EMERGING TECHNOLOGIES
A Survey of Technical and Economic Opportunities

Technology Administration
U.S. Department of Commerce

Spring 1990

UNITED STATES DEPARTMENT OF COMMERCE
International Trade Administration
Washington, D.C. 20230

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Mr. Mark F. Cantley
Directorate - General for Science
Research & Dev.
CUBE
Commission of the European Communities
Rue de la Toi 200
B-1049 Brussels, Belgium

Dear Mark,

Thank you for the information you sent me. Enclosed is the publication you requested.

As you may be aware, we have initiated a study of biotechnology in Eastern Europe, utilizing locals to prepare the chapters. In addition at this years Biotechnica at Hannover, (U.S.A. seminar) we are having presentations of biotechnology in eastern europe given by the authors of this study.

It was nice to see you in March and look forward to hearing from you again.

Sincerely,

Alfred Hellman
Science Advisor
for Biotechnology

Enclosure

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FOREWORD

Emerging technologies have the potential to create a multitude of new products and services and to substantially advance productivity and quality. This report identifies 12 emerging technologies in four major categories that feature a combined U.S. market potential of about $350 billion in annual product sales by the year 2000 and a world market approaching $1 trillion. If the United States takes maximum advantage of this economic potential of emerging technologies, further growth in the U.S. standard of living should result.

However, competition from the world's other two economic power centers, Japan and the European Community (EC), is strong. If current trends continue, this study indicates that, before the year 2000, the United States could lag behind Japan in most emerging technologies and trail the EC in several of them.

Based on knowledge of U.S. industry and overseas efforts, this report identifies 13 areas of opportunity for enhancing the likelihood of U.S. success in international competition. Changes and actions in these and other areas could improve the climate for economic development of *all* emerging technologies, including future additions from the U.S. science base.

The purpose of this report is to provide a source of information to be used by industry, labor, government and academe as programs and policies are developed to exploit new, emerging technologies. The report is *not* intended to set out a limited set of technologies which the government has pre-selected for support. Rather, it reflects the new international science and technology community's agenda of promising fields with large potential economic impact.

I believe that the information this report contains will facilitate a continuing dialogue in order to maximize the benefits that we can derive, as a nation, from the opportunities offered by emerging technologies. The goals of such dialogue are refined views, additional information, and—most importantly—consensus on what is worth doing and what are the appropriate roles for industry, government, labor and academe. Assuring U.S. industries' global competitiveness is foremost among the benefits that would accrue from exploiting emerging technologies. In turn, our economic security is a prerequisite for a strong U.S. defense posture and for maintaining and advancing the well-being of every citizen. I encourage your comments and suggestions on this important topic.

Robert A. Mosbacher
Secretary of Commerce

EXECUTIVE SUMMARY

This report identifies 12 emerging technologies that feature a combined U.S. market potential of $356 billion in annual product sales by the year 2000. The report discusses competition from the world's other two economic power centers, Japan and the European Community (EC). This study indicates that, if current trends continue, before the year 2000, the United States will lag behind Japan in most emerging technologies and will trail the EC in several of them.

Based on contacts with U.S. industry and information about activities abroad, this report identifies 13 areas of opportunity for improving the climate for economic development of all emerging technologies. The purpose of this report is that of an information base to facilitate discussions between industry, government, labor and academia. In this role, the report should be viewed as a living document subject to revision, updates and expanded coverage, moving along with the process of national consensus formation.

The following figures summarize the content of this document:

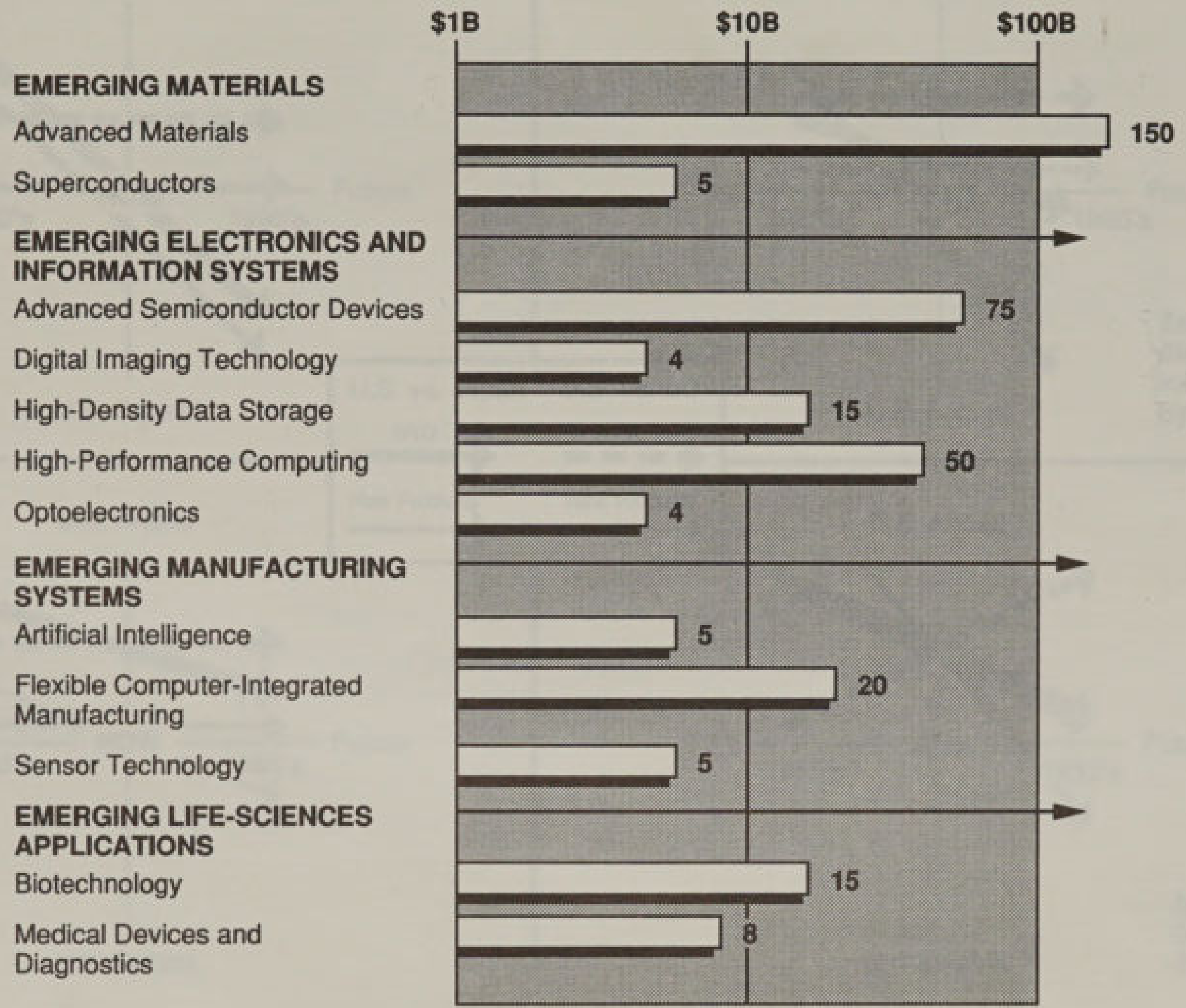
•*Emerging Technologies and Markets* is a tabulation of the emerging technologies together with their market potential. Twelve technologies are covered because they offer substantial economic benefits for U.S. industry by the year 2000. They are grouped into four major categories: Materials, Electronics and Information Systems, Manufacturing Systems, and Life Sciences Applications. The potential product markets are depicted in bar-graph-format: Annual sales in the U.S. market by the year 2000.
Source: Technical knowledge of staff of the U.S. Department of Commerce, in particular scientists and engineers of the National Institute of Standards and Technology; based on interviews with U.S. international science, engineering, and industrial experts.

