and waste heat.
Conserving energy in graphitization	Develop heat conductor and heat exchanger to recover and use heat generated during the graphitization process.
Ceramic infrared emitter	Develop high efficiency infrared emitter for use in industrial processes of drying and heating.
Coal burning MHD power generation	R&D on coal burner and channel for coal burning gas.
New aluminum smelting furnace	Replace electrolysis by using the blast furnace to reduce bauxite with coke.
Advanced electrohydrodynamic (EHD) heat exchanger	Augment condensation and boiling heat transfer by applying electric fields on the heat transfer surface.
Measuring thermophysical properties of high-temperature materials	Develop measurement methods for thermal conductivity, specific heat, and thermal emissivity of insulating materials at high temperatures.
Advanced combustion technology	Develop optical diagnostic techniques and a burner control system capable of maintaining combustion with minimized air intake.

	that are very hard, resist corrosion, have high dimensional accuracy, and can withstand high temperatures.
Synthetic membranes for new separation technology	Develop membranes that can separate and refine freely mixed gases or liquid mixtures.
Synthetic metals	Develop polymeric materials that are lightweight, resist corrosion, and conduct electricity like metals.
High-performance plastics	Use crystallization technique to create lightweight polymeric materials as strong as metals.
Advanced alloys with controlled crystalline structures	Use single crystallization and grain refining to produce superior alloys.
Advanced composite materials	Develop alloys that are lighter than aluminum and stronger than steel. To be used as structural materials when high reliability is achieved.
Photoactive materials	Develop new photoactive materials capable of exhibiting physical or chemical change in response to light. Essential for innovative optical devices.
BIOTECHNOLOGY	
Bioreactors	Develop new chemical reaction processes.
Large-scale cell cultivation	Develop method of replacing serum in a medium with various cell lines and making submerged cultures possible. Essential for future bioindustry.
Recombinant DNA	Use to obtain enzymes and produce bulk commodity chemicals.

TABLE B.5. (contd)

Technology	Objectives
NEW ELECTRONIC OEVICES	
Superlattice devices	Improve superlattice design techniques. Evaluate the physical and electrical properties in developing superlattice functional devices.
Three-dimensional integrated circuits (ICs)	Oevelop defect- and grain-free high-quality single crystals and optimal stacking arrangement.
Fortified ICs for extreme conditions	Create ICs with the ability to withstand high temperatures and mechanical vibrations. Nuclear reactor applications, among others.

TABLE B.6. Implementing Organizations for MITI's Basic Technologies for Future Industries Program (Anderson 1984)

Technology	Private Sector	Public Sector
NEW MATERIALS		
High-performance ceramics	Engineering Research Association for High Performance Ceramics	Government Industrial Research Institute (GIRI), Nagoya; GIRI, Osaka; Mechanical Engineering Laboratory (MEL); National Institute for Research in Inorganic Materials
Synthetic membranes	Research Association of Polymer Basic Technology	National Chemical Laboratory of Industry; Industrial Products Research Institute; Research Institute for Polymers and Textiles
Synthetic metals	Research Association of Polymer Basic Technology	Electrotechnical Laboratory (ETL); Research Institute for Polymers and Textiles
High-performance plastics	Research Association of Polymer Basic Technology	Research Institute for Polymers and Textiles
Advanced alloys with controlled crystalline structures	Research and Development Institute for Metals and Composites for Future Industries	MEL; GIRI, Nagoya; National Institute for Metals
Advanced composite materials	Research and Development Institute for Metals and Composites for Future Industries	Industrial Products Research Institute; MEL; GIRI, Osaka; Research Institute for Polymers and Textiles
NEW ELECTRONIC DEVICES		
Superlattice devices	Research and Development Association for Future Electron Devices	ETL
Three-dimensional ICs	Research and Development Association for Future Election Devices	ETL

TABLE B.6. (contd)

Technology	Private Sector	Public Sector
Fortified ICs for extreme conditions	Research and Development Association for Future Election Devices	ETL
BIOTECHNOLOGY		
Bioreactors	Research Association for Biotechnology	Fermentation Research Institute; Research Institute for Polymers and Textiles; National Chemical Laboratory of Industry
Recombinant DNA	Research Association for Biotechnology	Fermentation Research Institute; Research Institute for Polymers and Textiles; National Chemical Laboratory of Industry
Large-scale cell cultivation	Research Association for Biotechnology	Not known
Biodevices	Research Association for Biotechnology	Not known

TABLE B.7. MITI Research Institutes and Laboratories (AIST 1985)

Mechanical Engineering Laboratory (MEL)

Activities:	The MEL conducts advanced research in mechanical engineering that is applied to a broad spectrum of industrial needs. The Laboratory conducts ordinary, special, and designated research, and is an active participant in the Moonlight, Sunshine, and Basic Technologies for Future Industries Projects. Broadly speaking, MEL's objectives are energy efficiency, application of new materials to machine elements and structures, development of advanced robots, and development of new industrial technologies.
JFY85 Budget:	3.28 billion yen
JFY85 Staff:	291 (221 research, 70 administrative)
Year Established:	1937
Address:	2, Namiki 1-chome, Sakura-mura, Niihari-gun, Ibaraki 305
Telephone:	0298-54-2521

Fermentation Research Institute

Activities:	This institute conducts research in all areas of biotechnology important to Japan: recombinant DNA, large-scale cell cultivation, and bioreactors. Recent years have seen programs in hydrogen-producing microorganisms, ethanol production from biomass, and new enzymes for industrial processes, among others. The Institute is also the national repository of microorganisms cited in Japanese patents.
JFY85 Budget:	1.37 billion yen
JFY85 Staff:	86 (67 research, 19 administrative)
Year Established:	1940
Address:	1-3, Higashi 1-chome, Yatabe-machi, Tsukuba-gun, Ibaraki 305
Telephone:	0298-54-6023

TABLE B.7. (contd)

Electrotechnical Laboratory (ETL)

Activities:	The ETL is Japan's largest national laboratory specializing in electricity and electronics. In energy conservation, it is the primary government organization responsible for advanced battery and fuel cell research. Other energy technologies investigated include solar, ocean thermal, MHD, and fusion. Fundamental and applied research in solid state physics, electronic materials and devices, lasers, computer architecture, software engineering, robotics, and three-dimensional ICs are performed at ETL. The national standards for electricity, photometry, and acoustics are set by ETL as well.
JFY85 Budget:	9.04 billion yen
JFY85 Staff:	698 (556 research, 142 administrative)
Year Established:	1891
Address:	1-4, Umezono 1-chome, Sakura-mura, Niihari-gun, Ibaraki 305
Telephone:	0298-54-5006

National Chemical Laboratory for Industry

Activities:	The Laboratory concentrates on three main areas relating to the Japanese chemical industry: standardization of testing methods and hazard prevention; development of new energy technologies such as coal liquefaction, advanced heat pumps, biomass, and basic research in monocarbon chemistry; and use of biocatalysts and lasers to facilitate chemical reactions.
JFY85 Budget:	3.73 billion yen
JFY85 Staff:	377 (292 research, 85 administrative)
Year Established:	1900
Address:	1, Higashi 1-chome, Yatabe-machi, Tsukuba-gun, Ibaraki 305
Telephone:	0298-54-4431

TABLE B.7. (contd)

