Cooperating Research between Universities and Industries —Planar Antenna and Planar Microlens, as Its Examples—

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ABSTRACT
Cooperating Research between Universities and Industries is discussed with two examples of projects, where both technologies were born in university and developed by nicely organized cooperation research between university and companies, and finally commercialized into markets by industries. It is point out the importance of generation of truly novel concept for the success of cooperating research.

1. Introduction

We review with some examples the status of cooperating research performed between Japanese universities and industries. From many projects done in this decade we chose two typical cases made in the field rather close to the author' technical area. These were born in university research, developed through the cooperating works performed in universities and companies, and finally commercialized into markets. More extensive progress is expected along the expansion of communications and information processing.

2. Planar Radial Line Slot Antenna

Ultra-high efficiency (85%) and low-cost planar antennas named "radial line slot antenna (RLSA)" are developed for receiving direct broadcast from satellites (DBS). The RLSA was originally invented in Tokyo Institute of Technology in 1980. Its theoretical design has also been established in Tokyo Institute of Technology since then, while several companies have been supporting this development by providing manufacturing, product designing, field testing and partial financing. More than 0.3 million RLSAs have been commercially produced since 1989. The R & D history is surveyed below.

2.1 Background

(1) DBS System Picture

The DBS in the 12 GHz band is popular in Japan. High gain and low noise characteristics are strongly required for DBS receiving antennas; and reflector antennas have been utilized as the most popular devices. But planar arrays are attractive in many aspects and intensive researches have also been conducted, since the beginning of system planning in 1978.

(2) Element and Feeder Loss

Planar arrays consist of two components, that is feeding lines and the radiating elements. The former determines the efficiency, while both of them reflect to the cost. All of the arrays at that time adopted the conventional transmission lines as the feeder. They included microstrip-line, suspended-line and triplate-line antennas as are shown in Table 1. In

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[1] **Professor Emeritus**

Radial Line Slot Antenna

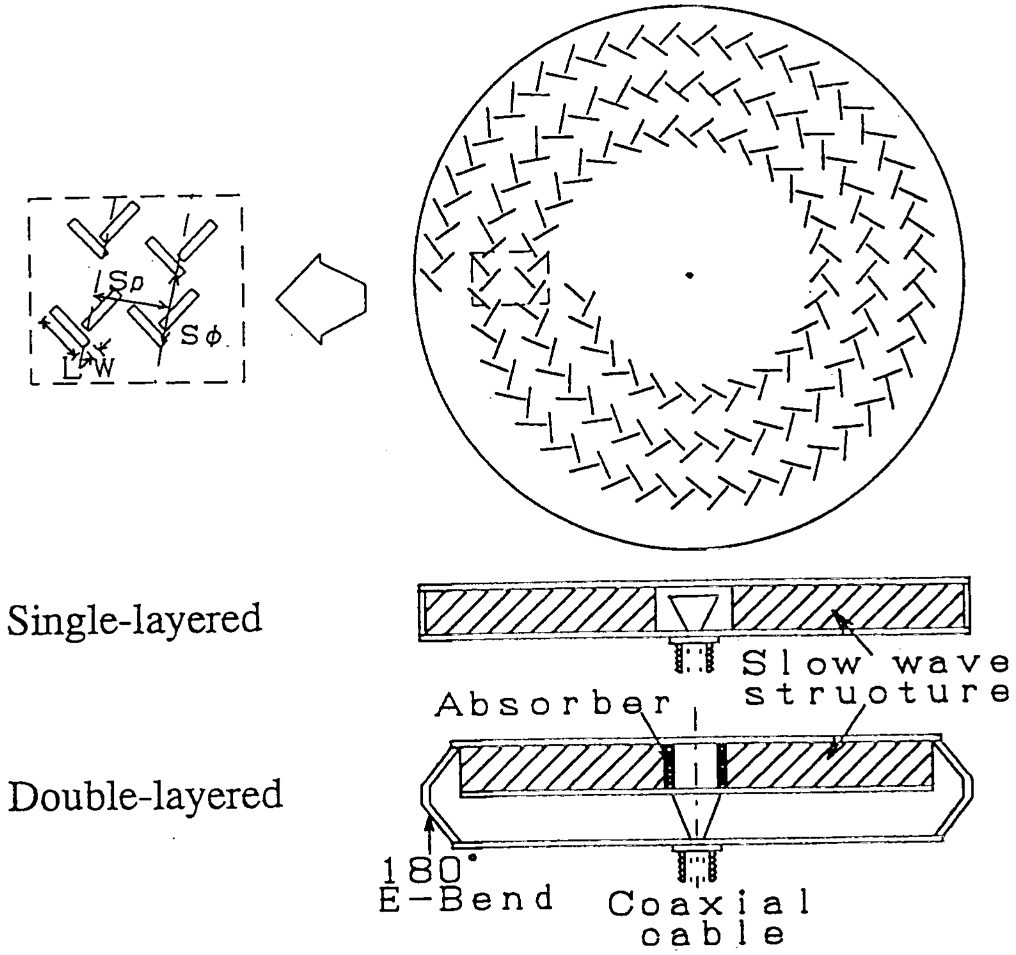

Fig. 1 The planar structure of radial line slot antenna

the 12 GHz band, these lines suffer from a large conductor loss and result in very low antenna efficiency of about 40%, which is much lower than 70% of conventional reflector antennas. Since the loss at the waveguide is negligible and the slots fit the waveguide well, a slotted waveguide array is thought to be a viable candidate for obtaining a high gain DBS receiving flat antenna.

(3) Military Example

The structure of a conventional slotted waveguide array, however, was very complicated. The high manufacturing costs prevented the commercialization and they have been applied only for military use. Therefore, a completely novel design was requested for reducing the cost of waveguide arrays.

(4) Research History

A radial line slot antenna (RLSA) was invented by Prof. Naohisa Goto of Tokyo Institute of Technology in 1980 [1]. Figure 1 shows a single-layered RLSA with the simplest structure.

In the single-layered RLSA, two conductor disks form a radial waveguide. Power is fed at the center of the guide and a radially outward traveling cylindrical wave is excited at the slots on the top plate. The unique arrangement of slots contribute to this simplest structure[2]. Those slots consisting of many pairs are arrayed along a designed spiral, each one of which functions a unit radiator of circular polarized wave. The lengths and spacings of the slot are varied over the aperture to maximize the antenna efficiency.

Here is another type of RLSA, double-layered ones. Although the structure is a rather complicated, the slot design is easier in that lengths and the spacings of slots can be constant over the aperture. So it was commercialized first [3].

(5) Important Developments

After the proposal of its concept, it took more than four years until the expected operation is achieved in a double layered RLSA and the research in Tokyo Institute of Technology demonstrated the feasibility of this antenna. The main difficulty was the manufacturing and assembling errors in the process. TOPPAN Printing Co. and ANTEN Corp. joined the group in 1985 and 1987, respectively. They improved the accuracy in manufacturing. At the same time, they introduced an etching technique to produce a large size slotted disk. This greatly contributed to speed up the design optimization, since the computer output data in the floppy disk was directly used to make the photo-mask for the etching. Based upon these, a remarkably high efficiency of about 80% was realized in 1987, which is about two times higher than the conventional arrays. The double-layer RLSA was then commercialized in 1989. The design optimization at that time, however, was based upon only the experiment.

In order to further simplify the structure and to realize the single-layer RLSA, theoretical optimization is indispensable, since all the slots have different length and spacing and numbers of parameters are too large to be optimized experimentally. The electromagnetic coupling analysis was started in 1987. In 1990, a fully theoretical design was established in Tokyo Institute of Technology and the slot design data began to be provided to the companies in the group producing commercial antennas.

2.2 Key Features and Uniqueness

Slot pair design for circular polarization
TEM cylindrical wave excitation
Multi-mode waveguide
Structure is the simple

2.3 Members of research group

Tokyo Institute of Technology, Dept. Electrical & Electronics Eng.
Prof. Naohisa Goto, Assoc. Prof. Makoto Ando (1982-), Res. Assist. Jiro Hirokawa (1988-), Students in Graduate School; 2 Doctors + 20 Masters, Undergraduate School; > 20, Research Students and Researchers from Companies; 10.

Companies
Arimura Inst. Tech. (1982-), TOPPAN Printing Co.(1985-), ANTEN Corporation (1987-)
NHK Spring/Hitachi Chemical/TOSHIBA/YAGI/INAX/ (1988-).

2.4 Period of research and finance 1980-present

Event	Year	Budget, Commercial Products
Invention	1980	
1981	$40,000	NHK Foundation
First operation	1984	
TOPPAN printing	1985	
High efficiency 80%	1987	$40,000 Ministry of Education
ANTEN Coop.	1987-Present	$200,000 Company
	1988-1991	$200,000 Ministry of Education
market (Double-layer)	1989	NEC, TOSHIBA
Patent (Slot Design)		(Patent Application 1981)
market (Single-layer)	1990	Panasonic
Computer design code		
U. S. Patent (Double layer)	1991	Fujitsu (Patent Application 1982)

2.5 Patent

Basics By Naohisa GOTO 1989-

Naohisa Goto/Arimura Inst. Tech/NHK 1990

Fringes jointly patented with companies

2.6 Industrial Contribution

a) The RLSA is the first high efficiency planar array which doubles the efficiency of conventional ones and exceeds parabolas.

b) The RLSA greatly simplifies the structure of slotted waveguide arrays. A single-layered RLSA is suitable for mass production. It is the first example of commercial waveguide array which was used to be utilized only for military. The production cost greatly depends upon the number of products. It is noted that the RLSA is already the most inexpensive antenna which is comparable to parabolas, although the planar arrays have only 5% share in the DBS antenna market.

c) The RLSA may open up a new academic field of high gain planar arrays.

2.7 Future plans

a) Enhancing the potential of RLSAs (toward 100% efficiency, wide-bandwidth, dual polarization)

b) A linearly polarized RLSA (terrestrial radio links, mobile communication)

c) Other applications

RF antennas for plasma etching/spattering of semiconductor device productions based upon the high power and high temperature handling capability.

3. Planar Microlens Arrays

3.1 Principle

The principle of a planar microlens is based on the ray refraction due to the refractive index distribution inside a glass substrate. This is substantially different from the conventional convex or concave lens which utilizes the refraction of light ray at spherical surfaces. It should be remembered that there is a rod lens having a gradient index in radial direction, which is known as a SELFOC lens developed by Nippon Sheet Glass Co. and NEC in 1968. On the other hand, the planar microlens introduced here has a three dimensional distribution of index.

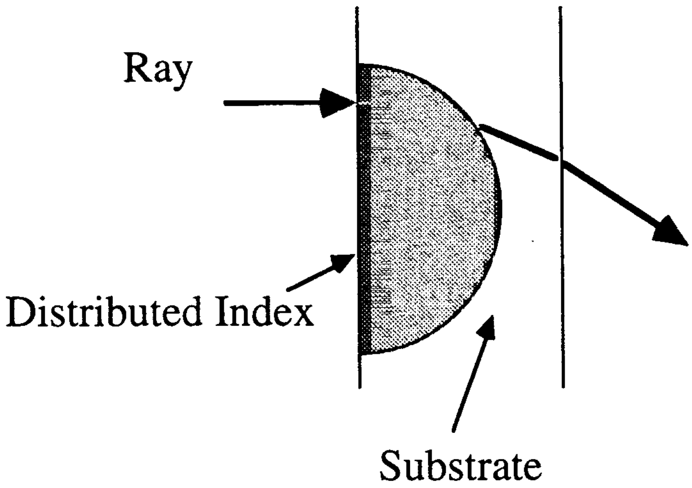

Fig. 2 The concept of a planar microlens.