•*U.S. Versus Japan and the European Community* depicts the current standing and the trends observed for the major categories of emerging technologies. Trend lines show the comparison to the world's other great economic powers; the horizontal dividing line indicates parity. Concern about the U.S. position increases with the steepness of the drop of a trend line. The two associated tables entitled ***U.S. Report Card*** give a more detailed view of current status and trends in world competition for all 12 emerging technologies.
Source: Compiled from the knowledge residing within the Department of Commerce, mostly from contributors within the National Institute of Standards and Technology and the International Trade Administration.

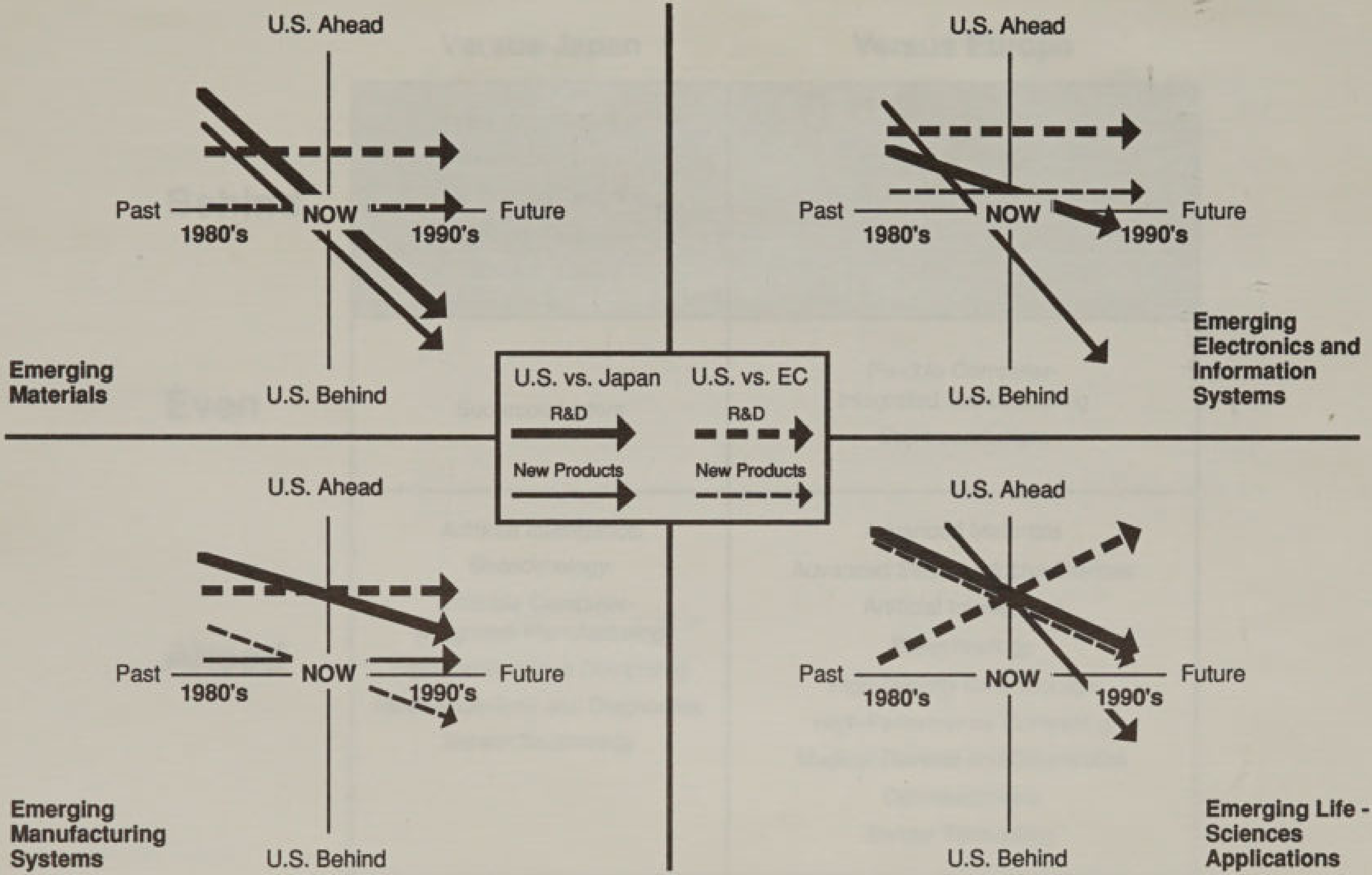
•The four groupings of ***Opportunities*** tabulate 13 areas where actions could be defined and implemented toward improving the climate and capabilities for competitive economic development of all emerging technologies; these 13 areas are not meant to be comprehensive. The four groupings reflect varying degrees of government-industry interaction.
Source: Compiled from the knowledge residing within the Department of Commerce.