Research Institute for Polymers and Textiles

Activities:	Application of biological and biomimetic polymers to organic solar cells, artificial organs, and pharmacologically active polymers. Development of highly functional polymers such as photosensitive resins, separation membranes, and resin-supported catalysts. Improvement of physical properties of composite and formed materials by three-dimensional fabrics, high-pressure processing techniques, and polymer whiskers. Development of innovative textile technology such as automatic sewing systems.
JFY85 Budget:	1.39 billion yen
JFY85 Staff:	128 (105 research, 23 administrative)
Year Established:	1918
Address:	1-4, Higashi 1-chome, Yatabe-machi, Tsukuba-gun, Ibaraki 305

National Research Laboratory of Metrology

Activities:	The National Research Laboratory of Metrology is Japan's leading institution for standardizing physical and engineering quantities. The laboratory develops measurement methods and equipment.
JFY85 Budget:	1.95 billion yen
JFY85 Staff:	228 (128 research, 100 administrative)
Year Established:	1903
Address:	1-4, Umezono 1-chome, Sakura-mura, Niihari-gun, Ibaraki 305
Telephone:	0298-54-4118

TABLE B.7. (contd)

Industrial Products Research Institute

Activities:	The Industrial Products Research Institute tends to be most active in technologies aimed at the general welfare of the Japanese people. Medical diagnostic equipment is the best example of its work. Energy-related research is conducted in the construction and evaluation of residential buildings and the development of synthetic membranes and advanced composite materials. Other work concerns industrial pollution, computer-aided design, and automated sewing systems.
JFY85 Budget:	1.35 billion yen
JFY85 Staff:	133 (105 research, 28 administrative)
Year Established:	1928
Address:	1-4, Higashi 1-chome, Yatabe-machi, Tsukuba-gun, Ibaraki 305

National Research Institute for Pollution and Resources

Activities:	The Institute conducts research in the exploitation and utilization of mineral and energy resources, especially coal mining and processing, and develops environmental protection techniques, industrial safety techniques for mines, plants, and factories. As part of the Moonlight Project, researchers here are working on alternative fuel combustion as applied to Stirling engines.
JFY85 Budget:	3.73 billion yen
JFY85 Staff:	347 (252 research, 95 administrative)
Year Established:	1920
Address:	16-3, Onagawa, Yatabe-machi, Tsukuba-gun, Ibaraki 305
Telephone:	0298-54-6610

TABLE B.7. (contd)

Governmental Industrial Development Laboratory, Hokkaido

Activities:	The seven regional governmental industrial research institutes serve the needs of their particular region. This laboratory has the primary responsibility for developing mining-related technologies central to the Hokkaido region. Energy-related projects include coal liquefaction and gasification, advanced heat pumps, biomass, and advanced nonmetallic materials. Other projects concern mining safety and pollution control.
JFY85 Budget:	1.19 billion yen
JFY85 Staff:	101 (74 research, 27 administrative)
Year Established:	1960
Address:	17-2, Higashi 2-jo, Tsukisamu, Toyohira-ku, Sapporro-shi, Hokkaido 061-01
Telephone:	011-851-0151

Governmental Industrial Research Institute, Tohoku

Activities:	Developing materials for geothermal power plants, new materials for selective recovery of metal ions, separation and refining technologies for low-grade clays and rare elements, and waste-water treatment technologies.
JFY85 Budget:	0.58 billion yen
JFY85 Staff:	56 (39 research, 17 administrative)
Year Established:	1967
Address:	2-1, Nigatake 4-chome, Sendai-shi, Miyagi 983
Telephone:	0222-37-5211

TABLE B.7. (contd)

Government Industrial Research Institute, Nagoya

Activities:	Recently, the Institute has been devoted primarily to R&D in fine ceramics, such as the manufacture of unusually fine alumina powders. It also conducts advanced research in solar energy, fluorine chemistry, and pollution control.
JFY85 Budget:	2.61 billion yen
JFY85 Staff:	260 (199 research, 61 administrative)
Year Established:	1952
Address:	1-1, Hirate-cho, Kita-ku, Nagoya-shi, Aichi 462
Telephone:	052-911-2111

Governmental Industrial Research Institute, Osaka

Activities:	The major emphasis in this institute is on the development of new materials. Energy-related R&D in advanced gas turbine engines, battery storage, fuel cells, and energy from hydrogen is also conducted. Approximately 25% of the budget is allocated to electrochemistry and battery research.
JFY85 Budget:	2.62 billion yen
JFY85 Staff:	230 (174 research, 56 administrative)
Year Estimated:	1918
Address:	8-31, Midorigaoka 1-chome, Ikeda-shi, Osaka 563
Telephone:	0727-51-8351

TABLE B.7. (contd)

Governmental Industrial Research Institute, Chugoku

Activities:	The Chugoku region is especially dependent on the sea. The Institute performs some research in ocean thermal and hydrogen energy, as well as metalworking and corrosion processes. Other projects concern environmental protection and use of marine resources. The Institute claims to have the world's largest hydraulic model.
JFY85 Budget:	0.67 billion yen
JFY85 Staff:	53 (41 research, 12 administrative)
Year Established:	1971
Address:	15,000 Hiro-machi, Kure-shi, Hiroshima 737-01
Telephone:	0823-72-1111

Governmental Industrial Research Institute, Shikoku

Activities:	The primary industry in Shikoku region is pulp and paper. The Chemistry Department of Shikoku is developing biochemical pulping methods for nonwood resources, industrial utilization of palm oil residue, waste-water treatment, and application of lignin and hemicellulose as industrial raw materials. The Machinery and Metal Department is concerned with the laser spraying of ceramics onto steel and other areas.
JFY85 Budget:	0.55 billion yen
JFY85 Staff:	45 (34 research, 11 administrative)
Year Established:	1967
Address:	3-3, Hananomiya-cho 2-chome, Takamatsu-shi, Kagawa 760

TABLE B.7. (contd)

Governmental Industrial Research Institute, Kyushu

Activities:	As a major center of Japanese minerals, Kyushu has new materials as its primary research focus. Recent projects have included developing carbon-ceramics composites, carbon fibers from pitch materials, and new metallic materials such as spongy cast metal. Kyushu is also conducting coal liquefaction research for the Sunshine Project and a hot-gas corrosion test for ceramics as a part of the Basic Technologies for Future Industries project under MITI. This institute is also conducting collaborative research in building materials with Thailand and Indonesia.
JFY85 Budget:	0.83 billion yen
JFY85 Staff:	91 (69 research, 22 administrative)
Year Established:	1964
Address:	Shuku-machi, Tosu-shi, Saga 841
Telephone:	09428-2-5161

Institutes without Energy Conservation-Related Projects

Geological Survey of Japan

TABLE B.8. Energy Conservation R&D at the Mechanical Engineering Laboratory (Eager 1985)

ORDINARY RESEARCH

Energy Engineering Department

- Ceramic engines
- Measurement of the diesel combustion process
- Combined droplets
- Transient boiling phenomena
- Heat utilization technology through phase change
- Heat transfer in advanced nuclear technologies
- Effects of atmospheric conditions on engine performance
- Control of multiphase flow
- Fluid engineering
- Micro leak flow
- Nonlinear waves in fluids

Materials Engineering Department

- Magnetic control of arc welding
- Localized coating by chemical vapor deposition
- Electrochemical abrasive polishing
- Electron beam surface treatment
- Application of new materials to press working
- Wear resistance of titanium compound-base ceramics
- Materials characterization by acoustic microscopy
- Interaction of synthetic oil and sliding surfaces

Production Engineering Department

- Super abrasive grinding
- Advanced cutting technology
- Adhesion technology

Machinery Department

- Tribology in roller bearings

SPECIAL RESEARCH

Industrial Standardization

- Test method of fuel economy of vehicles

New Materials Technology

- Solid state bonding of new materials
  - Solid-state bonding in ultrahigh vacuum friction welding