This device was invented in May 1979 at Rochester, NY by Prof. K. Iga during his attendance at the 1st Topical Meeting on Gradient-Index Optical imaging Systems [8]. At that time he was staying at Bell Labs. working on semiconductor lasers and this idea arose independent from the current job and the research at Tokyo Institute of Technology.

3.2 Background and Its Motivation

Most of lenses at around 1979 were discrete except some of insect eye lenses. The inventor felt that those lenses have such problems that;

a) Difficult to integrate many devices into optical circuits
b) Production is being conducted by batch process
c) Non-planar surfaces prevent us to put other devices intact to them.
d) Difficult to make accurately arranged 2-D arrays

These were substantially against the direction toward integration of optical components used in lightwave communications and optical information processing.

Prof. Iga got its idea and thought to fabricate using a masked substrate and diffusion of dopants having an increasing contribution of refractive index, if they can be introduced into low index substrate. He suggested to M. Oikawa who was a graduate course student at Tokyo Institute of Technology to use organic materials for initial trial. A partially polymerized MMA substrate and DAI monomers as dopants were attempted to form the proposed structure. It was successful and the first lens was realized [9].

Then they try to use glass substrates upon the collaboration with people in NSG, who were specialists of ion diffusion into glass materials to make SELFOC lenses. The thermal diffusion was tried to make such a lens resulting in a glass planar microlens [10]. The name of "planar microlens" was given by Prof. Suematsu who was taking care of students of Prof. Iga during his absence to U. S. A.. The lens power was, however, very week and only 0.05 of Numerical Aperture (NA) was obtained on an initial lens. It was considered that there were two ways to increase the NA; (i) Improvement of glass substrate to enhance the ion exchange [11], and (ii) use electric field to intentionally migrate ions into substrate [12]. These were both successful and the maximum resulting NA was 0.53 !! by putting a couple of lenses together [13]. It is important to note that nonlinear diffusion takes place, otherwise, only an error function type distribution may be coming out and lens action should not appear.

3.3 Applications

The application of the planar microlens and its arrays are;

a) Lightwave systems for coupling and collimating light beams

b) LCD projection TV displays to focus light into liquid crystal cells
c) Optical parallel interconnects
d) Optical parallel processing
e) Optical sensors

3.4 Collaboration

(1) Group Members

The members of collaboration are as follows;

[Tokyo Institute of Technology]

Prof. K. Iga, PhD student; M. Oikawa*, S. Misawa, X.Zhu, A.Akiba,
Master Course student; H.Sugiyama, M.Katoh , D. Intani (PhD student),
and Other research students

[Nippon Sheet Glass (NSG) Co. Ltd.]

Drs. K. Nishizawa, Y.Yamasaki, N. Yamamoto, M.Oikawa*
Other supporting technical staffs

(2) Terms for Cooperations

The period of collaboration is from 1979 to present. The cooperation research project was performed under the support of Ministry of Education, Science and Culture was done during the years of 1982-1983.

(3) Budget for Cooperations

The budget of the research for this work is about 2,000,000 Yen/Year. The clean room facilities including photolithography and thin film formation are used as common tools. In 1986-1988 they were supported by the Ministry of Education, Science and Culture upon Distinguished Research (Tokubetsu Suishin Kenkyu). The budget was 2.5 Million $.

(4) Patents Owners

Several patents were obtained from this study. The patent owners are as follows;

K. Iga , M. Oikawa, K. Nishizawa, and N. Yamamoto

3.5 Production, When and Who

In 1990, NSG Co Ltd. invested to make a factory to manufacture lens array samples at its Sagamihara Firm. The lens array is utilized in liquid crystal (LCD) projectors for large area TV displays manufactured by Sharp Co. Ltd. [14]. A 6×4 cm substrate contains about 400,000 microlenses which fit the size of LCD cells. The industrial contribution of lens array sales is over 1 Million $/Year. By using this technology, about 50 % of brightness has been improved. The price of LCD projector is from 2,000 $ to 10,000 $ according to performances.

3.6 Prospect

More productions for projection TV' s are expected. Advanced process technology and materials are required for HDTV use in future. Parallel optical interconnects are extremely interesting for computer applications ranging from main frame to personal computer levels. In particular, the optical subsystems used together with surface emitting lasers [14] are expected to open a new field of integrated arrayed components in lightwave systems and optical interconnects.

4. Conclusion

There should be a lot of works originally invented in universities and well developed through nicely organized cooperating works between and industries. We have introduced only two typical examples in this article. I believe that these are well recognized as really novel concepts by world wide specialist. It is extremely important for university research to produce new things never existing and hopefully to devote an effort to work with industrial people to reach the production levels. The author would like to point out that it is the time to seriously consider for people in industries as well as universities about the generation of truly novel concepts, otherwise both universities and industries could not survive in the restructuring processes toward 21st century.

Acknowledgments

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Integrative and Virtual Partnerships

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Abstract

Forces driving industry, academe and government in the United States to work together in wholly new ways include the reorientation of government R&D from military to economic security; expanding and increasingly competitive global markets; the availability of new communications and information technologies; and the changing character of corporate R&D. In response, the National Science Foundation, other federal agencies, state and local governments, and the private sector have been developing innovative experiments in integrative and virtual partnerships. Such experiments have revealed that the innovation process can be invigorated by enabling horizontally (across disciplines) and vertically (across the R&D continuum) integrated partnerships. Equally important, these partnerships provide the kind of education, training, and added value that the industrial work force needs to remain competitive in worldwide markets.

This paper offers a historical perspective of these partnerships and their development, describes the major extant set, suggests generic criteria for successful partnerships, and proposes a future vision for their enhancement in the context of the U.S. government's desire to exploit major infrastructure opportunities.

Introduction - Today's Scene

Industrial innovation is central to wealth creation and economic growth. Research and development (R&D) are critical elements of industrial innovation, elements for which the United States has consummate skill. During the past fifty years, new technology has been responsible for over 40% of the productivity gain in the United States.(1) However, R&D has significant economic impact only when applied to commercialization of products and services.

The old model of innovation as a linear path process, with new scientific knowledge created at the front of the path and new products, services, and markets garnered at the path's "end," is increasingly challenged.(2) Recent economic history has made it all too clear that research leadership does not translate automatically into economic success, especially when that research is focused on products rather than commercially-oriented process technologies.(3)

As William Spencer, President and CEO of SEMATECH states:[4]

> "For the nation's economic interests, the issue is not simply how much new knowledge is being generated but also how fast it is being translated into socially and economically beneficial products and processes. This argues for a more deliberate effort to move information and, especially, people between universities and industry."

We now realize that not only can scientific research drive technological innovation, but that it can also happen the other way around. In the larger sense, innovation depends upon a mutual, synergistic set of interactions that include not only science, engineering and technology, but social, political and economic interactions as well. As the figure on the following page illustrates, the process of innovation requires the concurrent integration of all elements party to the process.[5]

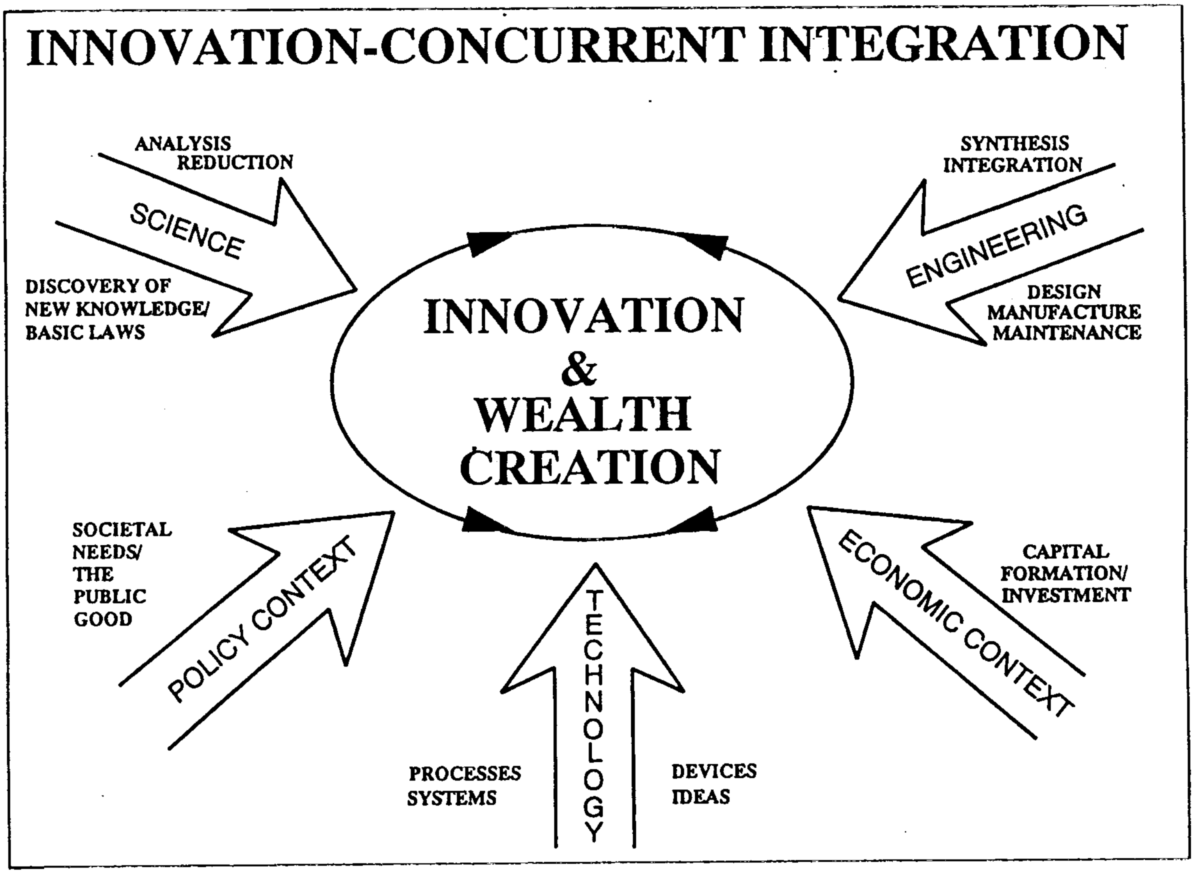
Innovation and wealth creation are nurtured or inhibited by our ability to communicate among these basic societal elements and to work them together concurrently. A critical element in this process is scientific inquiry, an analytic, reductionist process which involves delving into the secrets of the universe to discover new knowledge; i.e. the structured acquisition of knowledge. The U.S. excels at this paradigm, and must continue to sustain and nurture this rich intellectual infrastructure.[5]

The essence of engineering, on the other hand, is the process of integrating knowledge to some purpose.[6] In a sense, it is an activity focused on connecting the pedantic pieces of knowledge and technology to synthesize new products, processes, systems, services, and markets, which in turn create wealth for our society to share. As society's "master integrators", engineers have the functional background to effect some leadership in nurturing this concurrent and interactive activity.

In recent times, nations have increasingly exploited the process of innovation to become economic and technological powers. There are now new opportunities to create wealth and enhance the quality of life for our citizens, which will require us to mobilize science, engineering and technology resources on a scale unprecedented in history. This will also require higher levels of teamwork and cooperation in research, development and commercialization, and will also require wholly new ways of working together. Some of the driving forces toward this change are:

- A fundamental shift driving government support of R&D, from military to economic security. This has already resulted in radically different partnerships to create and commercialize "dual-use" technologies, i.e. ones that can simultaneously benefit the commercial and defense sectors.

- Expanding and increasingly competitive global markets. Capital, technology, information, and people now cross the borders of countries at accelerated rates.