EMERGING TECHNOLOGIES AND MARKETS

Annual Sales of $356 Billion in the U.S. by the Year 2000



U.S. VERSUS JAPAN AND THE EC



U.S. REPORT CARD: STATUS 1989

	Versus Japan	Versus Europe
Behind	Advanced Materials Advanced Semiconductor Devices Digital Imaging Technology High-Density Data Storage Optoelectronics	Digital Imaging Technology
Even	Superconductors	Flexible Computer-Integrated Manufacturing Superconductors
Ahead	Artificial Intelligence Biotechnology Flexible Computer-Integrated Manufacturing High-Performance Computing Medical Devices and Diagnostics Sensor Technology	Advanced Materials Advanced Semiconductor Devices Artificial Intelligence Biotechnology High-Density Data Storage High-Performance Computing Medical Devices and Diagnostics Optoelectronics Sensor Technology

U.S. REPORT CARD: TRENDS

	Versus Japan	Versus Europe
Losing Badly	Advanced Materials Biotechnology Digital Imaging Technology Superconductors	Digital Imaging Technology Flexible Computer-Integrated Manufacturing
Losing	Advanced Semiconductor Devices High-Density Data Storage High-Performance Computing Medical Devices and Diagnostics Optoelectronics Sensor Technology	Medical Devices and Diagnostics
Holding	Artificial Intelligence Flexible Computer-Integrated Manufacturing	Advanced Materials Advanced Semiconductor Devices High-Density Data Storage Optoelectronics Sensor Technology Superconductors
Gaining		Artificial Intelligence Biotechnology High-Performance Computing

OPPORTUNITIES FOR GOVERNMENT LEADERSHIP

THE COST OF RESEARCH AND MARKET INTRODUCTION

The Cost of Capital Determines the Business Horizon Especially for the Introduction of New Technology

- National Savings Rate
- Federal Budget
- Tax Laws

EXPORT POLICY

New Technologies Are the Strongest Assurance for Maintaining a Superior National Security Posture

- Speed of Approval Process
- Foreign Availability of Similar Products
- Re-Export Controls

REGULATORY CONSTRAINTS

New Products Require Evaluations of Their Impact on Health, Safety and Environment That Are Often Lengthy and Costly

- Streamlining Procedures and Harnessing Market Incentives
- Proper Balance of Protection Versus Economics
- Large Differences in Requirements Between Countries

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- Court Versus Out-of-Court Pathways
- Multiplicity of Laws Here and Abroad

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Technology Requires Special Skills To Assure High Quality, Low Cost and Competitively Timed Market Entry

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- Domestic Content and Preferential Buy Requirements
- Disregard for Intellectual Property and Non-Symmetrical Access to R&D

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- Extended Duration of Protection Periods
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- Availability of Methods, References and Data
- Industry Access to Government Facilities

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International Standardization Provides Equity Between Buyers and Sellers in Different Countries

- Industry and Government Participation in Standards Committees
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- Promote International Consideration of U.S. Technical Advances

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The Size and Accessibility of the U.S. Market Make It Appear Like It is "The World"

- Rise to Product Challenges From Abroad
- Enhance Export Opportunities
- Put to Use Technology and Innovation From Abroad

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- Customer Expectations
- Quality Through Process Design

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Organizational Integration Speeds Up Product Introduction, Lowers Its Cost, Improves Its Quality

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- Team Work and Process Orientation
- Computer (Information) Integration

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- Shared Facilities and Projects
- Antitrust Legislation
- Vertical Linkages and Integration

Report on
EMERGING TECHNOLOGIES
A Survey of Technical and Economic Opportunities

1. Purpose of the Report

For most of the period following World War II, the United States was dominant internationally and nearly self-sufficient in science and technology. Our university, industry, and government laboratories were the sources of the ideas for new products and processes which were produced by American factories using American workers and equipment and financed by American investors. Although in some instances U.S.-based multinational corporations operated overseas, this was generally to be close to raw materials or markets and to take advantage of lower labor costs. Products generally were based on technologies developed in the United States.

This dominance has eroded in recent years, and U.S. supremacy has been challenged. Many other countries have attained world-class capabilities in critical technologies and have focused on the timely commercialization of high-quality, cost-efficient products in the international marketplace. Many foreign governments have used subsidies and various other mechanisms to encourage development of specific advanced technologies and their commercial applications.

To remain competitive in this rapidly evolving international economic community, U.S. industry must match these developments by increasing emphasis on research and development of new products and emerging technologies and then on product commercialization and market share.

The purpose of this report is to provide a source of information to be used by industry, government and academia as programs and policies are developed to exploit new, emerging technologies. The report is *not* intended to set out a limited set of technologies which the government has pre-selected for support. Rather, it reflects the new international science and technology community's agenda of promising fields with large potential economic impact. It provides (1) a list and brief description of emerging technologies anticipated to be of major economic importance by the year 2000; (2) a comparison of these technologies with those considered important by major international competitors; and (3) an outline of some opportunities for policies, practices, and procedures that would help U.S. industry to introduce and gain market share from emerging technologies more effectively. Specific recommendations for improvements can result only from extensive deliberations involving industry, academia, labor, and government. However, it is hoped that this document constitutes at least a partial agenda for further discussions.

2. Economic Importance of Emerging Technologies

For purposes of this report, emerging technologies are broadly defined as follows:

An emerging technology is one in which research has progressed far enough to indicate a high probability of technical success for new products and applications that might have substantial markets within approximately 10 years.

In large developed economies such as the United States, economic growth requires that a substantial number of emerging technologies be under development simultaneously to diversify risk and broaden the future industrial base. Just as a mutual fund manager diversifies risk through a large portfolio of investments (expecting some failures), a country with a large diversified economy ought to take advantage of a large science base and rich technological resources to pursue development of as many emerging technologies as possible; this would assure maximum flexibility to capture the economic benefits from those technologies which eventually prove successful in the global marketplace.

This portfolio approach is a very different concept from the "targeted industry" strategy of some countries. In this approach, a few technologies or industries are singled out for intensive government support. Such a strategy might be appropriate for a developing country with limited technological resources, but it is probably not desirable for the United States.

Industry and government strategies for developing and exploiting emerging technologies depend to a great extent on assessments of the nature and magnitude of their economic potential. Emerging technologies must be viewed as having the potential to either

- *create new products and industries with markets of substantial size, or*
- *provide large advances in productivity or in the quality of products produced by existing industries which supply large, important markets.*

Some emerging technologies—usually self-contained products, such as new medicines, or processes, such as x-ray lithography—have important but focused impacts. Others substantially affect the economy by advancing the technical infrastructure or by improving the quality and efficiency of the manufacturing process. Examples are components of a computer-integrated manufacturing system, such as robots or machining centers or the factory control system itself.