TABLE B.8. (contd)

Technology for Establishment of Industrial Machining

- Wear and lubrication in hot metalworking
- Approach for wear resistivity
- Machining techniques for extremely hard-to-machine materials
  - Creep-feed grinding
  - Cutting technology under controlled atmosphere

Joint Research for Advanced Basic Technology

- Evaluation methods of reliability of rigid polymeric polymers
  - Inspection and evaluation of fatigue properties

Institute for Transfer of Industrial Technology (ITIT)

- Establishment of grinding operation standards
- Precision finishing of curved surfaces

DESIGNATED RESEARCH

Moonlight Project

- Advanced gas turbine
  - Gas turbine combustors
- Stirling engines
  - Test and evaluation methods
  - Seal technology
  - Heat exchanger technology
- Advanced heat pumps
  - Elemental instruments and systems

Basic Technologies for Future Industries

- High performance ceramics
  - Machining of ceramics
- Advanced alloys with controlled crystalline structures
  - Microstructure controlling technique
- Advanced composite materials
  - Fracture mechanics

Sunshine Project

- Hydrogen fueled engine

TABLE B.9. Organization of R&D at the Fermentation Research Institute (Lewis 1985b)

Microbe Exploration Department

- Microbe Exploration Division
- Gas Utilizing Microbe Division
- Geomicrobiology Division

Microbial and Biochemical Application Department

- Carbohydrate Fermentation Division
- Synthesized Material Fermentation Division
- Enzyme Technology Division
- Genetics and Breeding Division
- Cell Science and Technology

Microbe Engineering Department

- Resources and Energy Producing Microbe Division
- Biochemical Engineering Division
- Petroleum Fermentation Division
- Industrial Waste Treatment Division

TABLE B.10. R&D Projects of the Ministry of Construction, Excluding Research Institutes (NSF 1985b)

Project	Description
Construction industry use for waste materials	Use of earth, concrete, asphalt, coal ashes, and sewer sludge in landfills, ground improvement, and paving.
Restoring quake-damaged buildings	Conventional research for designing quake-resistant structures in order to strengthen existing buildings.
General lake water management	Develop techniques for forecasting the quality of lake water as well as controlling and improving the quality.
Building snow-resistant cities	Develop effective methods to move, melt, or otherwise dispose of snow.
Designing fire-resistant buildings	Systems approach to design incorporating fire-resistant characteristics of various materials, distributions of combustibles, floor plans, and building sizes.
Electronics-based systems for upgrading architectural techniques	Use of computers, sensors, and robots to make construction projects safer, more efficient, and higher quality.
Improving the durability of concrete	Understanding of how concrete structures deteriorate. Development of techniques to identify and measure deterioration. Development of techniques to repair existing structures and improve the durability of new ones.
New sewage treatment system using biotechnology	Techniques for fixing enzymes and microbes needed for sewage treatment and applications of these processes to actual treatment systems.

TABLE B.11. Japan's Research Association for Biotechnology (Lewis 1985b)

BIOREACTORS RESEARCH GROUP

- Mitsubishi Chemical Industries, Ltd.
- Kao Soap Co., Ltd.
- Daicel Chemical Industries, Ltd.
- Mitsubishi Gas Chemical Company Inc.
- Denki Kagaku Kogyo Kabushiku Kaisha
- Mitsui Petrochemical Industries

LARGE-SCALE CELL CULTIVATION RESEARCH GROUP

- Kyowa Hakko Kogyo Co., Ltd.
- Ajinomoto Co., Ltd.
- Takeda Chemical Industries, Ltd.
- Asahi Chemical Industry Co., Ltd.
- Toyo Jozo Co., Ltd.

RECOMBINANT DNA RESEARCH GROUP

- Sumitomo Chemical Co., Ltd.
- Mitsui Toatsu Chemicals, Inc.
- Mitsubishi-Kasei Institute of Life Sciences

TABLE B.12. Research Conducted at the Toyota CRDL (Toyota CRDL 1984)

Research Division	Research Areas
Engine, Heat, Fluid Dynamics	Combustion Heat transfer Catalysts Fluid dynamics Air pollution Energy technologies
Machinery and Systems	Vehicle dynamics Mechanical engineering Sound and vibration Control and robotics Structural analysis Computer science Textile engineering
Electronics and Instrumentation	Sensors Nondestructive evaluation Surface analysis Optics Magnetics
Physics and Chemistry	Surface science Tribology Thin films and polymer films Battery technology Corrosion Biochemistry
Materials	Ceramics Metals Polymers Composites Coatings
Materials Processing	Plastic forming Powder metallurgy Welding Surface treatment Casting

APPENDIX C

FUNDING--SUPPORTING DATA FOR SECTION 4.0

TABLE C.1. 1984 Government Outlays in Selected Industrial Nations in Billions of U.S. Dollars (Keizai Koho Center 1986)

Country	Government Outlays	Deficit	Deficit as Percent of Outlays	Debt	Debt as Percent of GNP
United States	867.7	-184.4	21.3	-1663.0	45.4
Japan	216.9	- 54.2	25.0	- 645.3	51.5
United Kingdom	138.2	- 10.9	7.9	- 190.5	47.1
France	113.2	- 14.9	13.1	- 74.7[a]	16.5[a]
Italy	113.0	- 12.3	10.8	- 209.3	68.8
West Germany	88.5	- 10.1	11.4	- 129.1	21.0

(a) 1983.

TABLE C.2. National Expenditures for Research and Development (NSF 1985a)

Country	1975 Total,[a] $ Billions	1975 Nondefense, %	1983 Total,[a] $ Billions	1983 Nondefense, %
Japan	11.0	99.5	20.2	99.6
United States	35.2	74.0	50.0	73.3
West Germany	7.7	94.2	10.5	96.1
France	5.3	81.1	7.6	78.7

(a) Expressed in constant 1975 dollars.

TABLE C.3. Total and Nondefense R&D/GNP: Japan Versus United States (NSF 1985a)

Year	Total R&D/GNP, % Japan	Total R&D/GNP, % United States	Nondefense R&D/GNP, % Japan	Nondefense R&D/GNP, % United States
1971	1.85	2.48	1.79	1.68
1973	1.90	2.32	1.84	1.62
1975	1.96	2.27	1.95	1.68
1977	1.93	2.23	1.92	1.67
1979	2.09	2.27	2.08	1.75
1981	2.38	2.43	2.37	1.87
1983	2.58	2.62	2.57	1.92

TABLE C.4. Sources and Performers of R&D in Japan and Western Nations (Anderson 1984)

Country (year)	Performers of R&D, %			
	Industry	Government	Private Nonprofit	Higher Education
Japan (1982)	68.7	11.1	4.2	16.1[(a)]
United States (1982)	71.1	12.9	3.2	12.8
United Kingdom (1978)	64.2	21.2	3.2	11.4
West Germany (1981)	67.6	5.3	10.9	16.2
France (1979)	59.5	23.6	1.4	15.5

Country (year)	Sources of R&D Funding, %			
	Industry	Government	Private Nonprofit	Higher Education
Japan (1982)	70.5	23.6	0.6	5.2
United States (1982)	49.3	47.2	2.1	1.4
United Kingdom (1978)	42.9	48.1	1.7	1.1
West Germany (1981)	54.4	43.1	0.9	--
France (1979)	43.1	36.6	0.6	14.5

(a) Most of these are national universities, but some are private or regional colleges.