INNOVATION-CONCURRENT INTEGRATION
ANALYSIS
REDUCTION
SCIENCE
DISCOVERY OF
NEW KNOWLEDGE/
BASIC LAWS
SYNTHESIS
INTEGRATION
ENGINEERING
DESIGN
MANUFACTURE
MAINTENANCE
INNOVATION
&
WEALTH
CREATION
SOCIETAL
NEEDS/
THE
PUBLIC
GOOD
POLICY CONTEXT
TECHNOLOGY
PROCESSES
SYSTEMS
DEVICES
IDEAS
CAPITAL
FORMATION/
INVESTMENT
ECONOMIC CONTEXT

In response, many firms are increasing their organizational "agility" through new kinds of partnerships, including those increasingly international in scope.[7] In a sense, today's innovation knows no national boundaries.

- New communications and information technologies are making it easier to communicate and share information all over the world.[8] Diverse management and production units can be rapidly assembled to form "virtual organizations" to accomplish specific goals, and then, just as quickly, be disbanded.

- There is an increasing realization that the U.S. will remain industrially competitive only to the extent that we have a well-trained and well-educated work force. This will require closer relationships between academe and industry.

- Corporate research labs are being downsized or redirected to shorter term market pressures, while at the same time, financially-constrained universities are increasingly seeking support from industry.[9]

- The boundaries between the science and engineering disciplines, and between "basic" and "applied" research are becoming increasing blurred. Likewise, the interval is shrinking between basic discovery and industrial innovation. New forms of university-industry-government partnership must be created to exploit the opportunities that will arise in areas such as biotechnology, optoelectronics, telecommunications, and computer software development, for example.

And through all of this is the growing realization that increasingly sophisticated technology deployment to the marketplace does not necessarily yield more jobs, and that the marketplace may not absorb new technologies as readily as the military.

Historical Perspective

Beginning with the large scale, systems-oriented R&D activities of WWII, we have come a long way in learning how to form integrative R&D partnerships. Almost a half century ago, Vannevar Bush's report, "Science--The Endless Frontier," established the framework from which NSF emerged. At the start of the report, he asserted, "Science can be effective in the national welfare only as a member of a team." [10]

Throughout its 43 years history the NSF has exhibited leadership in forming new kinds of partnerships for supporting research and innovation. In the 1970's, NSF pioneered such concepts as Industry/University Cooperative Research Centers (I/UCRCs). These centers established a model for collaborative university/industry research which continues today. Fifty such centers are currently in operation, carrying out research in a wide range of technologies, On average, these centers attract from industry about nine times the support provided by NSF. In recent years, other federal agencies have become substantial contributors as well.

The Small Business Innovation Research (SBIR) Program was another NSF innovation of the 1970's. These government/private sector partnerships have helped move countless research developments to the marketplace by supporting research to prove the technical feasibility of an idea. The NSF Program served as a model for the SBIR Development Act of 1982, which established a national SBIR program.

By the 1980's, as increasingly swift and more sophisticated technological change facilitated cross-disciplinary research, NSF responded with new types of partnerships, which integrated science, engineering, technology, and education. Among these were the Engineering Research Centers (ERCs), which were large and visible enough to influence academic culture and its reward structure. Over time, the ERCs have helped to include a systems-oriented focus in academic education and research, and served as a model for establishing similar centers in the U.S. and worldwide. These centers have established close working relationships with industrial firms. In 1992, the number of companies that were ERC members totaled 441 for the 18 centers, about a third of which were small business. Annual industrial support for the centers totals over $40 million, and an increasing number of engineers from industry are spending time working in the ERCs.

In the 1980's, the Science and Technology Centers Program, modeled partially on the ERC concept, was established to couple university-based scientists and engineers to focus on research with long-term technological horizons and provide a mechanism to exploit opportunities where the complexity of the research challenges require the advantages of collaborative science-engineering relationships.

In the early 1990's, NSF established the State I/UCRCs and the Engineering Education Coalitions (EEC) Program. The State I/UCRCs aim to enhance local and regional economic development, and actively focus on technology transfer and knowledge deployment, especially to small firms where many innovations and new jobs are created. The support of these technology-focused centers are equally shared by NSF, state governments and industry. Currently, nine states and 136 companies participate in ten centers.

The Engineering Education Coalitions Program was established to stimulate bold, new innovative and comprehensive models for systemic reform of undergraduate engineering education. The Program joins diverse groups of institutions ranging from large, research-intensive universities to predominantly undergraduate institutions, some of which serve minority populations and community colleges. Thirty-three institutions have joined together in four national coalitions, each of which is dedicated to educational experimentation in the integrative nature of the engineering process.

In addition to these NSF experiments in integrative and virtual partnerships, other federal agencies, state governments, the private sector, and other countries are developing some very innovative partnerships. For example:

- o The Advanced Technology Program (ATP) at the National Institute of Standards and Technology (NIST) provides matching grants for industry-led partnerships and consortia for development and commercialization of pre-competitive generic technologies.

- o The Department of Energy has established Cooperative Research and Development Agreements (CRADAS) between industry and the nation's 726 federal laboratories. CRADAS are one mechanism by which the federal laboratories can work with industry to transfer lab-developed technology and know-how to the private sector. This is a first step in the process of tapping for civilian commerce the government's enormous extant R&D investment . [9][11]

- o Overseas, the renowned Fraunhofer Society (FhG) has established 47 institutes throughout Germany. An example is the Fraunhofer Institute for Manufacturing Engineering and Automation, which receives 84 percent of its funding from industrial firms but manages to do state-of-the art research to build its in-house technical expertise, which its then sells to industry.[11]

- o Since the early 1980s, some states have supported regional centers that link local industries and universities together to promote the commercialization of new technologies. Pennsylvania's Ben Franklin Partnership is a good example. Through 1991, the Partnership's four regional Technology Centers created and retained over 24,000 jobs, started and expanded 1,800 new companies, commercialized 540 products and processes and leveraged over $750 million in non-state funds.[12]

- o The Advanced Manufacturing Center at Cleveland State University is another good example of a state-supported partnership. Its work is twofold: (1) industry-sponsored projects to solve company-specific problems; and (2) innovative research programs which push state-of-the-art industrial manufacturing technologies. The center is an affiliate of the Cleveland Advanced Manufacturing Program (CAMP), and is also linked closely to one of NIST's Manufacturing Centers. Students at all levels are involved in projects that have real educational *and* commercial impact.

- o In the rapidly changing private sector R&D paradigm, the distinguished David Sarnoff Center, formerly the jewel of RCA Laboratories, still prospers intellectually and continues to produce exciting new technologies but in a fresh venue for serving multiple companies and entities rather than a single parent.

More recently, the impetus of defense conversion has enabled federal agencies to join together to pioneer some radically different R&D partnerships, that cut deeply across agency boundaries. Two recent examples are the six-agency Technology Reinvestment Project and the ARPA/NSF Agile Manufacturing Initiative:

- o The Technology Reinvestment Project (TRP) is a federal effort to develop and commercialize "dual-use" technologies. Funded at $472 million in FY 1993, and jointly planned and executed by six federal agencies (ARPA/DOD, DOE, NASA, NIST, NSF and DOT), this initiative is bringing together defense and commercial industries, along with academe and state governments, to create new technologies, new efforts to deploy existing technologies, and innovative approaches to educating manufacturing engineers and the associated skilled workforce. Among the many innovative projects being supported is a partnership to demonstrate the use of corrosion-resistant, lightweight composites for repair and replacement of the nation's aging bridges and simultaneous creation of lightweight composite bridges for military use. Another partnership will develop a new airport radar system, derived from expertise with the Navy's Aegis battle radar system, that can detect hazardous weather conditions, such as wind shear, while simultaneously monitoring air traffic.(13)

- o The Agile Manufacturing Initiative (AMI) is supported through a partnership between NSF and the Advanced Research Projects Agency (ARPA). The AMI will facilitate and support university/industry/government teams to jointly articulate a national research agenda through an industry-led AMI Forum. It will also support research in university-based Agile Manufacturing Research Institutes (AMRI), and refine and test the validity of agile manufacturing concepts in application prototypes and proof-of-concept testbeds. These teams will use information networks to operate in virtual/distributed mode, which can facilitate pulling together national information resources while implementing advances on a regional basis.

Lessons Learned

Valuable lessons have been learned which will serve the nation well into the future. For one thing, experiments with partnerships have validated that fundamental research and discovery can coexist, and even flourish, with market-oriented research and industry collaboration. Researchers have long feared that industrial contact, and relationship to market relevance, would distort the nature of research and the allocation of government funds. With the shortening of the time from discovery to application, and as the boundaries between basic and applied research fade, this environment is changing. As Frank Press, former White House Science Advisor and President of the National Academy of Sciences, has stated:

> "Today's more powerful link between scientific leadership, economic security, and the quality of life will provide the new impetus and rationale for the support of science in the post-Vannevar Bush Era - - -."(14)

Also learned is that extending the "vertical" integration of a partnership, i.e. the range of activities along the R&D continuum, can speed the innovation process and the pace from discovery to application. Even more important, it is essential for providing students with the kind of education and training required for industry to compete successfully worldwide. Students, ranging from high school through doctoral studies, can greatly benefit from hands-on research experiences, shaped by exposure to real world industrial problems, all within a solid intellectual context.

However, in order to focus new university-industry-government partnerships on this kind of education and training, academic culture, which currently assigns low value to the integration of knowledge, needs re-consideration. NSF can provide leadership in helping effect this re-consideration. An important key is facilitating the exchange of people between universities and industry. [15]

After many tries, the federal government is slowly learning not to impose "solutions" or "models" on the private sector. If the partnership is forced or artificially contrived, it is likely to be ill-conceived and will require too much energy to hold it together. The "energy" holding a partnership together must be derived from the partners' mutually synergistic relationships. Likewise, the government should not require partnerships to be spatially or "virtually" distributed in the absence of a well-thought-out rationale, which is accepted by all of the prospective partners. Operating in a virtual or distributed mode can be greatly facilitated by the new computer-communications technologies but it must not be forced. There are intellectual and financial advantages to sharing physical space; e.g. the advantages garnered by industrial parks, such as California's Silicon Valley, North Carolina's Research Triangle park, and Japan's Tsukuba Science City. The context or "models" for integrative and virtual partnerships should be jointly developed by the stakeholders "up front", who then share provision of resources to catalyze/enable the partnerships to form.

Vision for the Future

The nation has learned that the innovation process can be invigorated by enabling horizontally (across disciplines) and vertically (across the R&D continuum) -integrated partnerships. Equally important, through such partnerships the kind of education and training that the industrial work force so desperately needs to remain competitive in worldwide markets can be simultaneously provided. But what are the next steps to take?

First, we need to recognize that many of the "pieces" of a holistic national policy are already in place (such as the ERCs, the I/UCRCs, the NIST Manufacturing Centers, etc.). We need to find new ways of teaming to effectively connect these pieces together.

Actually, some of this is already happening in a natural way . For example, some of the ERCs must contend with re-competition following the eleven year limit for which NSF support has expired. Some are becoming more vertically integrated as they turn more to industry for support. Other ERCs are establishing links with other kinds of centers, such as NSF-supported supercomputer centers.

In consultation with industry, academe, and state governments, the federal government should consider enabling the formation of new kinds of partnerships, such as university-based centers that support the full range of the innovation process; i.e. fundamental research, engineering integration, applications, proof-of-concept, demonstration, contract research, technical consultation, employee exchange, student research and training, and outreach and extension services. Academe's role in such partnerships should always be focused on its primary mission, i.e. education and knowledge generation. However, academe may need to expand how it defines its student body, which may increasingly incorporate the industrial work force at all age levels.