Emerging technologies are also important because they will drive the next generation of R&D and spin-off applications. When an industry uses a new technology to design or improve a product and successfully carries it to the commercial marketplace, that new or improved product becomes the starting point for development of the next generation of products or services. Hence, leadership in an emerging technology provides the basis to become a major player in developing or commercializing successive generations of breakthroughs in that or a related technology.

In addition to their economic impact, their influence on next-stage technology and their relevance to national defense (Appendix C and D), emerging technologies affect social and political systems. Advances in computers and communications, for example, are changing work practices and the work environment itself; the removal of geographical limitations on work locations and the increased capability for communicating large quantities of information have affected social and political behavior.

3. The Emerging Technologies

Emerging technologies expected to be of economic importance by the year 2000 are listed in table 1. A more detailed explanation of what these technologies encompass, how they are rooted in science, and how they affect the markets is presented in Appendix A. Their potential impact on national defense is also presented in Appendix A by cross reference to the 1989 *DOD Critical Technologies Plan* and summarized in Appendix C. Market estimates are solely intended to provide rough guidance and to indicate current perception of economic potential.

The list of emerging technologies was generated using published material (see list of References), knowledge residing within the Department of Commerce which reflects strong interactions with U.S. industry and the international scientific and technical community, and extensive iteration involving the many technical experts contributing to this report. The selected emerging technologies cover the full range from post-basic-research to post-early-commercialization. All entries are projected to have substantial economic impact and to exhibit rapid rates of technical progress. A comparison of this list to the 1987 report of the Department of Commerce[1] is given in Appendix B.

These 12 emerging technologies can be aggregated[2] into four major categories:

Emerging Materials
Emerging Electronics and Information Systems
Emerging Manufacturing Systems
Emerging Life Sciences Applications

Technologies in these four categories are likely to have not only substantial economic impact but also very large indirect infrastructure and social impact. Many also will have substantial national security impact. Furthermore, they each affect several industry sectors and a multitude of products, processes, and services.[3] Finally, it must be noted that three of these categories already are being aggressively pursued by Japan and Europe (see table 4) with ambitious proposals to establish extensive programs in the fourth (Manufacturing Systems).

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[1] National Bureau of Standards Internal Report 87-3671, June 1987.

[2] Several of these emerging technologies support more than one category; they were listed where they likely will make their primary beneficial contributions.

[3] Most of the emerging technologies are also dependent on each other. For example, advances in materials, semiconductor devices, and computing affect nearly all of the other emerging technologies.

The emerging technologies of table 1 represent only a subset of all the critical and important technologies. Technologies that are still just scientific opportunities were not listed; also excluded were technologies which have already fully entered the marketplace.

An example of the former is *Nanotechnology*. Although molecular manipulation, nanolithography, and molecular electronics offer exciting prospects for extremely dense electronics, custom-designed materials, and novel pharmaceuticals, unresolved scientific questions make market development by the year 2000 extremely unlikely.

Among the important technologies with a well-established market are those expected to expand and/or restructure by the year 2000. These technologies will benefit not only from some of the emerging technologies but also, significantly, from the introduction of well-known technologies in use elsewhere. For these reasons, they are summarized below:

Building Technology: Major development is now occurring in the areas of flexible and modular manufacturing, intelligent buildings, facilities diagnostics, construction quality assurance, use of new materials, and earthquake and geotechnical engineering. Buildings and other facilities are being equipped with sensors, data processors and actuators to monitor the environment and provide security, safety, air quality, thermal and lighting control, and dynamic structural response.

Chemical Catalysis Technology: Approximately 20 percent of the U.S. gross national product is generated through the use of catalytic processes. Continuing development of catalysts with improved reactivity, selectivity, and stability will permit the manufacture of new materials, reduce the cost of existing products, and increase yields. Significant advances are occurring in the areas of computer modeling of complex catalytic reactions, creation of catalysis designed at the molecular level, and highly specific catalysis that produces few undesirable reactions.

Energy Technology: Environmentally acceptable and economically viable generation, control and transmission of electric power is a prerequisite for a technology-based society. New insulating materials, advanced instrumentation and sensors as well as modern computing and communication technologies will help assure efficient and reliable transmission systems. The depletion of resources, dependence on oil imports, and world environmental concerns (greenhouse effect) will be strong incentives towards the realization of both clean and ultra-safe nuclear power generation which will require full use of existing technologies, many of the emerging technologies, and the development of new standards.

Fire Safety Technology: Significant advances have been made in the area of polymer thermal degradation, advanced sensing and extinguishment techniques, and risk prediction, management, and control. These new abilities to predict and prevent fires cost-effectively have potentially very favorable economic and competitive consequences for a wide array of industries including not only the construction industry but also transportation, aircraft, plants and facilities.

Table 1. The Emerging Technologies

EMERGING TECHNOLOGY	MAJOR TECHNOLOGY ELEMENTS[a]
	Emerging Materials
Advanced Materials	Structural and Functional Ceramics, Ceramic and Metal Matrix Composites, Intermetallic and Lightweight Alloys, Advanced Polymers, Surface-Modified Materials, Diamond Thin Films, Membranes, Biomaterials
Superconductors	High-Temperature Ceramic Conductors, Advanced Low-Temperature Conductors
	Emerging Electronics and Information Systems
Advanced Semiconductor Devices	Silicon, Compound Semiconductors (GaAs), ULSI, Memory Chips, X-ray Lithography
Digital Imaging Technology	High Definition Systems, HDTV, Large Displays, Data Compression, Image Processing
High-Density Data Storage	High-Density Magnetic Storage, Magneto-Optical Storage
High-Performance Computing	Modular/Transportable Software, Numerical Simulation, Neural Networks
Optoelectronics	Integrated Optical Circuitry, Optical Fibers, Optical Computing, Solid-State Lasers, Optical Sensors
	Emerging Manufacturing Systems
Artificial Intelligence	Intelligent Machines, Intelligent Processing of Materials and Chemicals, Expert Systems
Flexible Computer-Integrated Manufacturing	CAD, CAE, CALS, CAM, CIM, FMS, PDES, Integrated Control Architectures, Adaptive-Process Control
Sensor Technology	Active/Passive Sensors, Feedback and Process Control, Nondestructive Evaluation, Industrial and Atmospheric Environmental Monitoring & Control
	Emerging Life Sciences Applications
Biotechnology	Bioprocessing, Drug Design, Genetic Engineering, Bioelectronics
Medical Devices and Diagnostics	Cellular-Level Sensors, Medical Imaging, In-Vitro and In-Vivo Analysis, Targeted Pharmaceuticals, Fiber Optic Probes

[a] An explanation of acronyms can be found in Appendix A.