TABLE C.5. Japan's Energy R&D Budget in 1985 (IEA 1986)

Energy Program	1985, $M	Total Energy[a] Budget, %
Nuclear (Nonbreeder)	769.6	49.4
Advanced Nuclear (Breeder and Fusion)	440.7	28.3
Coal	146.5	9.4
Renewable Energy	70.5	4.5
Energy Technologies (e.g. Transmission, and Storage)	60.4	3.9
Oil and Gas	57.9	3.7
Conservation	12.3	0.8
• Transportation	7.1	0.5
• Industry	1.7	0.1
• Buildings	0.3	0.0
• Other	3.3	0.2
Total	$1557.9	100.0

(a) These percentages have been rounded.

TABLE C.6. 1978 to 1985 Government Conservation Budgets, Reported in Millions of 1985 Dollars (IEA 1986)

Country	1978	1979	1980	1981	1982	1983	1984	1985
Japan	62.1	26.1	31.6	18.2	10.7	11.7	11.9	12.3
United States	185.3	249.4	380.9	266.8	162.5	226.7	169.7	173.6
Canada	19.5	19.4	25.5	37.2	43.4	54.6	54.8	50.4
United Kingdom	22.9	20.8	20.2	21.5	40.5	44.3	32.6	37.1
Spain	2.3	3.0	2.2	3.3	8.1	25.2	38.0	34.4
Sweden	23.5	27.2	29.9	32.3	36.6	35.4	28.0	22.3
Italy	13.5	11.0	15.6	11.6	14.9	21.6	25.9	19.3
Netherlands	13.6	15.7	17.0	17.3	13.8	19.0	16.6	19.2
West Germany	32.4	25.5	38.2	43.5	28.7	22.1	12.9	14.2

TABLE C.7. Moonlight Project Budget, 1983 to 1985 (AIST 1984a; AIST 1986)

Project (Duration)	Funding, Billion Yen[a] JFY 83	JFY 84	JFY 85
Advanced Gas Turbine (1978 to 1987)	4.40	2.57	1.21
Advanced Battery Storage (1980 to 1990)	1.10	1.29	2.20
Fuel Cell Power Generation (1981 to 1986)	2.03	3.67	4.78
Stirling Engines (1982 to 1987)	0.96	1.25	1.67
Advanced Heat Pumps (1984 to 1991)	0.00	0.03	0.61
Leading and Basic Technologies	0.19	0.23	0.23
Other	0.92	0.61	0.46
Total	9.59	9.63	11.15

(a) These numbers have been rounded.

TABLE C.8. Japan's Conservation-Related R&D Budget for JFY 1985 (AIST 1985; Landgrebe 1986; Committee on Laser Diagnostics and Prediction of Combustion 1986; "ERATO Looks to Other Countries," 1985)

Conservation Project	Million Yen	Million U.S.$[a,b]
MITI : MOONLIGHT PROJECT	11,091	49.29
• Fuel Cells	4,776	21.23
• Advanced Batteries	2,201	9.78
• Stirling Engines	1,673[c]	7.44
• Advanced Gas Turbine	1,207[c]	5.36
• Advanced Heat Pumps	607[c]	2.70
• Leading and Basic Technologies	227	1.01
• Other	400	1.78
BASIC TECHNOLOGIES FOR FUTURE INDUSTRIES	3,968	17.64
• High-Performance Ceramics	961	4.27
• Advanced Composite Materials	721	3.20
• Advanced Alloys	610	2.71
• Synthetic Membranes	556	2.47
• Bioreactors	446	1.98
• Synthetic Metals	375	1.67
• High-Performance Plastics	299	1.33
NEDO	400	1.78
• Methanol Utilization	400	1.78
MESC : UNIVERSITIES	190	0.84
• Combustion and Laser Diagnostics	190	0.84
STA : ERATO	1,524	6.77
• Amorphous Metals and Intercalation Compounds	459	2.04
• Ultrafine Particles	349	1.55
• Superbugs	329	1.46
• Fine Polymers	247	1.10
• Solid Surfaces	140	0.62
TOTAL	17,173	76.32

(a) These numbers have been rounded.
(b) 225 Yen = $1.
(c) Much of this research was performed by NEDO.

TABLE C.9. R&D Budget of the Ministry of Construction, 1984 to 1985 (NSF 1985b)

Budget Item	JFY84[a]	JFY85[a]
Construction industry use of waste material	76.1	67.9
Fire-resistant building design	62.6	67.7
Restoring quake-damaged structures	79.1	56.3
Lake water management techniques	65.4	48.9
Building snow-resistant cities	61.2	41.6
Electronics-based systems for upgrading architectural techniques	38.4	65.6
Improving durability of concrete	--	145.6
New sewage treatment systems using biotechnology	--	103.0
Improving durability of buildings	69.5	Completed
Construction technology evaluation	14.3	13.3
Public Works Research Institute	2,536.6	2,553.1
Building Research Institute	1,750.4	1,751.7
Appropriations related to other government agencies	352.0	196.3
Geographical Survey Institute	32.2	32.2
Overseas construction technology development projects	31.1	24.7
Total	5,168.9	5,167.9

(a) In million yen.

TABLE C.10. Budget and Staffing Trends of MITI Institutes and Laboratories (AIST 1982)

Facility	Budget, in Billions of Yen 1981	Budget, in Billions of Yen 1985	Staff (Research/Admin.) 1981	Staff (Research/Admin.) 1985
MEL	2.97	3.28	106/25	105/23
ETL	9.02	9.04	567/163	556/142
Fermentation Research Institute	0.99	1.37	63/21	67/19
National Chemical Laboratory for Industry	3.91	3.73	300/97	292/85
Research Institute for Polymers and Textiles	1.14	1.39	106/25	105/23
Industrial Products Research Institute	1.15	1.35	108/35	105/28
National Research Laboratory of Metrology	1.86	1.95	131/109	128/100
GIRI, Hokkaido	1.38	1.19	74/32	47/27
GIRI, Tohoku	0.61	0.58	39/19	39/17
GIRI, Nagoya	2.66	2.61	208/66	199/61
GIRI, Osaka	2.49	2.62	176/67	174/56
GIRI, Chugoku	0.74	0.66	54 Total	41/12
GIRI, Shikoku	0.48	0.55	35/11	34/11

TABLE C.10. (contd)

Facility	Budget, in Billions of Yen 1981	1985	Staff (Research/Admin.) 1981	1985
GIRI, Kyushu	0.92	0.83	70/25	69/22
Geological Survey of Japan	4.64	4.41	410 Total	252/135
National Research Institute for Pollution and Resources	4.32	3.73	262/106	252/95

TABLE C.11. Budget and Staffing Trends of STA Institutes and Laboratories (STA 1983; STA 1985)

Facility	Budget, in Billions of Yen		Total Staff	
	1981	1985	1981	1985
Institute of Physical and Chemical Research	9.45	11.10	619	620
National Research Institute for Metals	3.70	3.83	457	447
National Institute for Research in Inorganic Materials	1.60	1.77	169	166
JRDC	4.19	4.20	79	81
JICST	4.28	4.66	329	328
National Aerospace Laboratory	10.00	10.01	470	456
National Space Development Agency	86.07	88.86	920	931
National Institute of Resources	0.26	0.26	41	42
Japan Atomic Energy Research Institute	82.99	91.67	2,407	2,548

TABLE C.11. (contd)

Facility	Budget, in Billions of Yen 1981	1985	Total Staff 1981	1985
Power Reactor and Nuclear Fuel Development Corporation	124.91	137.78	2,741	2,794
National Institute of Radiological Sciences	5.84	5.55	412	447
Japan Marine Science and Technology Center	5.02	6.90	138	146
National Research Center for Disaster Prevention	2.17	2.09	119	118