It is clear that these new forms of partnership, which may cut across the missions of a number of agencies, will require unprecedented levels of interagency and university-industry-government cooperation. In this context, federal interagency partnerships might well benefit from a fiscal "forcing function"- e.g. allocation of funds to an interagency partnership rather than to specific federal agencies. The drive to do this come from the government's desire to exploit some major infrastructure opportunities; e.g. the development of a broadband, interactive telecommunications network linking the nation's schools, libraries, health care facilities, government offices, and other public information producers;[16] or a focus on extant defense R&D to improve the nation's civil infrastructure systems for better flow of commerce.

To meet tomorrow's challenges, science and engineering research - the Endless Frontier, as Vannevar Bush referred to it - must be pursued with courage and vision. More than ever before, this means embracing new forms of partnerships and holistic systems for delivering the benefits of research to society.

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WHAT IS THE ROLE OF FUTURE COMPANY FOR BASIC RESEARCH ?

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Shortly after the end of the Cold War, a global shift in thinking took place. The world began changing its focus from militarism to commercialism, from East-West conflicts to North South issues. Global cooperation is becoming more and more important. These situations are changing company management philosophy.

Today, countries can be classified into three (3) tiers ; advanced countries, mid-industrialized countries and pre-industrialized countries. Suitable industries may differ for each of these three tiers. In advanced countries, labor-intensive industries can't be pursued due to higher labor and welfare costs. Such industries should be transferred gradually to mid-industrialized countries in the form of multinational operation. These industries should be operated multinationally. Companies should create new industries with the concurrent innovation process using the fruits of basic research.

Therefore collaboration between companies and universities in basic research will be more and more important. Basic research is essential for survival of future companies.

1. Introduction

After the end of the Cold War, the world began changing toward a "borderless" economy. In accordance with this change, the role of the company, the nation, the university, and the people could not avoid changing.

In this paper, "What is the role of the future company for basic research?" will be examined from the viewpoint of company management philosophy.

2. Company management philosophy

2-1 Paradigm shift of company management

Company management philosophy should correspond with the environment. Then management philosophy should change with the change of environment.

After the end of the Cold War, old ideas were fell apart and a global shift in thinking took place (Fig.1).

Politics are being increasingly globalized. The United Nations and the Peace Keeping Organization have been taking an important role in settling international disputes. Though there isn't a big war, ethnic conflicts are arising in many countries. Scarcity of energy and environmental protection should be globally examined as a rapid increase of the population in the 21st century is estimated.

The economy is becoming borderless. IMF for controlling currency exchange rates, GATT for keeping fair trade, and OECD for cooperatively developing the technology and economy have been established. Activities for helping undeveloped countries, such as ODA, is becoming important.

Also in technology, the trend is moving from nationalism toward globalism. As industry still will be important for human life even in the 21st century, technology should create new industry, that is, industrial renaissance. Big science projects such as space science should have a global alliance. Mutual assistance will be more significant to solve common problems for many countries such as environmental protection.

To summarize, the whole world is changing its focus from militarism to commercialism, from East-West conflicts to North-South issues. Global cooperation is becoming much more important than the world had ever anticipated. These emerging situations are changing company management.

2-2 What is the company?

Today, the relation among companies, universities, nations and people should be examined considering these paradigm shifts (Fig.2).

People originally pursued individual happiness.

The main functions of nations are to provide security, infrastructure, welfare and so on to the people through the government.

The main functions of university are education, diversification of culture and research. Universities should conduct challenging basic research as they need not fear bankruptcy.

The company strives to give a return of the fruits to the stake holders such as investors, employees and society. This is important for the company to survive.

These four functions operated effectively in the past. However they have to find their respective global roles in accordance with the paradigm shift.

3. Role of the future company

3-1 Competitive key points of industry

The world is changing toward a "borderless" economy. From the viewpoint of industry, a counterplan for each country could be considered by classifying countries into three tiers according to the degree of their industrialization as shown in Table 1. This table indicates various conditions and factors that influence competitiveness, as well as key points to improve competitiveness.

In advanced countries, the GNP per capita is greater, and labor and welfare costs are higher but better infrastructure is available. This means the greater efficiency is accompanied by higher costs. Demand for standard commodities already has been saturated and, from the viewpoint of cost competitiveness, it is difficult for conventional industries to survive as they are. Thus, these industries need to equip themselves with capabilities to produce higher value-added commodities using advanced technology developed through R&D activities. That is, the key point of competitiveness is innovation, or creating new industries. Matured conventional industrial technologies must be transferred gradually to mid-industrialized and pre-industrialized countries.

In mid-industrialized countries, the GNP per capita is medium, with medium level infrastructure, and the demand for standard commodities is increasing. The appropriate industry there is capital and technology intensive in conventional industries with medium-level technology obtained by technology transfer from advanced countries. Mid-industrialized countries must improve production by themselves in order to survive. For them, production is the key point of competitiveness.

Finally, in pre-industrialized countries, the GNP per capita is low, but the infrastructure is poor. The appropriate industry there is labor intensive. Such a industry should be obtained by technology transfer, and financial aid from abroad is necessary so that industry can meet global environmental protection requirements. Even if labor cost is inexpensive, labor training is necessary for industry operation. Therefore, education is a key point of competitiveness.

3-2 Strategy of the future company

To summarize this concept, the future company is characterized by diversification and globalization. Fig. 3 shows the strategy of the future company. For the 1st step, the company should create a 2nd diversified industry in an advanced country using the innovation and simultaneously transfer of the original industry suitably modified to a mid-industrialized country. A successful innovation should be such that the 2nd diversified industry is better than the original industry from a business stand point. Only in this case, can R&D be evaluated as excellent. For the 2nd step, further innovation should be accomplished to create a 3rd diversified industry and transfer the 2nd diversified industry to a mid-industrialized country. The transferred original industry in a mid-industrialized country is further transferred to a pre-industrialized country with suitable modification and financial aid for environmental protection. These steps should be continuously repeated. Such a company will be an everlasting balanced organization, which will consist of multi-national, multi-qualified individuals to make continual innovations.

3-3 Requirement for survival

At last, let us consider "innovation". In order to a get wholly new industry, basic research is indispensable. New industry should meet customer satisfaction and win competition. Fig. 4 shows two models explaining such an innovation process.

First is a linear innovation model. According to this model, innovation starts from basic research and goes through stages of development, production, and marketing. In this model, it is considered that the greatest challenge is on research, and subsequent development, production and marketing are then easier to tackle. This kind of innovation process will be applicable only for established industries.

Second is a concurrent innovation model. In this model, innovation will be achieved by a concurrent approach of research, development, production, and sales in parallel. These steps may be taken simultaneously. This model regards all these steps.... research, development, production, and sales.... as equally important and difficult to tackle.

Cooperation in basic research between companies and universities will become more important. In this sense, company should conduct a basic research to survive.

4. Examples of cooperative research activities to be considered as basic research

As an example of basic research in Sumitomo Electric Industries, Ltd. (SEI), high-temperature superconductivity (HTSC) will be explained.

The national research institutes, universities, and industries of the United States, Europe and Japan began their HTSC research in 1986 when HTSC was discovered. Fig. 5 shows the present condition of HTSC application. HTSC will undoubtedly lead to key future industries, though it is also clear that this technology cannot be brought immediately to wide practical use. Therefore, this research should be called "basic research".

Such basic research in a pre-competitive stage should be conducted by international cooperation to avert the risk of large investment. Fig. 6 shows the international cooperation between Japan and the U.S. in HTSC research. Japanese companies and U.S. companies have been conducting HTSC research by establishing a government supported consortium. The International Superconductivity Industry Summit (ISIS) has been established since 1992 to industrialize HTSC in 2000 by the U.S. Council on Superconductivity for American Competitiveness (CSAS) of the U.S., the Consortium of European companies determined to use Superconductivity (CONECTUS) of Europe and International Superconductivity Technology Center (ISTEC) of Japan as shown in Fig.7. The 1st meeting was held in Washington D.C. in 1992 and the 2nd meeting was held in Hakone, Japan in 1993 to discuss the future HTSC market. By the way, it so happens that the ISIS have the same name as the Egyptian goddess who can change the fate of humans and possibly the fate of future superconductivity.

Many excellent results have been achieved by such collaboration. SEI and

MIT have been collaborating on HTSC and have ascertained the behavior of HTSC as shown in Fig. 8 first in the world. In the Superconducting Super Collider (SSC) project, SEI was in charge of developing superconducting wire and has shown satisfactory results. As is well known, the SSC project was unfortunately stopped by the U.S. Congress.

5. Conclusion

In advanced countries, the company is able to survive only by creating new industries using basic research fruits and making multinational operations by transferring labor-intensive industries to developing country.

Running counter to this trend are nationalism and protectionism that are still observed in the world. Such movements may cause industries to fall behind the forefront of international research, and thus bring about their decline.

As a result of these facts, I'd like to conclude that the companies in advanced countries must conduct a basic research as their main strategy.

Fig. 1 PARADIGM SHIFT OF COMPANY MANAGEMENT

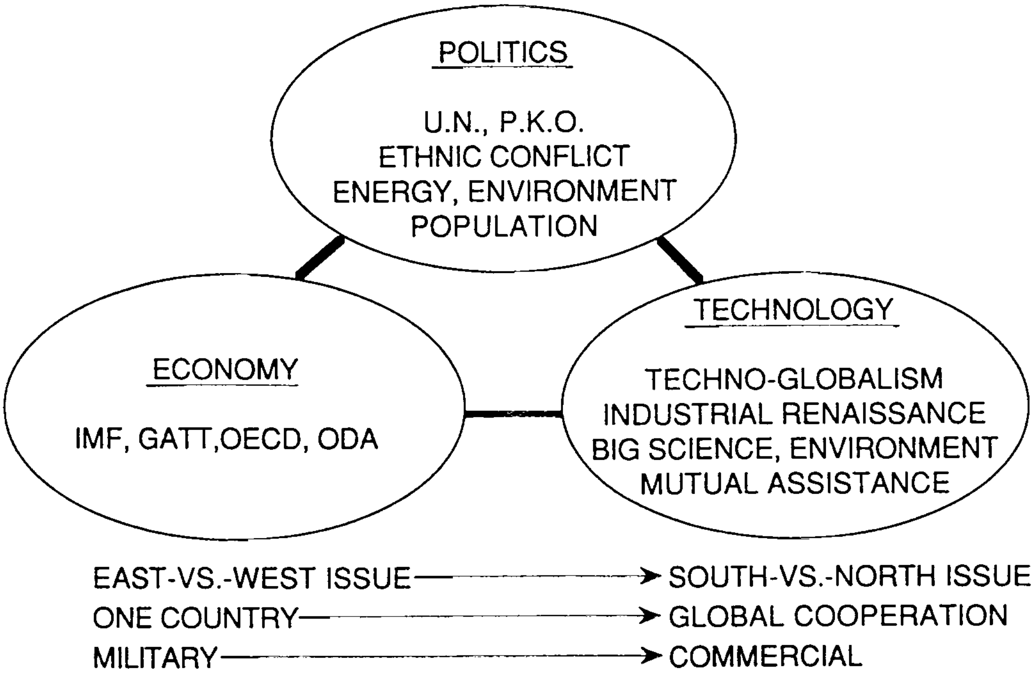


Fig. 2 What is the Company & University?