Source: Technical knowledge of staff of the U.S. Department of Commerce, in particular scientists and engineers of the National Institute of Standards and Technology; based on interviews with U.S. international science, engineering, and industrial experts.

Microwave Technology: Individual microwave components and antennas, and integrated systems containing these components are finding new and expanded applications in areas such as radar for robot vision, collision avoidance, and wind shear detection as well as communications for direct satellite broadcast, personal communications, and worldwide position determination. Further development of microwave technology strongly depends on advances in materials processing and the design and fabrication of integrated circuitry for very high frequencies.

Radiation Processing Technology: Accelerators and radionuclide sources are being used in sterilization of foods and materials, curing of polymers (especially in the electronics industry), radiation-induced catalysis, and waste processing. Entirely new products with unique mechanical, electrical, and temperature resistance properties are possible. The use of toxic materials and heat is avoided when these approaches are substituted for conventional techniques.

4. Emerging Technologies in the International Context

In today's global economy, a multitude of national economies interact with each other through trade. The role that governments have assumed in supporting research, technology, and its applications varies over a wide spectrum of activities (see also Appendix E). For example, in Japan, emphasis is placed on reducing ideas to practice; efforts are coordinated and sponsored by a variety of organizations, led by the Ministry of International Trade and Industry (MITI). The governments of the countries forming the European Community (EC) address issues across the board, ranging from basic research to prototype products with strong emphasis on full EC-wide coordination by 1992. The debate in the United States centers on to what degree, if any, should the United States deviate from the approach that has served its economy well in the past, i.e., the traditional focus of Government support of basic research, defense technology, and agency mission-oriented R&D.

If foreign firms develop products based on emerging technologies faster and more effectively than U.S. companies, then the price, performance and quality of foreign products may surpass U.S. offerings. In contrast, comparative success by U.S. firms in bringing emerging technologies to market will stimulate more and better quality jobs, increase exports, reduce imports, and contribute directly to material wealth. Not only will such success improve the U.S. civilian industrial base, but it will foster improved national security directly through dual-use technologies and indirectly by advancing the country's economic strength. Furthermore, it will enhance the ability of the United States to spawn the next generation of technology advances: the emerging technologies of the future.

Table 2 summarizes the driving forces that have created the new competitive realities. Table 3 provides a summary of the relative standing of the United States, Japan, and the European Community in R&D and product introduction. The information contained in table 3 was compiled from the knowledge residing within the Department of Commerce, mostly from contributors within the International Trade Administration and the National Institute of Standards and Technology. Other experts and organizations might not agree with every detail of this information but it represents the best estimates based on the Department's extensive experience; further discussions are needed to refine our knowledge and to analyze the driving forces and causes for the status and trends depicted by table 3. Table 4 compares the categories of important emerging technologies made in this report, with those in Japan and the European Community.

Table 2. Past versus Present: The New Environment for Emerging Technologies

Acceleration and globalization of the generation of technology:

Today, technology is generated at an accelerating pace in many industrialized countries. Rapid information exchange and mobility of people often make new technical ideas quickly available on a global scale. It can no longer be taken for granted that the country originating a new idea will be the country most likely to reap its economic benefits.

Differentials in the cost-of-capital:

Higher interest rates, cultural practices, and tax laws combine to make the effective cost of capital funds for U.S. firms more than twice as high as for their Japanese competitors and substantially higher than for European firms.

Globalization of industries:

Multinational corporations (based in the U.S. or abroad) decide what to produce and in which country. These decisions are based on sophisticated analyses of the manufacturing costs and of the capabilities of modern laboratories and factories anywhere in the world.

Integration of the manufacturing process:

Japanese manufacturers have pioneered the integration of the manufacturing process which has resulted in substantial time savings in product introduction as well as in superior product quality. Research shows Japanese firms generally introduce manufactured products twice as fast as U.S. firms.

Increased cost of prototype production:

The complex, multidisciplinary nature of emerging technologies, as well as the need to establish special test and/or process facilities and demonstration projects, often makes it prohibitively expensive for even large corporations to go it alone. Investment requirements can exceed hundreds of millions of dollars.

Expanded scope of benefits from emerging technologies:

The potential benefits from an emerging technology easily transcend the scope (i.e. the product portfolio) of most, if not all, U.S. corporations. Thus, return on investment for an individual firm is either unattractive or, if adequate, misses out on opportunities to exploit applications in other industries.

Source: Compiled from the knowledge residing within the Department of Commerce, mostly from contributors within the International Trade Administration and the National Institute of Standards and Technology.

Table 3. Relative Standing in Emerging Technologies: U.S. versus Japan and EC

	JAPAN		EUROPEAN COMMUNITY	
	R&D	Product Introduction	R&D	Product Introduction
Advanced Materials	o ↓	− ↓	+ ↔	o ↔
Advanced Semiconductor Devices	o ↔	− ↓	+ ↔	o ↔
Artificial Intelligence	+ ↔	+ ↔	+ ↑	+ ↔
Biotechnology	+ ↓	+ ↓	+ ↑	+ ↔
Digital Imaging Technology	o ↓	− ↓	o ↓	− ↓
Flexible Computer-Integrated Manufacturing	+ ↔	o ↔	+ ↓	− ↓
High-Density Data Storage	o ↔	− ↓	+ ↔	o ↔
High-Performance Computing	+ ↔	+ ↓	+ ↑	+ ↑
Medical Devices and Diagnostics	+ ↔	+ ↓	+ ↔	+ ↓
Optoelectronics	o ↔	− ↓	o ↔	+ ↔
Sensor Technology	+ ↓	o ↔	+ ↔	o ↔
Superconductors	o ↓	o ↓	o ↔	o ↔

Current Status:
+ = U.S. Ahead
o = U.S. Even
− = U.S. Behind

Trend:
↑ = U.S. Gaining
↔ = U.S. Holding
↓ = U.S. Losing

} (as compared to Japan/EC)

Source: Compiled from the knowledge residing within the Department of Commerce, mostly from contributors within the National Institute of Standards and Technology and the International Trade Administration.

Table 4. Comparison of Emerging Technology Categories: Japan, EC and U.S.