APPENDIX D

SPECIFIC AREAS OF CONSERVATION RESEARCH--SUPPORTING DATA FOR SECTION 5.0

TABLE D.1. Research Schedule of MITI's Program in Advanced Ceramics (National Research Council 1984)

```
          Activities                1982      1984      1986      1988      1990
MANUFACTURE

 1) Powder preparation                    Pilot scale
                                  /----------------------/

 2) Forming and sintering
    - mechanisms                  /-------------------------------------/
    - materials                   /-------------------------------------/
                                    Test piece   Model I       Model II

 3) Finishing and joining
    - techniques                               /-------------------/
    - mechanisms                  /------------------/
    - machine development              /-------------------------------------/
                                       Survey; Fundamental; Practical Machine

EVALUATION

 1) Properties
    - powders                     /-------------------------------/
    - sintered bodies             /--------------------------------------------/

 2) Nondestructive
      Evaluation                            /-----------------------------------/
                                             Survey    Fundamental   Application

 3) Proof testing
    - rupture                       /------------------------------------------/
    - lifetime prediction                     /-------------------------------/

APPLICATION

 1) Design technology
    - structural analysis         Survey
                                    /------------------------------------------/

                                            Static      Dynamic      Complex
    - tests on models             Survey   Structure   Structure    Structure
                                  /-------------------------------------------/

 2) Performance
      Verification                                  /--------------------------/
                                                     Survey      Rig       Rig
                                                                 design    tests
```

TABLE D.2. Japan's Engineering Research Association for High-Performance Ceramics (National Research Council 1984)

Member Company	Research Assignment
Toshiba Corporation	Sintering of silicon nitride
Kyocera, Ltd.	Optimization of the sintering process
Asahi Glass	Shaping and sintering of silicon carbide ceramics
NGK Spark Plug	Two-step sintering of silicon nitride
NGK Insulators	Develop technical assessment methodology
Showa Denko K.K.	Fabrication of silicon carbide
Denki Kagaku Kogyo K.K.	Fabrication of silicon nitride from silicon powders or silicon halides
Toyota Machine Works	Apparatus for testing bending strength at high temperatures
Kobe Steel	Sintering of silicon nitride by hot isostatic processing
Toyota Motors	Measurement of high-temperature strength
Inoue Japan	Machining and fabrication
Sumitomo Electro-Chemical	Minimizing grain size distribution
Kurozaki Refractories	Corrosion tests
Shinagawa Refractories	Thermal fatigue testing
Ishikawajima Harima Heavy Industries	Design of mechanical parts

TABLE D.3. Timetables for Heat Pump and Stirling Engine R&D from the Moonlight Project (AIST 1984)

Activity	HEAT PUMPS 1984	1985	1986	1987	1988	1989	1990	1991
Study on working fluids and materials	/---	---	---	---/				
System evaluation		/---	---	---	---	---	---	---/
Plant construction			Bench plant			Pilot plant		
- systemization	/---	---	---	---	---	---	---	---/
- design		/---	---	---	---	---	---/	
- elemental technologies	/---	---	---	---	---	---	---/	
- construction			/---	---	---	---	---	---/
Studies on integrated systems	/---	---	---	---	---	---	---	---/

Activity	STIRLING ENGINES 1982	1983	1984	1985	1986	1987
System evaluation	/---	---	---	---	---/	
Stirling engine	/---	---	---	---	---	---/
Application system		/---	---	---	---	---/
Multifuel application		/---	---	---	---	---/

TABLE D.4. Timetable and Goals of Advanced Battery R&D (Moonlight Project) (AIST 1984; Landgrebe 1986)

Activities	TIMETABLE 1980	1982	1984	1986	1988	1990
Development of advanced batteries	Fundamental study	1-kW class		10-kW class	1000-kW class	
	/----------	----------	----------	----------	---------/	
R&D on system technology	/----------	----------	----------	----------	---------/	
		Design and fabrication				
Demonstration test				Design and fabrication	System test	
				/----------	----------	----------
Total system study	Analysis of load patterns and optimum configuration		Environment and safety problems		Evaluate economy and overall system reliability	
	/----------	----------	----------	----------	----------	----------

GOALS	
Output	1000 kW
Standard time	8-h charge/8-h discharge
Efficiency	>70 % (ac input/output)
Service life	~10 years (1500 cycles)
Environmental impact	Conforms to all environmental quality standards

TABLE D.5. Timetable of Fuel Cell R&D, Moonlight Project (AIST 1984)

Fuel Cell Type	1981	1982	1983	1984	1985	1986
	Fundamental study					
Phosphoric acid	/----------	----------	----------	-----/	1 MW-class	
			/----------	----------	----------/	
		1-kW class		10-kW class		
Molten carbonate	/----------	----------	----------	----------	----------	----------/
					1-kW class	
Solid oxide	/----------	----------	----------	----------	----------	----------/
		1-kW class				
Alkaline	/----------	----------	----------	----------	-----/	
	Optimization of power system					
Total system	/----------	----------	----------	----------	----------	----------/

TABLE D.6. Key Researchers and Projects in Combustion R&D (Committee on Laser Diagnostics and Prediction of Combustion 1986)

Research Project	Researcher	Affiliation
VELDCITY MEASUREMENTS		
Measurements of integral length scales during short period with multipoint laser Doppler velocimeters (LDVs)	Dr. N. Nakatani	Osaka University
Improvement of laser Doppler anemometer (LDA) for measurement of velocity in spray jet with particle discrimination	Dr. M. Maeda Dr. K. Hishida	Keio University
Flow characteristics of unsteady jet injected into the prechamber of an engine	Dr. T. Asanuma Dr. T. Iijima Dr. K. Katayama	Tokai University
Flame quenching and unburned hydrocarbons on the wall of a spherical combustion vessel	Dr. Y. Hamamoto Dr. E. Tomita	Okayama University
Gas velocity measurements in a combustion chamber of a stratified injection (SI) engine by LDA with fiber-optic pick-up	Dr. T. Obokata	Gunma University
PARTICULATE MEASUREMENTS		
Fourier transform method for particle distribution	Dr. T. Murakami	Kyushu University
Characteristics of diesel sprays by bi-dimensional light-scattering image processing method	Dr. I. Shimizu	Ibaraki College of Technology

	Researcher	Affiliation
Photographic study of soot formation in a diesel flame with a rapid compression machine	D. T. Kamimoto Dr. H. Kobayashi	Tokyo Institute of Technology
Application of twin pulse laser holographic interferometry	Dr. Y. Yamamoto	Tokai University
TEMPERATURE AND SPECIES CONCENTRATION MEASUREMENT		
Development of a real-time flame spectrometer	Dr. T. Ohsawa Dr. T. Ozaki	Tokyo Nonkoh University
Two-color coherent anti-Raman spectroscopy (CARS) temperature measurement	Dr. Y. Adachi Dr. S. Maeda	Tokyo Institute of Technology
Measurement of 3-dimensional flame temperature fields by holographic interferometry and computed tomography	Mr. S. Satoh	Ship Research Institute, Ministry of Transport
CARS studies of the vibrational relaxation of nitrogen molecules behind shock waves of hydrogen-oxygen mixtures	Dr. H. Matsui	University of Tokyo
Measurement of species concentration	Dr. S. Yamagishi	Ship Research Institute, Ministry of Transport
FLAME STRUCTURE AND COMBUSTION MODELING		
Structure of turbulent premixed flames	Dr. A. Yoshida	Tokyo Denki University

TABLE D.6. (contd)