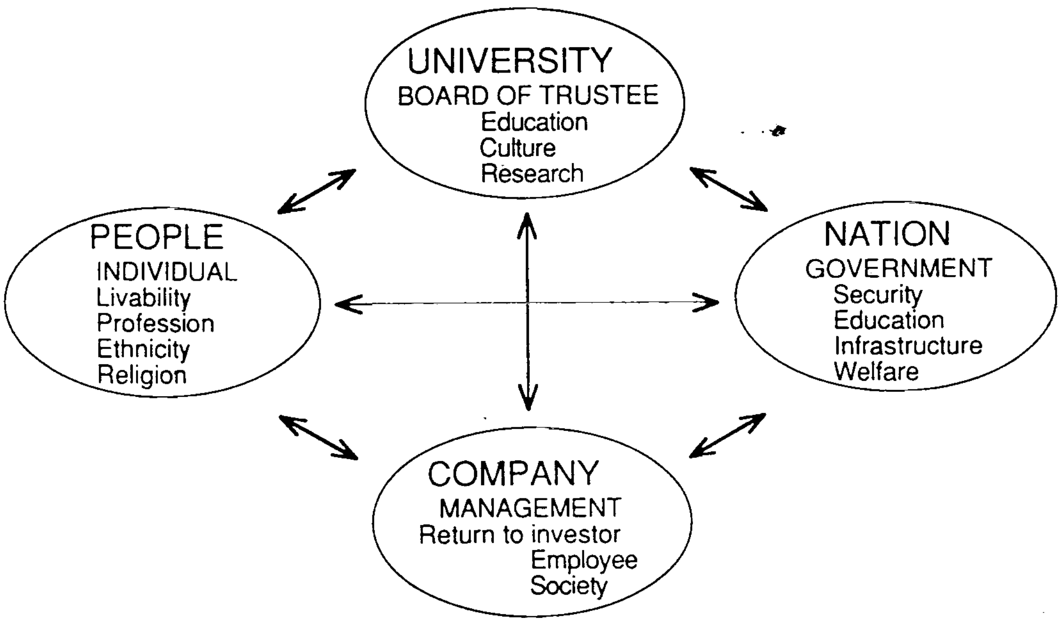


Table 1 COMPETITIVE KEY POINTS OF THE INDUSTRIES

Tier		Advanced Countries	Mid-industrialized Countries	Pre-industrialized Countries
GNP		High	Medium	Low
Labor Cost		High	Medium	Low
Infrastructure		Well-developed	Becoming Better	Poor
Demand		Saturated	Increasing	Coming Later
Elemental Industry	Type	High Value Added R&D Intensive	Capital &Technology Intensive	Labor Intensive
	Example	Airborne Pharmaceutical Computer Photonics	Automobile Consumer Electronics Steel Industry	Agricultural Products Assembly Industry Natural Resources
Technology		High Tech. from R&D	T.T. from Outside & Self-improvement	T.T. from Outside with Aids
Competitive Key Points		Innovation	Production	Education

Fig. 3 STRATEGY OF FUTURE COMPANY

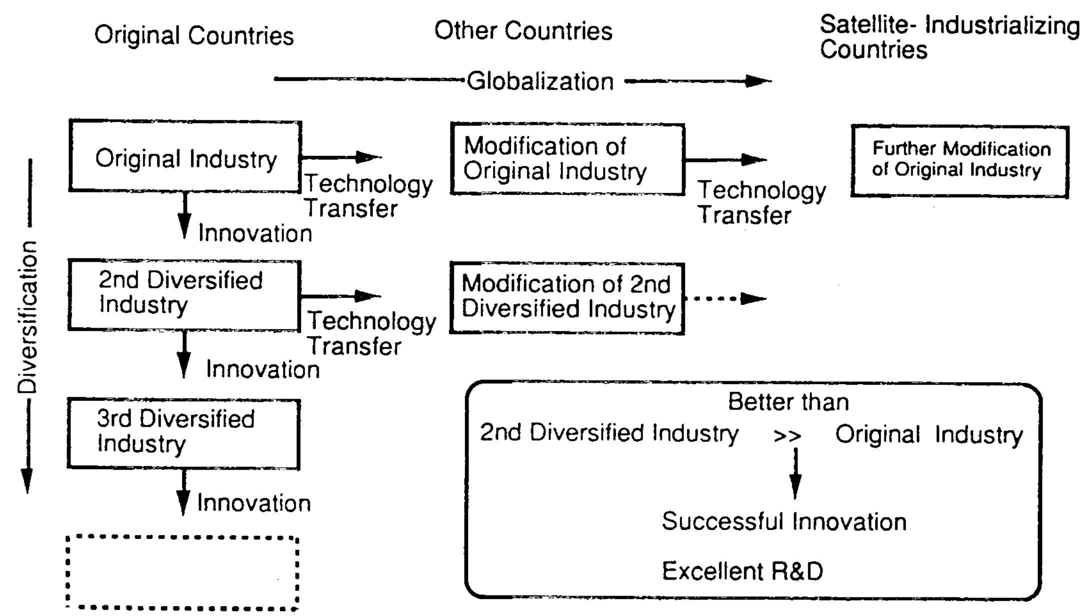


Fig. 4 REQUIREMENT OF SURVIVAL

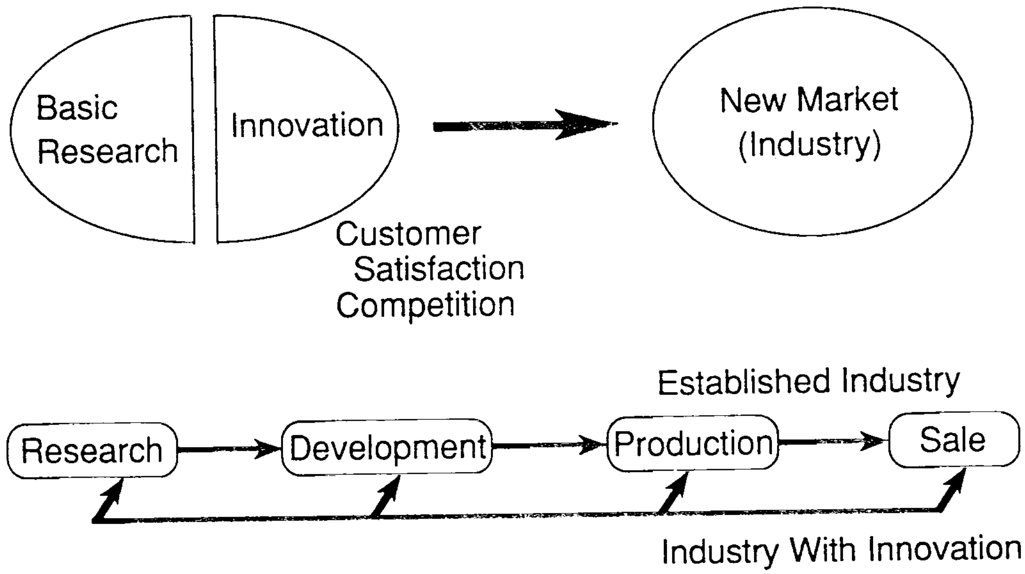
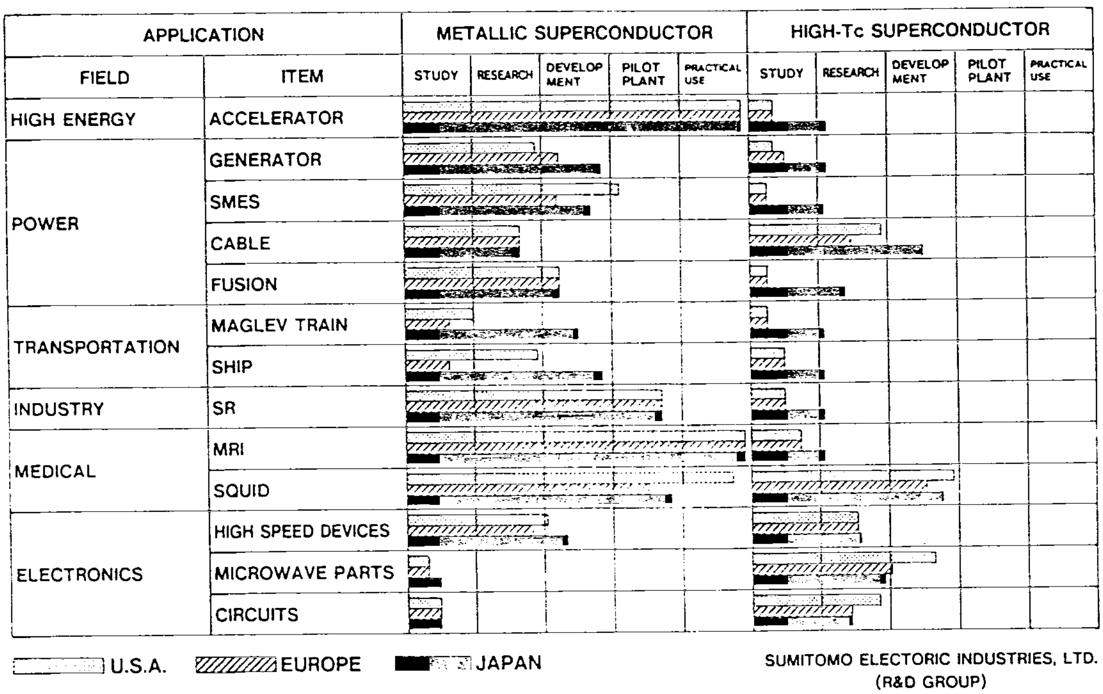


Fig. 5 PRESENT CONDITION OF SUPERCONDUCTIVITY APPLICATIONS

Oct.1993



SUMITOMO ELECTORIC INDUSTRIES, LTD.
(R&D GROUP)

Fig. 6 Collaboration between U.S. & Japan on Superconductivity R&D

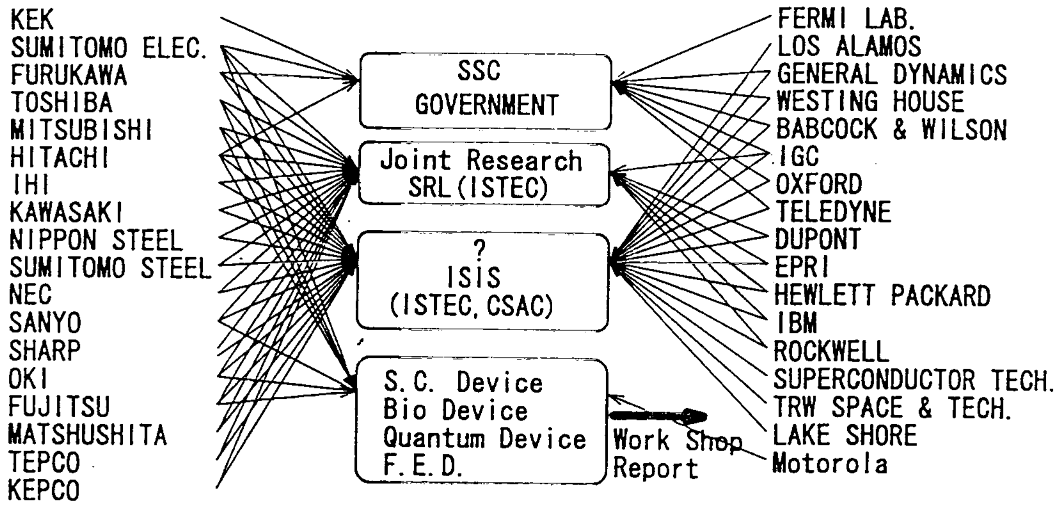
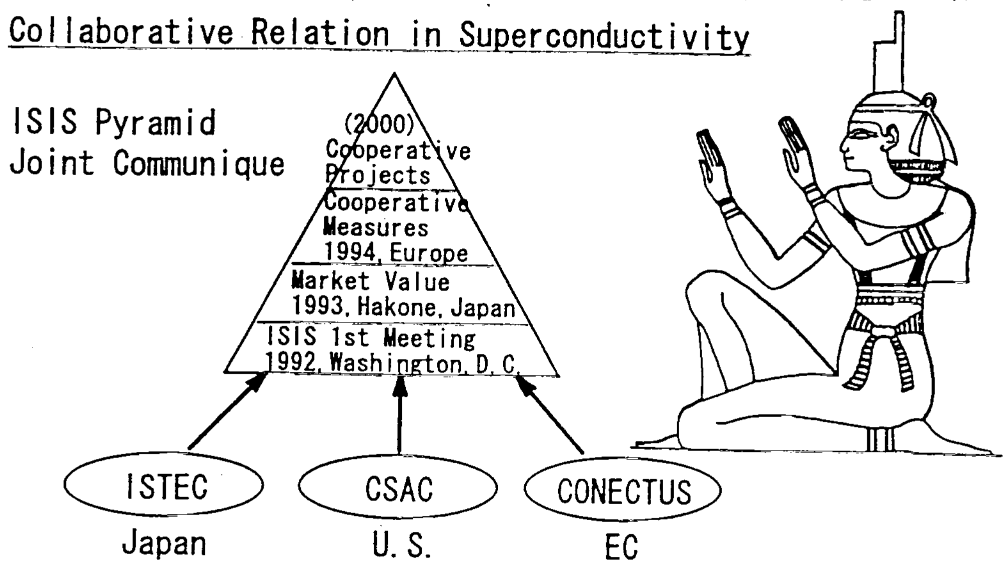