JAPAN[a]	EUROPEAN COMMUNITY[b]	U.S.[c]
New Materials	New Materials	Emerging Materials
Biotechnology Biomaterials	Biotechnology	Emerging Life Sciences Applications
Software Engineering Electronics	Information Technology	Emerging Electronics and Information Systems
–	–	Emerging Manufacturing Systems
–	Energy	–

[a] MITI White Paper, *Trends and Future Tasks in Industrial Technologies.*
[b] *First Report on the State of Science and Technology in Europe.*
[c] This report.

5. Opportunities for Change

In this chapter many of the factors that affect emerging technologies are discussed. Together they form an environment that significantly influences the effectiveness and speed of new product or process introduction as well as the likelihood that significant shares of the global market can be attained and sustained. These phenomena are often thought of as barriers that must be overcome. This discussion concentrates on areas (summarized in table 5) where opportunities may be found to modify the environment so as to lower the generic barriers to the effective development and commercialization of emerging technologies. Appendix B compares this list to the 1987 DOC report (see footnote 1 on page 7). The factors identified are preliminary, based on initial thoughts, and do not cover all areas comprehensively.

Table 5. Opportunities for Change

The Cost of Research and Market Introduction
Engineering Training and Education
Integration of R&D, Design and Manufacturing
Improving the Quality of Products and Services
Improving the Technology Infrastructure
Product and Interface Standards
Dependence on Domestic Technologies and Markets
Industrial Cooperation
Protecting Intellectual Property Rights
Laws of Product Liability
Regulatory Constraints
Export Policy
Restrictive Foreign Trade Practices

Source: Compiled from the knowledge residing within the Department of Commerce.

The Cost of Research and Market Introduction

Low capital cost can facilitate the development and commercialization of new products in at least two ways. First, projects are less expensive, thus decreasing risk for large companies and making it easier for small enterprises to enter the market. Second, the required rate of return can be correspondingly smaller, and higher risk or longer term projects are much more likely to be undertaken. Such considerations would therefore encourage longer business horizons.

In the early stages of the R&D process, commercialization is an uncertain and relatively distant event, and thus the investment risk is relatively high. Although investments at this early stage can yield large payoffs, the rewards may be too far in the future to be acceptable, even though the generic technology often can be applied to a number of distinct markets. Once the generic technology is developed and applications begin to enter the marketplace, the time to payoff is reduced, but the cost may be larger for late entrants to the field who must first catch up in technical expertise. For example, generic ceramics technology may have applications in such diverse markets as automobile engines, medical implants, machine tools, optoelectronic devices, and electronic capacitors.

It is very difficult to compare capital costs in different countries, and even the most sophisticated analyses are only estimates. Recent studies show, however, that capital costs in the United States are substantially higher than in some European countries and have been perhaps two to four times the costs in Japan. Prevailing interest rates play a fundamental role in the cost of capital, especially for small entrepreneurial companies. These rates are influenced by many factors, including the size of the public-sector debt and the rate of individual savings.

For larger firms, which may support research using income from other products, the impact of tax laws may be just as important. At a time when foreign countries continue to employ a variety of incentives to encourage the exploitation of emerging technologies, recent changes and uncertainties in the U.S. tax laws have had the effect of reducing the availability of funding for research and development by U.S. firms.

The research and experimentation tax credit, for example, was originally enacted in 1981 with an expiration date of December 31, 1985. The credit, which has subsequently been extended repeatedly, is presently scheduled to expire on December 31, 1990. The Bush Administration is actively seeking to make the credit permanent. Since 1984 the business community has not known whether the R&D tax credit will continue from one year to the next, creating great uncertainty. This has undermined to some extent the original intent of the legislation, namely that the credit become a factor in encouraging U.S. business to engage in long-term planning for R&D.

Engineering Training and Education

Success in global competition depends upon the availability of a well-educated and highly skilled work force. It depends equally upon the effective management and motivation of the work force. Design engineering, manufacturing engineering, and the management of technology are three areas of particular importance for the success of emerging technologies.

Design engineering involves an appreciation of the importance of the relationship between design and productivity. Designing for manufacturability is very important to assure product quality and cost-effective production. Furthermore, everyone connected to a product manufacturing line plays an important role in feeding information on the manufacturing process back to the designers. These concepts are key ingredients in productivity improvement and are widely practiced particularly by Japan.

Manufacturing engineering requires a full appreciation of the interdisciplinary nature of modern production methods. Accordingly, manufacturing engineers are trained in a broad program with contributions from many disciplines. Decades ago, American engineering schools moved away from the curriculum of engineering practice into a curriculum of engineering sciences. This resulted in a shortage of adequately trained manufacturing engineers; current emphasis is on reversing this situation.

Management of technology requires a broadly based, generalist engineer/business graduate to create an integrated, interdisciplinary team approach to the manufacturing enterprise. The required skills span fields such as basic engineering concepts, business knowledge, systems analysis, operations research, and computing. If this need is to be met by new graduates, it may take many years before they could expect to have a substantial impact in industry. Therefore, a good understanding of technical factors by existing managers is very important. It is also important to transmit the knowledge base on management technology from industrial and governmental organizations to the schools.

Integration of R&D, Design, and Manufacturing

In the current global competitive market, rapid transformation of emerging technologies and product improvements into commercial products is critical, but this transformation is often hampered by inadequate integration of R&D, design, production, and marketing. With tighter integration, Japanese firms often can transform an emerging technology into a commercial product twice as fast as U.S. firms.

Integration removes formal barriers between R&D, design, manufacturing, and marketing. Each phase is continuously alert for problems that might be encountered in later stages. In its ultimate realization, research, development, design, prototype production, and marketing progress nearly simultaneously.

Integration, including concepts such as concurrent engineering, total quality, and just-in-time production, require new tools to manage and disseminate information within an organization. Information about all aspects of the manufacturing process must be made readily available to everyone involved in production. Technology itself, in the form of advanced computer systems and new concepts in information management, has proven to be an effective facilitator.

Improving the Quality of Products and Services

Poor product quality often results from decisions and actions that preceded actual production, particularly in the design phase or in purchasing parts and materials. Improvements in the quality of the finished product must, therefore, focus on all aspects of the production process, with special emphasis on the early design phases and on sensing and process control. Adequate attention in these early stages may also lessen the time needed to produce a commercial product. Being first to market is not enough if the quality of the product is inadequate, especially if higher quality products also enter the market.