Research Project	Researcher	Affiliation
3-dimensional geometric shape modeling for flames from multidimensional images	Dr. J. Doi	University of Tokyo
In-cylinder measurement of turbulence by Homodyne principle	Dr. M. Ikegami Dr. M. Shioji Dao-Yuan Wei	Kyoto University
Modeling of flame propagation in constant volume vessels	Dr. M. Kohno Dr. K. Iinuma	University of Tokyo Hohsei University
Experimental study on direct-injection charge stratification	Dr. Y. Daisho Dr. T. Saito	Waseda University
STANDARD BURNERS		
Standard burners	Dr. T. Ohsawa Dr. A. Yoshida	Tokyo Nonkoh University Tokyo Denki University

TABLE D.7. Key University Researchers in Heat Transfer R&D (Kuo 1983)

Researchers	Fields of Expertise
UNIVERSITY OF TOKYO	
Dr. S. Nishio	Direct contact condensation Turbulence promoters Quenching
Dr. K. Takano	Turbulence promoters
Dr. M. Tado	Turbulence promoters
Dr. N. Kasagi	Impinging jet
Dr. M. Akiyama	Direct contact heat transfer
Dr. T. Ueda	Boiling
TOKYO INSTITUTE OF TECHNOLOGY	
Dr. Yasuo Mori	Respected in all fields of heat transfer
Dr. H. Yoshida	Convection enhancement Turbulence promoters
Dr. A. Yabe (now at MITI)	EHD effect Condensation
KYUSHU UNIVERSITY	
Dr. K. Nishikawa	Boiling
Dr. T. Ito	Boiling
Dr. T. Fujii	Condensation
KYOTO UNIVERSITY	
Dr. F. Ogino	Condensation
Dr. K. Gimi	Boiling
Dr. K. Suziki	Heat exchanger optimization
TOHOKU UNIVERSITY	
Dr. Takeyama	Heat transfer enhancement (fins, tubes)

TABLE D.7. (contd)

Researchers	Fields of Expertise
NAGOYA UNIVERSITY	
Dr. R. Izumi	Enhanced heat transfer
Dr. H. Yamashita	Enhanced heat transfer

TABLE D.8. Biotechnology Research Schedule, 1981 to 1990 (Lewis 1985a)

Areas of Investigation	Stage 1	Stage 2	Stage 3
Bioreactors	Screening of microorganisms and/or enzymes	Optimum conditions of each bioreactor	Evaluation of new bioreactors in bench scale
Cell cultivation	Selection of cell lines and research of media	Optimum conditions of cell culture	Evaluation of cell culture process in bench scale
Recombinant DNA	New host-vector system and cloning of useful genes	Efficient expression of new genetic materials	Evaluation of new genetic materials in bench scale

TABLE D.9. Bioreactor Projects of the Research Association for Biotechnology (Lewis 1985b)

Company	Research Project
Kao Soap Company	Microbial oxidation of higher alkyl compounds. Some 12,000 domestic and foreign soil samples were collected and the following strains isolated: n-hexadecane assimilating, alkyl-chloride chloride assimilating, and n-hexadecane assimilating thermophile microorganisms.
Daicel Chemical Industries	The goal of this project is to develop a bioreactor that can produce acetic acid using CO_2 and hydrogen. Anaerobic bacteria from bottom mud of rivers, lakes, and seas in Japan and elsewhere were collected and screened for strains that accumulated large amounts of acetic acid. A new species of the genus *Acetobacterium* was found that could concentrate over 20 g/L of acetic acid.
Denki Kagaku Kogyo KK and Mitsui Petrochemical Industries	Screening of microorganisms with high aldose reductase activity. It was found that in 24 hours only yeast had high sorbitol productivity, and a strain of *Candida tropicalis* that produced 73 g/L of sorbitol was identified.

TABLE D.10. Government and University R&D in Bioreactors (Lewis 1985a)

Organization	Research Areas
Fermentation Research Institute	- Utilization of nitrogen fixation by microorganisms - Coenzyme recycling systems - New host-vector system using *E. coli*, *Bacillus subtilis*, and yeast - Carbohydrate production using cellulase - Microbial engineering for decomposition of mercury compounds and PCBs - Nitrogen fixation - Ethanol production from biomass
GIRI, Osaka	- Utilization of untapped timber resources
Industrial Products Research Institute	- Suitability of synthetic polyamine acid composite film as surface coating material
University of Tokyo (Institute of Applied Microbiology)	- Microbial cell activity and fermentation physiology - Mechanism of bacterial enzyme synthesis - Structure and function of biomembranes - Process design of bioreactor - Quantitative approach to energy conversion through biological membranes - Process analysis of microbial growth - Production of ethanol from immobilized yeast
Kyoto University	- Continuous cellulase production - Construction of enzyme conjugates - Enzyme immobilization

TABLE D.11. Key Government and University Researchers in Tribology R&D

Organization	Key Researchers	Technical Focus
MEL	Dr. Tsuya (head of tribology facility)	- Subsurface cracking - Ceramic coatings - Solid lubricants
GIRI, Nagoya		- Metal cutting and grinding processes - Boronizing of steel
GIRI, Osaka		- Mechanisms of dry sliding wear in ceramics
GIRI, Kyushu		- Cutting tool materials for cutting titanium-boride based cements - High-performance grinding
Tohoku University	Professor Tamai Professor Kato	- Boundary lubrication - Sliding wear - Gear lubrication
Tokyo Institute of Technology	Professor Sasada (he and staff are principal mechanical tribology consultants to Toyota) Professor Okabe	- Basic mechanisms of wear - Surface films - Materials characterization - Debris particle formation
University of Tokyo, Main Campus	Professor Hori Professor Someya	- Polymer bearings - Rotodynamics - Journal bearings
University of Tokyo, Research Campus	Professor Kimura Professor Soda (retired; chief chemical tribology consultant to Toyota)	- Elastohydrodynamic lubrication - Contact fatigue - Wear
Agricultural University of Tokyo	Professor Yamamoto	- Contact fatigue - Wear
Electrocommunication College in Tokyo	Professor Naruse	- Gear lubrication

APPENDIX E

INTERNATIONAL COLLABORATION--SUPPORTING DATA FOR SECTION 6.0

TABLE E.1. Formal Japanese Bilateral Agreements and Exchanges of Notes in International Science and Technology (agreements concerning energy conservation are underlined) (Ishizaka 1983; AIST 1985)

Country	Implemented	Fields of Cooperation
United States	1961	Scientific exchange Science education Earth sciences, space, astronomy Biological sciences Mathematics, physics, chemistry Engineering Others
United States	1964	Water technology Pasture seeds Toxic microorganisms Micoplasma diseases Safety and recreation Wind and seismic effects Protein resources Forestry Fire research and safety Earthquake prediction Marine development Others
South Korea	1968	Scientific education Information exchange Earth and space sciences Biological sciences Mathematics, physics, and chemistry Engineering
Canada	1972	Fire prevention/construction Environment Space and telecommunications Agriculture Marine development Transportation Others
USSR	1973	Nuclear power Agriculture

TABLE E.1. (contd)

Country	Implemented	Fields of Cooperation
France	1974	Marine science and technology Life Sciences New energy resources Energy conversion Building engineering Space communications New materials Electronics Biotechnology
West Germany	1974	Marine science and technology Safety of nuclear fuel cycle Nuclear reactor development Biological sciences Environmental protection New energy resources High temperature gas furnaces Information systems High energy physics Space research New materials
USSR	1974	Scientific and technical exchange
Romania	1975	Not stipulated
East Germany	1975	Not stipulated
Phillipines	1975	Meteorological standards
United States	1975	Air pollution Industrial waste treatment
Bulgaria	1978	Not stipulated
Czechoslovakia	1978	Not stipulated
Poland	1978	Not stipulated
Thailand	1978	Electric/photometric standards
Peru	1978	Low-grade complex ores
Thailand	1978	Utilization of non-woody fibers for paper making