Fig. 7 ISIS : International Superconductivity Industry Summit

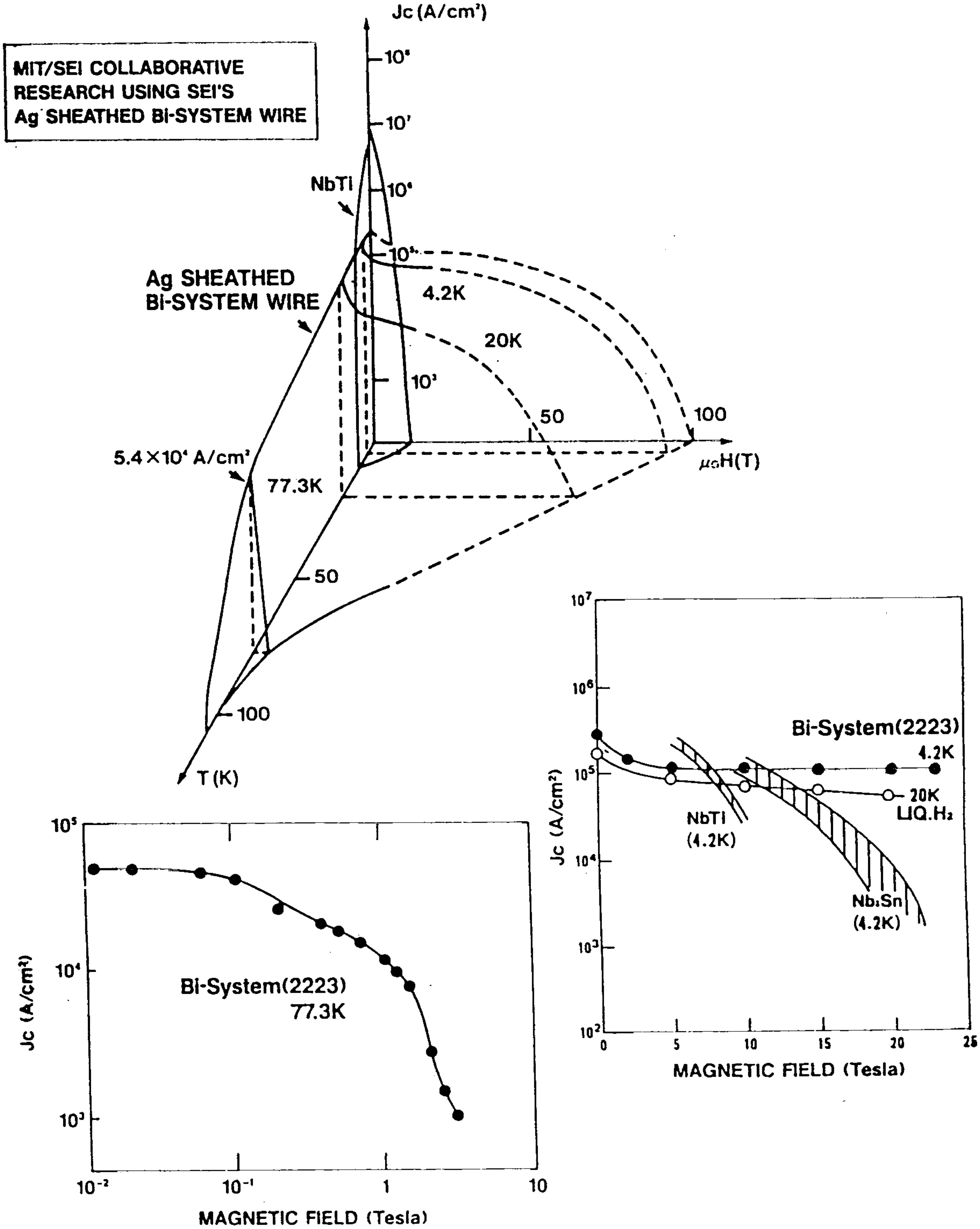


ISTEC : International Superconductivity TEchnology Center
CSAC : U.S.'s Council on Superconductivity for American Competitiveness
CONECTUS: CONsortium of European Companies determined To Use Superconductivity

Fig. 8 EXAMPLES OF COLLABORATION

WIRE

MIT/SEI JOINT RESEARCH



Corporate R&D in the United States

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The nature of corporate R&D in the United States will continue to evolve but at an increasingly rapid pace for the following reasons:

1. Computers and telecommunications have made information ubiquitous.
2. As countries develop, their R&D budgets increase - the overall worldwide R&D budget is increasing.
3. Knowledge about critical technologies and within a given technology about critical needs is pervasive worldwide.
4. The ratio of Research to Search (R/S ratio) for knowledge changes in industries and in countries. Search in the present context means to seek knowledge that has already been acquired by research carried out by others.

These developments lead to changes in corporate R&D in the United States and to shifts in priorities. For example:

1. The R/S ratio will decrease in industries such as computers and communications now, and in pharmaceuticals in the future.
2. As the R/S ratio decreases at corporate laboratories in the United States, basic research and exploratory technology will increasingly become the domain of universities.
3. For the United States to optimize industrial R&D, it will require an increasingly closer cooperation and planning between industrial, university, and governmental laboratories.

Reference:

P. Chaudhari, "Corporate R&D in the United States," to be published, Physics Today; see also Proc. IUPAP General Assembly, Nara, Japan (1993).

The following viewgraphs and others will be shown and explained at the meeting to provide support for the thesis presented in the preceding two pages. These viewgraphs are taken from the National Critical Technologies Panel (1993).

TABLE 3.1

ANNOUNCED FOREIGN TARGETS[1]

Technology-Intensive Sector	Japan	European Community	France	Germany
Applied Molecular Biology	●	●	●	●
Distributed Computing and Networking	●			●
Electricity Supply and Distribution	●	●		●
Flexible Integrated Manufacturing	●	●	●	
Materials Synthesis and Processing	●	●	●	●
Microelectronics and Optoelectronics	●	●	●	
Pollution Minimization and Remediation	●		●	
Software	●	●		●
Transportation	●	●	●	●

[1]Some member nations of the European Community (EC) have announced different targets than the EC collectively.

TABLE 3.2

RELATIVE U.S. PATENT ACTIVITY

nology-Intensive Sector	United States	Japan	Germany	United Kingdom	France	Taiwan	Korea	Total[1]
lied Molecular Biology	●		●	●	●			8,703
ributed Computing and working	◎	●		●	◎	◎	●	8,044
tricity Supply and ibution	◎	◎	◎	◎	●	◎	●	11,799
ible Integrated ufacturing	◎		●	◎	◎	◎		7,168
erials Synthesis and essing	●	◎	●	◎	◎	◎		9,986
oelectronics and electronics	◎	●			◎	●	●	7,206
tion Minimization and ediation	◎		●	◎	◎	◎		4,437
ware	◎	●				◎	●	2,230
sportation		◎	●	◎	●			5,022
l of Above	25,952	14,985	4,838	1,773	1,884	113	300	64,594
	36,800	20,431	6,915	2,442	2,519	174	339	96,514

rld total, including countries not listed.

= higher than average level of patenting activity in this sector

= average level of patenting activity in this sector

k = below average patenting activity in this sector

TABLE 3.3

FOREIGN RESEARCH CENTERS IN THE U.S.

nology-Intensive Sector	United Kingdom	France	Germany	Japan	Korea	Taiwan	All Others	Totals
ied Molecular Biology	●	●	◎					75
ibuted Computing and orking			◎	◎	●			29
ricity Supply and bution								0
ble Integrated ufacturing			●	◎				3
rials Synthesis and essing			●	◎				12
electronics and electronics			◎	◎	●		●	67
tion Minimization and ediation				●				3
are				●				28
portation				●				5
of Above	13	12	29	128	10	0	30	222
	13	12	35	158	13	0	31	262

= receives heavy emphasis relative to emphasis by other countries

= receives some emphasis relative to emphasis by other countries

= receives little emphasis

TABLE 3.4

HIGH-TECHNOLOGY FOREIGN SUBSIDIARIES IN THE U.S.

echnology-Intensive Sector	United Kingdom	France	Germany	Japan	Korea	Taiwan	Total
pplied Molecular Biology		◎	●				146
istributed Computing and etworking				●	●	●	273
lectricity Supply and istribution		●	●			◎	53
lexible Integrated lanufacturing	◎	◎	◎	◎			599
laterials Synthesis and rocessing	◎	◎	●				345
licroelectronics and ptoelectronics	◎	◎		●	●	●	495
ollution Minimization and emediation	●						49
oftware	●	●			●		100
ansportation	●	●			●		92
tal of Above	682	296	502	621	18	32	2,151
tal Industry and Technology	829	363	673	704	21	32	2,623

= heavy representation of subsidiaries relative to that by other countries

= average representation of subsidiaries relative to that by other countries

nk = little representation of subsidiaries in this sector

TABLE 3.5

FOREIGN DIRECT INVESTMENT IN U.S. INDUSTRIES, (1988-1990)

Technology-Intensive Sector	United Kingdom	France	Germany	Japan	Korea	Taiwan	Total
Applied Molecular Biology	●	●	●				44
Distributed Computing and Networking	⊙			⊙	●	●	88
Electricity Supply and Distribution	●	●		⊙			43
Flexible Integrated Manufacturing			●	●			92
Materials Synthesis and Processing		⊙	●	⊙		●	164
Microelectronics and Optoelectronics				⊙	⊙		136
Pollution Minimization and Remediation	●	●	⊙	⊙			18
Software	●	●		⊙			32
Transportation	⊙	⊙	⊙	⊙	⊙		210
Total of Above	137	52	94	499	12	6	827
Total Manufacturing and Other Technology Sectors	223	89	142	706	19	11	1218

● = heavy investment relative to that by other countries

⊙ = average investment relative to that by other countries

blank = little investment in this sector

Desirable Relationship between Government and Universities for Advancement of Basic Research

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ABSTRACT

Roles of universities upon basic researches have been tremendously changing. Researches are required to be friendly to people of other fields. They must not be performed from too much specified viewpoints. We must avoid demerits due to so-called 'istism'. Science and technology must be supoorted by general public by constructing science and technology simpler and easier to understand. Universities are required to generalize technologies into industrial sciences. The author proposes intelligent materials to make technologies enjoyed and supported by general public.