Beyond the many definitions of quality for performance, appearance, reliability, after-sale service, form, fit, and function, quality ultimately refers to how well customers' expectations are met in a competitive environment. This definition implies that there can never be an absolute determination of product quality; it has to be evaluated in terms of other products and the expectations of the user. This evaluation is especially important for a product sold on the international market because the preferences and expectations of users may vary from country to country. In 1987 the United States took a major step to focus attention on the importance of excellence in quality management by establishing the Malcolm Baldrige National Quality Award. Since 1988, five U.S. companies have received this award from the President of the United States.

In other countries, most notably Japan, techniques and processes for achieving consistently high quality have progressed much more rapidly and have been more widely adopted than in the United States. In contrast to the Japanese method of incorporating quality control in all phases of the design and manufacturing process, U.S. firms (and the U.S. government) often limit quality control to "inspecting quality in." Thus there is often no incentive for suppliers to invest in advanced, comprehensive methods.

Improving the Technology Infrastructure

The technology infrastructure consists of the science, engineering, and other technical resources that private industry needs to produce and market products and services competitively. For example, industry draws upon externally provided generic technologies, technical information, and research and test facilities.

In many cases, the development of an emerging technology by industry can be accelerated by joint efforts which may involve government laboratories, universities, and university research centers. These joint efforts are especially important in addressing elements of the generic technology where no single industry has the resources or the focus to undertake the research and where underinvestment in the generic technology would otherwise result.

Other important aspects of the technology infrastructure are methods that enhance the productivity of both the R&D and production phases and the efficiency of market development. They include measurement and test methods, interface standards, quality assurance models and methods, critically evaluated reference data and research, other technical and economic data, and test facilities. Increased use of capital-intensive research and test facilities, for which industry pays only the operating costs, would greatly facilitate research and product development.

Product and Interface Standards

Standards play an essential role in domestic commerce and international trade by providing written descriptions of products or services that can be used in transactions to assure equity between buyers and sellers. Increasing worldwide emphasis on the development and adoption of international standards by national standards organizations and governmental bodies has the potential to reduce protectionism. It is, therefore, vital to promote free-trade concepts in international arenas, especially for newly emerging technologies.

Influence on the international standardization process can be exerted best by strong participation in domestic standards committees and technical advisory groups to international committees and by concentrated efforts to maintain a vigorous presence in international fora especially holding secretariats in international committees and working groups.

One of the major impacts of EC 1992, the European Community's agreement to establish a single internal market by the end of 1992, will be European adoption of international standards, where available. This policy underscores the need to have good international standards in place early on. Lacking them, the European regional standards organizations, CEN and CENELEC, will develop their own standards to implement EC directives. The United States, lacking the right to participate in the European regional bodies, will have to promote European consideration of U.S. technical advances. Similarly, to the degree the United States works closely with developing countries, the promulgation of standards compatible with those in the United States will be encouraged.

Dependence on Domestic Technologies and Markets

The size and ready availability of the U.S. market to new products and services often results in a complacent attitude in domestic companies, which do not fully appreciate the need for competing with foreign firms. Especially in emerging technologies, where entrepreneurial (often small) firms dominate, a narrow focus on the U.S. market can prove to be a costly mistake. American companies, separately and in joint ventures, increasingly should seek export opportunities abroad and anticipate challenges in the United States from new foreign competitors.

A special challenge lies in overcoming the mind set of technical and management staff, which has often been called the "not invented here" syndrome. More aggressive pursuit of technology developed overseas is imperative for U.S. industry to exploit the emerging technologies. An increased awareness and acceptance of technological innovation occurring abroad would help U.S. industry to design and manufacture advanced products and use the most modern processes. New legislation and international agreements have paved the way for improved U.S. access to foreign government supported R&D.

Industrial Cooperation

Cooperative arrangements among nonaffiliated firms in the private sector are often essential for successful technological innovation and commercialization. For some technologies, cooperative efforts may be the only way of reducing the risk of developing innovative product options. The required facilities are expensive to build and will only become available to many U.S. firms if they are able to share the cost and risk of design and construction.

The substantive principles of U.S. antitrust law have generally been regarded as reasonable and as supporting efficient industry activity and low prices for goods and services. Also, through increasingly sophisticated analysis, U.S. antitrust enforcement agencies and courts have improved in their ability to differentiate between anticompetitive and benign business arrangements. However, for U.S. firms in particular, uncertainty about the applicability of the antitrust laws to such arrangements may chill a significant amount of potentially beneficial industry activity. The antitrust legal process is extremely lengthy and expensive, and business uncertainty as to its outcome remains a significant problem.

Traditional approaches to reducing antitrust uncertainty include issuance by the Justice Department of "business review letters," which indicate that agency's enforcement intentions with respect to particular proposed conduct. More recently, enforcement guidelines have been issued, and laws to provide clarity or "safe harbors" in specific areas have been proposed by the Executive Branch and passed by the Congress. Key enactments were the Export Trading Company Act and the National Cooperative Research Act.

The Bush Administration is seeking to reduce antitrust uncertainty in the especially important area of industry cooperation in the production of goods. It proposes to broaden the National Cooperative Research Act to cover joint production ventures in addition to the joint R&D ventures presently covered by that Act. Joint production ventures registered under the provisions of this legislation would be protected against treble damages in private suits. They would also be assured that their arrangements cannot be judged *per se* illegal, but will instead be evaluated under a "rule of reason" framework which is sensitive to actual, rather than presumed, competitive effects.

Regardless of legislative restrictions, cooperative ventures in the United States are less common than in other industrial countries (Appendix E). To some extent this is a result of custom and attitude. For example, instead of working together, domestic firms often push to have their own solutions accepted as a national standard because this strategy will often confer a short-term advantage in the domestic market. Such a strategy might not be optimal in the longer term, however, because it increases the vulnerability of domestic producers to foreign competition.

There also may be advantages in vertical linkages between a producer and its suppliers and customers. Such agreements might violate restraint-of-trade laws under certain circumstances. These vertical linkages can be conduits for technological innovation and are often exploited by foreign industry; it is less common for U.S. companies to do so. The strong working relationship between U.S. airplane manufacturers and commercial airlines is an exception and demonstrates the power of such relationships. Customer demand for advances in speed, payload, fuel efficiency, and range encouraged manufacturers to develop new airfoil designs, materials, engines, and wide-bodied airplanes.