TABLE E.1. (contd)

Country	Implemented	Fields of Cooperation
Australia	1978	Coal utilization Solar energy Conservation
United States	1979	Nuclear fusion Coal conversion Solar energy/photoconversion Geothermal energy High-energy physics Others
Hungary	1979	Not stipulated
Chile	1979	Calcium-alkaline magmatism
Indonesia	1979	Oil-spill clean up
United States	1980	Space research Basic physics Life sciences Environment Medicine Agriculture/forestry Others
China	1980	Refining of pig iron Agricultural pesticides Others
Australia	1980	Not stipulated
Thailand	1980	Geothermal energy
Brazil	1980	Niobium-based superconductor
South Korea	1980	Remote sensing techniques
Philippines	1980	Industrial waste utilization
Malaysia	1980	Lightweight building materials
Sweden	1980	Polymers and composites Ceramics Lignin Biotechnology Medical technology

TABLE E.1. (contd)

Country	Implemented	Fields of Cooperation
Indonesia	1981	Marine science and technology Energy Medicine Agriculture Earth sciences Architure/civil engineering Space Meteorology Telecommunications Industrial development Information systems Others
Yugoslavia	1981	Not stipulated
South Korea	1981	Numerical control software for press tools
South Korea	1982	Grinding operation standards
Malaysia	1982	Utilization of vegetable oils
Turkey	1982	Analysis of earthquake faults
Sri Lanka	1983	Utilization of rubber wood
Malaysia	1983	Utilization of palm residues
Indonesia	1983	Waste water from textile mill
China	1983	Refractory mineral resources Controlling coal dust explosions
Brazil	1983	Carbonatite mineral deposits
Thailand	1983	Agri-wastes for building materials
Philippines	1983	Survey of oil and gas fields
Brazil	1984	Continuous ethanol fermentation
China	1984	Opaque pottery glaze
Indonesia	1984	Polypropelene modification

TABLE E.1. (contd)

Country	Implemented	Fields of Cooperation
South Korea	1984	Force standards
Thailand	1984	Frequency power standards
Philippines/Indonesia	1984	Mass measuring instruments
Singapore	1985	Finishing technology of curved surfaces
Malaysia	1985	Palm oil chemical resources
Turkey	1985	Quarternary crustal movement
Philippines	1985	Slow-release fertilizer
Indonesia	1985	Soil-based building materials
France	1985	New doped SiO_2 glasses
West Germany	1985	Highly sensitive detection using stabilized lasers

TABLE E.2. IEA Implementing Agreement on Combustion Processes

Annex: 1) Combustion System Modeling and Diagnostics

Type: Task Shared

Operating Agent: United States

Status: Ongoing (began in 1976; new agreement signed in 1983)

Objective: To improve fundamental and applied combustion technology that is developed to provide predictive design capabilities for internal combustion engines and furnaces.

Tasks: Japan's most recent research activities in this area include combustion in spark ignition engines; combustion and emission of diesel engines; industrial burner design using laser and computer techniques; gas flows containing fine particles; measurement of turbulent combustion flows; and picture processing of spray characteristics.

TABLE E.3. IEA Implementing Agreement on Advanced Heat Pump Technology

Annex: 4) Heat Pump Center

Type: Cost shared

Operating Agent: West Germany

Status: Ongoing (Began in 1982; renewed in 1985 for 3 years)

Objective: To encourage the commercialization of heat pumps that save significant amounts of energy; to facilitate international trade in heat pumps; to improve the quality of information on heat pumps.

Tasks: Japan, like all the other members, provides funding for the Center and contributes information on national programs upon request.

Annex: 10) Large Industrial Heat Pumps

Type: Task shared and cost shared

Operating Agent: Belgium

Status: Ongoing (began in 1986)

Objective: Investigation of the status and future prospects of industrial heat pump applications.

Tasks: Unknown

TABLE E.3. (contd)

Annex: 11) Stirling Engine Technology

Type: Task shared and cost shared

Operating Agent: United States

Status: Ongoing (began in 1986; set to end in 1988)

Objective: The first objective is to gain a strategic assessment of the technology of Stirling-engine-driven heat pumps through international cooperation. A secondary objective is to identify specific topics for further cooperative research.

Tasks: Japan, Sweden, and the United States will exchange summaries of Stirling engine research in their respective countries. The United States, as Operating Agent, will use the information to conduct a strategic assessment of the technology. Specific emphasis will be placed on comparing the free-piston approach of the United States with the kinematic-drive approach of Japan and Sweden.

Annex: 12) Simulation and Design of Compression Heat Pumps

Type: Task shared and cost shared

Operating Agent: United States

Status: Ongoing (began in 1986; set to end in 1988)

Objective: To assess the adequacy of techniques for modeling the seasonal performance of air-source heat pumps and to define needs for additional fundamental information and research activities.

Tasks: Each participant contributes a computer program for modeling heat pump seasonal performance and field data for cross-validation.

TABLE E.3. (contd)

Annex: 13) Working Fluids and Nonazeotropic Mixtures

Type: Task shared and cost shared

Operating Agent: Sweden

Status: Ongoing (expected to begin during the fourth quarter of CY1986)

Objective: To increase the knowledge of state and transport properties of high temperature working fluids and nonazeotropic mixtures.

Tasks: Each participant will contribute the results of a research project on measurement or assessment of data on state and transport properties.

Japan has also participated, but was not the Operating Agent, in three completed annexes: 1) Common Study; 3) Industrial Heat Pumps; and 6) High Temperature Working Fluids for Compressor Driven Systems.

TABLE E.4. IEA Implementing Agreement on Alcohol and Alcohol Blends as Motor Fuels

Annex: 2) Alcohol Production

Type: Task Shared

Operating Agent: Canada

Status: Ongoing (1986 to 1989)

Objective: To exchange technical information related to advanced alcohol production techniques.

Tasks: Each participant pledges material on specific projects.

Annex: 3) Methanol-Fueled Diesel Field Trials

Type: Cost Shared

Operating Agent: Canada

Status: Ongoing (1986 to 1989)

Objective: To accumulate data from participants' field trials of diesel buses so as to provide a broader base of evaluation.

Tasks: Each participant pledges material on specific fleet tests.

TABLE E.4. (contd)

Annex: 4) Technology Exchange

Type: Cost Shared

Operating Agent: Sweden

Status: Ongoing (1986 to 1989)

Objective: To collect, analyze, and disseminate information on all aspects of motor alcohols, and to create a common basis of information related to market introduction.

Tasks: Each participant pledges information on results in its country and known results of nonparticipants.

Japan and the United States participated in the recently completed Annex 1) Common Study. The annex was cost shared with Sweden as the Operating Agent.