The most desirable relation between Government or Ministry of Education and University may lie in the situation where University has freedom to pursue fundamental research supported and encouraged by Government who is satisfied with the fruit of the research. In order to achieve this happy relation, however, both sides have to realize the essential roles of basic researches performed at Universities. The roles are rapidly and tremendously being changed. Recently we notice undesirable effects arising from the one side sense of values by the group too much specified. The present speaker call this 'istism'. Logic is perfect there in the closed circle. Istism often loses a sight based upon global scale. An example is observed in the materials science. Until very recently materials have been developed through mixing many components to improve durability or other kinds of performance. This way of development of materials, however, causes difficulty of capability of recycle. Materials scientists are now asked to be aware of environmental issues. Total material design to optimize fabrication process, reliability during use and recycle capability is now to be established. For recycling cooperation of public people is essential. We have to take social factors into account. The total design is achieved only by interdisciplinary joint work.

Effort to attain prosperity of a company or local society sometimes leads to troubles to the neighbors. The most essential role of the university is, therefore, to educate students to be able to think things upon global scale of sense of values.

The other undesirable effect due to the istism is the situation where public people cannot understand technology at all.(Table 1) They feel segregated and separated from technology. And finally they become opposing the technology. They are not cooperative to decrease environmental impact unless they understand technology. It is afraid that so-called advanced technology can give merit only to very limited group. The present speaker defines this as 'technomonopoly'. Technology must be developed more simply to be more easily understood for public people to enjoy technology and to become more cooperative.(Table 2) The speaker proposes to establish 'technodemocracy' instead. Technology must be reformed immediately. The initiative of reforming must be taken by University. In order to distribute knowledge primarily limited to and owned by the specified group to global scale society as generalized knowledge, required is the action of generalization. This is also to be initialized by University. Generalization is achieved through construction of advanced industrial science or academic guiding principles.

University professors have potentiality and freedom, and duties to propose novel but essential academic concepts. They have to find new routes of science and technology. They are not asked to run very fast along the way already well defined by other precedent people. Originality is only ascertained by the people who propose their own concept at the risk of scholar's status.

Interdisciplinary research or cooperation helps develop language to explain concept or facts to the group of different fields. This relieves the undesirable effects due to the istism. It also stimulates novel ideas to create the advanced academic scheme. Questions from different fields are often the source of new findings or creation of novel concept. The speaker is conducting several interdisciplinary research projects.(See Table 3) One is to develop intelligent materials with self diagnosis function applied for strengthening concrete structure instead of steel bars. This is the project among civil engineering, materials science and sensor technology. Next is to develop infrared ray sensors with partially carbonized fibers. This is the project among materials science, electronics engineering and safety engineering. During conducting the joint research program we learn how to communicate and how to mutually be technologically promoted. Interdisciplinary relation is not necessarily limited to the one among technological fields. Feedback from public people helps develop technology more well accepted.

The most important role is now to generalize knowledge primarily owned by very limited group for people all over the world to enjoy the fruits of technology or technology itself. The real originality is to develop advanced but very simple and essential technology. Application of too much complicated technology leads to again technomonopoly.

Government is asked to encourage this movement by University not only for the benefit of the country but also for the benefit of people all over the world.

Table 1 Aspects of Spaghetti Syndrome:

>Complex structure

>Design possible only by complicated structure

>Misunderstanding; The more complicated, the more advanced

>Trivial preferred, Essential ignored

>Degradation of essential performance

>Loss of public acceptance

Table 2 Merits of Simple Technology or structure:

>Easy to Fabricate

>Easy to Understand

>Public People's Contribution Possible

>Easy to Recycle

Table 3 Intelligent Materials

Intelligent Materials R & D Program

A session at PAC-RIM Ceramic International Congress

Very Frequent Symposia upon the Intelligent Materials

Definition: Materials with autonomy

1st rank: self-adjustment, self-recovery, self-diagnosis

2nd rank: tuning capability

reliable during use recyclability after use

Examples:

>PTC thermistor heating element, self adjustment of resistance

>Photochromic glass, self adjustment of light transmittance

>Wood, self adjustment of humidity as Shohsohin temple

>Partially stabilized zirconia ceramics, self-recovery during use and self-degradation after use

>Carbon fiber and glass fiber reinforced plastic to replace steel bars in concrete structure, self-diagnosis monitoring current stress and memorizing past maximum strain without additional sensors

>p/n hetero contact chemical sensors, self-recovery for humidity sensor and tuning capability of sensitivity and selectivity for gaseous species

Aims of R $ D:

>Revolution of Technological System, From Technomonopoly suffering spaghetti syndrome to Technodemocracy, Virtue in Technology

Strategy of R & D and Design of Intelligent Materials:

>Priority on Simplicity

Wisdom parameter defined as

Iw=No. of Merits/(No. of Components)!

>Interdisciplinary interaction

>Hybridization or integration between different materials with opposite characters; acid/base, p/n, conductor/insulator, high modulus/high tenacity, etc.

Table 4 (a) Typical Examples of Interdisciplinary Co-operatMion upon Materials with Self-diagnosis Function

Cooperation among

>University of Tokyo=Theory and Design,

>Shimidzu Corp=Fabrication and Installation and

>Sogo Security and Guard Co.=Sensing

Design:

>To suppress disadvantage of sudden fracture keeping enough stiffness at least at the first stage of loading stress, Hybridization of materials, a stiff material with a tough material.

>To get a distinct notice while the hybrid material is alive, Choice of a conducting material for the stiff material and an insulating material for the tough material. If the conducting and stiff material is solely used, loss of conductivity means diagnosis death. The presence of the tough material the loss of conductivity does not mean the death of the hybrid material until the tough material finally fractures. A typical combination is carbon fiber and glass fiber

History:

>Shimidzu corp. has been finding a non-rusting material which can replace steel bars to reinforce concrete structure. Rusting of steel bars gives a serious trouble to expand the structure. The mechanical behaviors of the hybrid, carbon and glass fibers, is satisfactory.

>Yanagida at University of Tokyo has once proposed the concept of self-diagnosis with the hybrid material in a symposium. Director

of the research laboratory of Shimidzu was listening the proposal.

>Dr.Mutoh has conducted the joint R & D program who now works for the security and guard system co.

Applications: Large scale construction difficult for tiny sensors to cover the whole area.

>Airplanes

>Bridges

>Highways

>Landslides

Periodical monitoring to check the past maximum damage than continuous monitoring to check current strain.

Table 4 (b) Other cases of interdisciplinary joint research program

>P/N hetero-contact type chemical sensors program

>Infrared ray irradiation sensor program with use of a partially carbonized semiconductor fiber.

"The Relationship between University Research and Industrial Innovation"

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I

My paper will focus on the relationship between university research and industrial innovation. I find it useful to begin by identifying 3 features of the American university system that are highly relevant to these concerns.

1. Scientific research in the US is heavily concentrated in the university context, probably to a greater degree than in any other industrial country. This has been especially true of basic research. In Japan a far higher proportion of scientific research is carried out in private industry. In Germany a large fraction of basic research is carried out by the Max Planck Society (the successor to the earlier Kaiser Wilhelm Society) and much applied scientific research is conducted by the Fraunhofer Society (founded in 1949). It is important to add, however, that the large-scale commitment of US federal funds to the support of university science is a post World War II development.

2. A distinctive feature of the American higher educational system, which follows partly from my first observation, is that that system brought about a unique synthesis of advanced research with graduate and professional education. The American university has developed arrangements that enable future scientists to serve an invaluable apprenticeship by allowing them to

participate in research projects with distinguished scientists as a central part of their graduate education. I believe that this has been one of the most creative features of the American higher educational system.

3. American universities, perhaps partly because of their relative newness, but also because of the extreme diversity of their origins and constituencies and their high degree of decentralization, have historically been flexible and distinctly responsive to the needs of the business and industrial communities. This feature became somewhat less conspicuous after the Second World War when large-scale federal expenditures led to a strong concentration of basic science in American universities.

American universities have never been heavily subject to centralized control. The university system has highly diverse component parts, including strong public and private sectors. Even in recent decades when the financing of research has been subjected to a high degree of centralization, decisionmaking with respect to research has remained, in important respects, largely decentralized. The emergence of a state university system in the nineteenth century meant that each state had a university that was subject to local control and whose long run prosperity and success were heavily beholden to the needs of local industries and to the priorities established by state legislatures. This responsiveness was particularly apparent in the contributions to local agriculture that were made by the so-called land grant colleges and agricultural experiment stations.

In this context, intellectual innovations were quickly seized upon and introduced into university curricula as soon as their potential utility became apparent. When the economic importance of electricity became obvious, with the introduction of the dynamo in 1882, MIT (also a land grant college) offered its first course in electrical engineering (1882). Cornell followed suit in 1883 and awarded the first doctorate in the subject as early as 1885. The histories of other engineering disciplines - especially chemical and aeronautical engineering - are broadly similar. Furthermore, it was no accident that the subject of statistics was introduced rapidly in the US and acquired curriculum and departmental status long before this happened in Europe. Nor was it an accident that pioneering roles in introducing statistical techniques were played by Iowa State University and the University of North Carolina. Both of these universities had strong agricultural experiment stations where sophisticated statistical analysis was essential in evaluating the results of agricultural experiments.

II

The main thrust of my discussion so far has been the extreme openness of the American university system to industrial needs, combined with the high degree of concentration of scientific research within the university community. Superimposed on this system, in the past few decades, has been the growing proximity between the scientific and technological realms, so that technological advance in industry has become increasingly dependent upon the ability of the industrial sector to exploit the findings of university science. Thus today, and increasingly in the future, commercial success will be dependent upon ways of improving the organizational arrangements and the incentive structures that dominate the university/industry interface. The ability to improve the functioning of that interface will undoubtedly be an important determinant of future leadership in high technology industries.

Such prospective improvements need to take into account the fact that the organization of scientific research activity has altered in character in the past several decades. For example, there is much evidence that scientific knowledge of a kind that is most likely to be useful to high technology industries has to be pursued in an increasingly interdisciplinary fashion. In recent years, medical science has benefitted immensely, not only from research in "nearby" disciplines such as biology, genetics and chemistry, but also from nuclear physics (magnetic resonance imaging, radioactive tracers, radiommunoassays), tomography, electronics, and materials science. Some sense of the wide range of sources of change in medical science may be derived from a casual stroll through the intensive care unit of any major teaching hospital. The impact of new techniques of instrumentation, originating in physics research, upon medicine has been profound, even if we confine attention to new noninvasive diagnostic technology for internal imaging of the human body. That role was explicitly recognized a few years ago when two physicists received a Nobel Prize in medicine for the development of computer-aided tomography (CAT scanner). Tomography, magnetic-resonance imaging, and ultrasonic imaging have transformed modern medical practice.

In pharmaceuticals, there have been explosive advances in the related fields of biochemistry, molecular and cell biology, immunology, neurobiology and scientific instrumentation. These advances are creating a situation where new drugs, with specific properties, can be targeted and, to an increasing extent, designed, in striking contrast to the randomized, exhaustive and expensive screening methods that characterized pharmaceutical research in the past.

New technologies of the type just referred to are, unavoidably, the product of research of an interdisciplinary nature. That is to say, successful outcomes require close cooperation by an increasing number of specialists. This has been increasingly true of innovation in many other fields as well, including some of the most important innovations in the 20th century. The transistor was the result of the combined efforts of physicists, chemists and metallurgists. The scientific breakthroughs leading to the discovery of DNA was the work of chemists, biologists, biochemists and, far from least, x-ray crystallographers. More productive seed varieties, such as the high-yielding rice varieties developed at the International Rice Research Institute in the Philippines that have transformed the food supply situation in Asia, were the work of geneticists, botanists, biochemists, entomologists and soil agronomists.