TABLE E.5. International R&D Collaboration Through the Japan Society for the Promotion of Science (JSPS 1985)

Research Subject	Japanese Participant	Participating Country	Duration
Basic studies in two-phase flow and two-phase MHD	University of Tsukuba, Prof. Shigeki Morioka	France	April to June 1984
Superplasticity in wood	Nagoya University, Prof. Tomio Takemura	Switzerland	September to November 1984
Fracture of metallic materials during high-temperature creep	Tohoku University, Prof. Hajime Suto	United Kingdom	April to May 1984
Electrochemistry of metals and metal oxides	Hokkaido University, Prof. Norio Sato	West Germany	July to September 1984
Plasticity of metals	Institute of Space and Astronautical Science, Prof. Ryo Horiuchi	United States (Los Almos National Laboratory)	March to April 1985
Elevated temperature mechanics of materials	University of Tokyo, Prof. Yasuhide Asada	United States (Renssalaer Polytechnic Institute)	April to July 1984
Scale-up and optimum design of aerobic fermentor	Osaka University, Prof. Hisaharu Taguchi	Israel	August to October 1984
Energy transduction in biomembranes	Jichi Medical School, Prof. Yasuo Kagawa	United Kingdom	October 1984
Chemical engineering research in catalytic reactors	Yokohama National University, Prof. Noriaki Wakao	Canada	February to June 1985

TABLE E.5. (contd)

Research Subject	Japanese Participant	Participating Country	Duration
Composite materials strength and its application to future generation composite materials development	University of Tokyo, Prof. Akira Kobayashi	United States (University of Delaware)	March to July 1985
Experimental study of new superconducting materials	Tohoku University, Prof. Yoshio Muto	West Germany	April to September 1984
Characterization of solid catalyst surfaces and their reactivity	Hokkaido University, Prof. Isamu Toyoshima	India	March to October 1984
Surface chemical study of corrosion and passivation of iron-base alloys	Hokkaido University, Prof. Norio Sato	Sweden	April 1983 to March 1985
Synthesis of fibrous graphite intercalation compounds and development of their new applications	Toyohashi University of Technology, Prof. Tetsuo Takaishi	France/United States	April 1983 to March 1985
Study on polymer concrete as composite material	Akita University, Prof. Makoto Kawakami	Belgium	May 1984 to May 1985
Control of polymer synthesis	University of Tokoy, Prof. Shohei Inoue	Brazil	July to August 1984
Studies on MHD electrical power generation	Tokyo Institute of Technology, Prof. Susuma Shioda	China	May to June 1984

TABLE E.5. (contd)

Research Subject	Japanese Participant	Participating Country	Duration
Study of crystalline defects	University of Tokyo, Prof. Masao Doyama	China	September 1984
Identification of structure of organic compounds and polymers	Osaka University, Prof. Kouichirou Hayashi	China	October 1983 to April 1984
Numerical calculation on 3-dimensional flow in turbo-machinery	University of Tokyo, Prof. Hiroyuki Takaka	China	November to December 1984
Mathematical modeling of field up- and downstream of flame stabilizer	University of Tokyo, Prof. Yoshimichi Tanida	China	November 1984
Aerothermodynamic design and calculation of turbomachinery	University of Tokyo, Prof. Hiroyuki Takada	China	November to December 1984
Mechanism, pressure drop, and measurement of two-phase flow	Nagoya University, Prof. Motoji Jinbo	China	April to May 1984
Internal friction resulting from hydrogen in metals	Tohoku University, Prof. Masahiro Koiwa	Italy	May to June 1984
Catalysis by zeolites	Tokyo Institute of Technology, Prof. Tatsuaki Yashima	South Korea	October 1984
Hollow fiber bioreactors	University of Tokyo, Prof. Shintaro Furusaki	South Korea	June to July 1984

TABLE E.5. (contd)

Research Subject	Japanese Participant	Participating Country	Duration
A study on the utility of alternative fuel in diesel engines	Hokkaido University, Prof. Tadashi Murayama	South Korea	July to August 1984
Ferrous metallurgy	Kyushu University, Prof. Yoichi Ono	South Korea	October 1984
Heat transfer problem considering temperature difference between sands and water for ATES (aquifer thermal energy storage) recovery	Yamagata University, Takao Yokoyama	Netherlands	April 1984 to August 1985
Theory of plasticity and viscoplasticity of metals	Osaka University, Prof. Hiroshi Kitagawa	Poland	October 1983 to October 1984
Fundamental study on welding metallurgy	Osaka University, Prof. Yoshiaki Arata	Poland	September 1984 to March 1985
Analysis of energy transfer mechanisms in phycobiliproteins by biochemical technique	Okazaki National Research Institutes, Prof. Mamoru Mimuro	Switzerland	April 1984 to September 1985
Fundamental studies of combustion phenomena using counterflow-flame technique	Saitama University, Prof. Hiroshi Tsuji	Soviet Union	October 1984
Diffusion and point defects in metals	University of Toykyo, Prof. Masao Doyama	Soviet Union	March to May 1984

TABLE E.5. (contd)

Research Subject	Japanese Participant	Participating Country	Duration
Theoretical and experimental study of binary and ternary alloys	University of Tokyo, Prof. Masao Doyama	Soviet Union	March 1984 to January 1985
Plasticization of wood and its applications	Kyoto University, Prof. Takuo Yokota	United States (Virginia Tech)	January 1984 to December 1985
Basic studies in MHD electric power generation	Tokoyo Institute of Technology, Prof. Susumo Shioda	United States (Montana State)	January 1983 to December 1985
Electron transfer and catalysis in polymer-metal complexes on electrode surfaces	Waseda University, Prof. Eishun Tsuchida	United States (California Institute of Technology)	January 1983 to December 1985
Studies on the effective use of energy in the processing of agricultural products	University of Tokyo, Prof. Hiroshi Morishima	Indonesia	March 1985
Studies on the effective use of energy in agricultural operations	University of Tokyo, Prof. Osamu Kitani	Indonesia	January 1985
Research on deformation processing for metals	Tokoyo Institute of Technology, Prof. Takashi Jinma	Indonesia	March 1985
Free conversion heat transfer	Tokyo Institute of Technology, Prof. Kunio Hijikata	Indonesia	March to April 1984
Study of corrosion prevention by inhibition	Kyoto University, Prof. Takahide Wakamatsu	Indonesia	September to December 1984

TABLE E.5. (contd)

Research Subject	Japanese Participant	Participating Country	Duration
Exchange of scientists in heat transfer, biotechnology, and polymer science	Kyoto University	Malaysia	December 1984
Research cooperation in ceramic science, combustion chemistry, and polymer science	Kyoto University	Malaysia	February 1985
Radiation chemistry on polymers	Osaka University, Prof. Koichiro Hayashi	Singapore	November to December 1984
Technology assessment of fermentation process	Osaka University, Prof. Junichi Koizumi	Singapore	July to August 1984
Alcoholic fermentation of cassava without cooking	Kyushu University, Prof. Yojiro Koba	Thailand	November to December 1984
Studies on alcoholic fermentation of starch materials without cooking	Kyushu University, Prof. Seinosuke Ueda	Thailand	March to April 1984
Application study of immobilized enzymes	Osaka University, Prof. Hirosuke Okada	Thailand	March to May 1984
Cellulase production and alcohol fermentation by thermotolerant microorganism	Kyushu University, Prof. Shinsaku Hayashida	Thailand	March to May 1984
Utilization of lignocellulose by anaerobic fermentation	Nagoya University, Prof. Shoichi Shimizu	Thailand	October to December 1984

TABLE E.5. (contd)

Research Subject	Japanese Participant	Participating Country	Duration
Planning and control of urban traffic	University of Tokyo, Prof. Masaki Koshi	Thailand	March 1985
Absorption refrigeration	Seikei University, Prof. Akira Tsuchnida	Thailand	November to December 1984
Emulsion polymerization and its applications	Osaka University, Prof. Koichiro Hayashi	Thailand	March to April 1985
Ethanol fermentation by flocculating yeasts and microbial hydroxylation of lithocholic acid	Osaka University, Prof. Hisharu	Thailand	October 1984
Microbial and enzymatic conversion of agricultural wastes to useful substances	Nagoya University, Prof. Shoichi Shimizu	Thailand	December 1984 to January 1985

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