It is important to appreciate that multidisciplinary research of a kind that yields significant new insights has seldom, if ever, emerged from an ex ante agreement among research workers in different disciplines that collaboration is a "good idea." Rather, it has developed historically from the emergence of unsolved problems at the research frontier of a particular discipline - e.g., cell biology - that required a better understanding of the role of certain processes that were the specialty of scientists in a different discipline - e.g., chemistry. The eventual outcome - biochemistry - has thus been a natural outgrowth of the changing requirements of an expanding body of research knowledge. Similarly, geophysics emerged as an independent subdiscipline of geology when it became possible to apply the methodologies that had developed in physics to the understanding of the structure and the dynamics of the earth (as well as other planets). Finally, the introduction of new techniques of instrumentation has led, time and again, to a beneficial crossing of the traditional boundaries between physics and chemistry. All of this serves to emphasize the importance, not of planning, but of organizational flexibility, since the need to cross from one discipline to another in the progress of research is not something that can be anticipated.

Indeed, in some cases the interdisciplinary nature of technological progress has been imposed by quite unanticipated shifts in the underlying bodies of scientific knowledge upon which that progress has depended. The transition from the transistor to the integrated circuit brought with it a shift from essentially mechanical techniques of fabrication to chemical techniques. In the field of semiconductors a dominant trend has been the continued shrinkage in the size of electronic devices. This has created a situation where further technological progress now involves thinking in entirely different disciplinary terms. Specifically, the unit of analysis for further progress in miniaturization is no longer solid material but, rather chains of molecules. At this point the required knowledge is no longer of the kind in which electronics engineers have been trained. Rather, it is theoretical chemistry.

The increasing importance of interdisciplinary research brings with it serious organizational problems. I have already said that it is a process that cannot readily be planned. Moreover, such research often runs counter to the traditional arrangements, training, priorities and incentive structures of the scientific professions. This is especially true in the academic world where tremendous emphasis is placed upon working, and publishing, within well-recognized disciplinary boundary lines. In this respect the organizational structure of the American university, along well-defined disciplinary lines, poses some serious problems and limitations as the solution to research problems comes to rely increasingly upon research that is multidisciplinary in nature. Substantial changes may be necessary if American universities are to make as great a contribution to technological leadership in the future as they have done in the recent past.

III

At the same time, a major strength of scientific research in the American university system has been the highly successful interface that it has developed with the industrial world. This relationship has not been without its problems and dangers. Industrial financing of university research runs the inevitable danger that universities will have their research agendas increasingly set by their external sources of finance. While this is a common and widely-accepted occurrence with respect to what is sometimes called "generic research," it could have serious dysfunctional consequences if this were to happen to research of a more fundamental nature. If this were to happen there would be a real threat that university scientists might lose their intellectual autonomy, focus upon short-term problems of immediate interest to industry, and thereby suffer a loss of effectiveness as the leaders in fundamental research. Although such potential loss of autonomy is an ever-present threat, particularly in a period such as the present when some federal sources of university research and instrumentation support have declined, there is little evidence, at least so far, that this threat has become a reality.

In fact, the interface between the university and industry has recently been enriched by institutional innovations whose purpose is to bring about more effective interchanges between industry and the university community, especially where there is a widely-held judgment that progress at a particular research frontier may be of great commercial value. Stanford University has a Center for Integrated Systems, with financial support from twenty corporations, which is devoted to developing large-scale integrated microelectronics circuits. MIT's Whitehead Institute, which has a huge private endowment, is devoted to biomedical research. MIT has also had a ten year research contract with Exxon Research and Engineering Company to support research in the field of combustion - a critical field in which systematic knowledge is still surprisingly fragmentary. West Germany's huge chemical and pharmaceutical company, Hoechst A.G., has given the Massachusetts General Hospital, a teaching arm of the Harvard Medical School, $50 million for the support of basic research in molecular biology. Additionally, and more worrisome, Harvard's Dana-Farber Cancer Institute has an agreement with Sandoz Pharmaceutical Ltd. that includes agreements on the sharing of patent rights and royalties.

The university/industry interface has also been reshaped by important initiatives that have come from the federal government as well as private industry. The NSF has embarked on a program to establish a number of engineering research centers on university campuses. These centers, often explicitly interdisciplinary in nature, are a new form of university research organization in which the federal government (and, to a lesser degree, state and local governments) will bear the primary financial risks - at least in the early stages. There is a strong underlying emphasis on computers and specialized engineering skills working in close liaison with the more traditional scientific disciplines of physics, chemistry and biology.

There are now a number of these ERCs. Columbia University has a center of telecommunications, the University of California at Santa Barbara has one on robotics, Rutgers University and the University of Delaware on composite materials (Delaware since closed?), the University of Maryland and Harvard University on the application of advanced computers to the design of communications systems, MIT on the improvement of manufacturing processes in the biotechnology industry, and Purdue University on highly automated manufacturing systems.

These ERCs are research institutions of recent vintage, and their limited track records so far render it difficult to evaluate their effectiveness. Indeed, it is one aspect of their institutional novelty that it is not entirely clear by what criteria their performance ought to be evaluated. On the academic side there is a concern that the university's strong commitment to research of a long-term nature will be eroded by an increasing focus upon short-term problems of a less fundamental nature because research priorities are being determined at least partly by commercial considerations. Closely connected is the concern that academic scientists will lose their freedom to determine their own research agenda as private industry comes to play a more prominent role in financial support. How to protect this autonomy ought to be a serious concern of science policymakers, since such autonomy is essential to the long-term creativity of the scientific research community. In this context it is worth recalling that the system of peer review and other protective arrangements were introduced when the federal government became a large-scale patron of university research after the Second World War. At the same time, while providing such protection, how might the concerns of the university research community be better "meshed" with the very different concerns of private industry? How can the desire of private industry to acquire proprietary control over new developments be reconciled with the traditional (and essential) openness of communications channels in the university world? What assurances can both federal and private sponsors provide for continuity of research support, a problem that has become increasingly severe over the past decade or so? Moreover, the increasing importance of research centers at universities represents a shift in the balance of financial support away from the individual scientist and in favor of some form of larger cooperative group. Is this suppression of the individual research worker in favor of some larger team concept a healthy one for university science? These are all difficult questions; how they are answered will play a central role in future university/industry relations.

At the same time that these questions are raised about institutional innovations, it is well to ask questions about the continued efficacy of the older arrangements that have been central components of the system that was put in place in the years after the Second World War. Clearly the much-prized autonomy of the university research professor has always been severely limited by the research priorities established by the federal government through its various agencies - DoD (which has also had a notorious penchant for secrecy), NIH, NSF, Department of Energy, etc. That system has always "orphaned" many categories of university research that were not recognized as high priority by the federal patrons of science. Moreover, the peer review system, however imperfect, has been an invaluable device for quality control and for limiting politically-based intrusions upon the research community. In the past fifteen years or so, however, that system has been increasingly violated by direct congressional earmarking (as well as "Presidential Initiatives") of large projects that have bypassed the peer review system - earmarking that has amounted to straight-forward "pork barreling." "Ear-marked" funds amounted to about $700 million in 1992, a year in which the entire NSF budget was approximately $2 billion.

IV

The discussion so far has focussed primarily on the university portion of the university/industry interface. This has been in keeping with the focus of this conference: "Promoting Basic Scientific Research in Universities." But, insofar as this paper is concerned with the relationship between university research and industrial innovation, it is essential to say something about the industrial users of the knowledge produced at universities.

The economic effectiveness of universities as producers of knowledge that ultimately turns out to be useful will depend on the capability of the private sector to exploit that knowledge. Even the most brilliant and creative university research will have little consequence unless private industry has the scientific and technological sophistication for monitoring and evaluating and, perhaps even more important, expanding upon the findings of university research. In this respect, the basic reason that scientific research at American universities has played such a large role in the past economic life of the country is that they interacted with an industrial sector that also possessed considerable scientific sophistication.

The industrial research laboratory has been one of America's most significant institutional innovations. A number of the best American industrial research laboratories have performed excellent research at the scientific frontier as well as at the technological frontier. This statement certainly applies to Bell Labs, IBM, General Electric, du Pont, and Eastman Kodak, as well as a number of others. Scientists at these firms have occasionally won Nobel Prizes. But to end the discussion at this point would be very misleading. These firms have achieved considerable commercial success in the past not because of their ability to perform first-rate scientific research, but because their research capabilities were effectively linked to technological and commercial skills that are the ultimate determinants of economic performance.

It must be emphasized that scientific research at universities typically terminates very far from the point at which a marketable product has become available. It is extremely easy, especially for academics, to overstate the role of the R of R&D. The conversion of new scientific findings into new final products typically requires dealing with numerous uncertainties and resolving any number - sometimes literally thousands - of technical difficulties. It is important to remember that R&D expenditures for the US consist of two-thirds D and one-third R. Moreover, eventual commercial success is likely to be determined by a number of complementary skills quite unrelated to university science - especially the skills associated with the marketing and the distribution of new products and the ability to feed back the early reactions of consumers to specialists responsible for improved product design and performance.

The most successful American research laboratories in private industry have done much more than simply to demonstrate that it is possible to conduct research of both a fundamental and multidisciplinary nature in a commercial, "mission-oriented" context. The most successful have been those that have created close interactions, and exchanges of information, between those performing the research, on the one hand, and those responsible for the management of production and marketing, on the other. These information exchanges have been vital to commercial success. Successful innovations have been much more than just a "packaging" of information that was produced by scientific research and that simply flowed downstream where it was assembled into a new product by clever designers and engineers. It has been much more of an interactive process, with vital information flowing upstream as well as downstream.

V

Finally, I suggest that it is necessary to rethink the very meaning of the term "basic research." By general agreement, the term has been reserved for research activities that involve the quest for fundamental understanding. In the traditional natural sciences such a quest has often been identified with research that is remote from any concern with practical application. But this has, in turn, led to a view of basic research that treats as primary the lack of concern with practical applications, rather than with the search for fundamental understanding of natural phenomena. This is not only unfortunate; it is positively bizarre. It is a serious misconception to think that if research is "basic" this means that it is not motivated by or funded because of its promise to deal with a class of practical problems. The NIH is today, by far, the largest funder of university research. There are excellent, and totally utilitarian reasons, why this should be the case.

It is important to understand that a very large fraction, probably well over one half, of current university research is focused upon what Herbert Simon has called "the sciences of the artificial." These fields are, by their nature, linked into technologies and the practical problems of industry, medicine, agriculture and other areas of human concern. Consequently, the very distinction between the applied sciences and engineering, on the one hand, and basic research on the other, has lost much of its operational significance. "Practical" medical studies of carcinogenic processes often involve research in cell biology of a most fundamental nature. Research in the field of computer science may involve the development of new fields of mathematics, or a fundamental inquiry into the way humans solve problems, and the way the brain works. Research on steam turbine design or the design of aircraft wings may lead to advances in the analysis of turbulence, a phenomenon that is central to a deeper understanding of many aspects of the physical universe, such as the formation of weather patterns. In all such areas, a concern with very practical problems may result in advances in knowledge at a basic level. It is worth recalling that Carnot formulated the Second Law of Thermodynamics while attempting to understand the determinants of the thermal efficiency of a steam engine, and that Pasteur formulated the modern science of bacteriology around 1870 while attempting to deal with the problems of fermentation and putrefaction in the French wine industry. In these, as in many other instances, scientific knowledge of a high degree of conceptual generality grew out of the analysis of a particular problem in a very narrow context.