Vertical linkages may have other advantages as well. U.S. producers (e.g., of semiconductors) are often relatively small, highly entrepreneurial, individual companies. Many lack the financial strength to fund expensive product development projects and to tide them over during cyclical downturns in the business cycle. Others must raise short-term capital by licensing new technology to other companies that often then become competitors. Their Japanese counterparts, on the other hand, are large, diversified, and vertically integrated. They can afford to be much more patient, to take a longer term view of the development cycle, and to give support to other segments of the company. The downstream product lines of the company also provide a stable internal market for the new products and feedback on outside consumer demand.

Furthermore, Japan is well positioned to capture the significant "economies of scope," or the multiple applications of emerging technologies, because of the way Japanese industry is organized. Extensive interindustry and interfirm cooperative relationships, including vertically integrated networks under common control, allow the introduction of new materials and components simultaneously in many different applications and markets.

Protecting Intellectual Property Rights

U.S. businesses rely upon strong intellectual property protection to realize the benefits of emerging technologies. In fact, the rate of development of emerging technologies may well depend upon patents as security for R&D and marketing investment and upon trademarks to build and protect reputations for quality. Barriers exist where laws, regulations, or enforcement procedures are inadequate. When innovation is neither rewarded nor encouraged, markets are either forfeited, left untapped, or are underdeveloped.

Examples of domestic barriers include (1) the inadequacy of the statutory 17-year patent term for certain agricultural and pharmaceutical products subject to extensive premarket testing, (2) the uncertain rules concerning the protection of software, (3) the difficulty in patenting biological inventions (plants and animals), and (4) the absence of effective protection for process patent holders against imports of products made abroad illegally using the patented process.

The Omnibus Trade and Competitiveness Act of 1988 directs the U.S. Trade Representative to identify those foreign countries that deny adequate and effective protection of intellectual property rights to U.S. firms or that deny fair and equitable market access to U.S. firms relying on intellectual property protection. This would include, for example, a nation's outright appropriation of foreign-owned technologies or of creative and artistic works. Other problems include the needs for international harmonization of patent laws and for measures to address counterfeiting, piracy, and the protection of industrial property.

Laws of Product Liability

It is important to evaluate the effect that U.S. product liability and tort laws have on innovation, emerging technologies, and the general ability of domestic companies to compete in the international market. In particular, the following issues have often been cited:

- The U.S. has a patchwork of 50 different sets of State laws on product liability. Cases based on similar facts, but tried in different States, can produce strikingly different and contradictory results.

- The transaction costs for all parties involved in litigation are enormous.

- The costs of insurance for product-liability-related protection are particularly high.

The Bush Administration has announced an initiative to seek significant reform of the product liability system. The Administration has placed its strong support behind bipartisan product liability legislation. The Administration will develop additional reform provisions including fault-based manufacturer defenses to liability ("state-of-the-art defense"), limits on punitive damages, extension of the limit on joint and several liability, and a time limit that a product is subject to liability. The purpose of the Administration initiative is to help preserve the U.S. competitive posture, while at the same time safeguarding consumer interests.

Regulatory Constraints

Government regulations significantly affect the vast majority of new technologies and products. Somewhere in the cycle of research and development, production and marketing, most new products will face testing, evaluation or approval for health, safety or environmental reasons. The processes by which products are developed are equally regulated—from traditional operations like the mining, transporting and smelting of ores to "gene-splicing" or the irradiation of foods.

Federal regulations alone impose costs of over $100 billion annually on the U.S. economy. Our stringent health, safety and environmental standards entail unusually high costs which must be reflected in the prices charged for U.S. goods and services. Regulatory costs and uncertainties sometimes deter investment in regulated activities, which can mean reduced innovation and slower productivity growth. Smaller-scale businesses in highly competitive industries are especially disadvantaged by regulatory burdens.

The international competitive effects of regulation are difficult to measure because they tend to be masked by externalities such as shifts in currency values, foreign government subsidies, and dumping. Recent studies appear to demonstrate that regulatory costs significantly affect capital formation.

Continuing the regulatory reform policies of the previous Administration, the Bush Administration is committed to reducing regulatory burdens and costs on industry wherever possible without endangering health, safety, or the environment. To that end, particular stress is being placed on streamlining regulatory procedures and harnessing market incentives to serve regulatory goals.

Export Policy

U.S. exports are controlled for national security purposes. Such controls do not serve their intended purpose if they inhibit the sale of goods and technology that are no longer strategic or are available from foreign competitors.

Unnecessary restrictions have three effects: First, the controls significantly limit U.S. industry's access to foreign markets. Even if such access is not precluded, the cost of doing business in those markets is increased. Second, the U.S. Government exercising control over the re-export of foreign products incorporating U.S. parts and components has led a number of foreign manufacturers to redesign their products so that they do not contain U.S. components. Third, limiting sales to the domestic market reduces the profitability and increases the cost of the product. In the long run, this contributes to the erosion of the industrial base for defense-related products.

There are currently two export control processes that relate to security interests of the United States. Products that are weapons systems, or primarily of military use, are included on the Munitions List provided for in the Arms Export Control Act (AECA) and issued by the State Department's Office of Munitions Control (OMC). The Department of State, in consultation with the Department of Defense, reviews license applications for exporting such goods.

Dual-use items are placed on the Commodity Control List requested by the Export Administration Act (EAA); the review process for license applications is administered by the Commerce Department, which can consult with DOD.

The EAA generally stipulates that an export license not be required for reasons of national security, for a product if there are similar products of comparable quality available on the international market from foreign sources in quantities sufficient to render the U.S. control ineffective. The AECA, however, contains no such "foreign availability" clause, and industry often finds export license applications rejected only to see a potential customer turn to an alternative foreign supplier, thereby hurting the U.S. competitive posture in the world market.

In addition to these national security controls, some U.S. exports are controlled by the Commerce Department for foreign policy reasons, such as nonproliferation (nuclear, missile, chemical weapons precursors), anti-apartheid, and anti-terrorism. These controls are imposed to achieve U.S. objectives to distance the United States from objectionable activities of certain governments or to support international agreements with other nations. Unlike national security controls, foreign policy controls are not automatically removed due to foreign availability, although it is taken into consideration.

The Omnibus Trade and Competitiveness Act of 1988 made some very substantive changes in the Export Administration Act. One change virtually eliminates re-export controls on foreign products which contain less than 25 percent U.S. parts and components, and on all products being re-exported into COCOM countries. (COCOM = Coordinating Committee consisting of the U.S., Canada, a number of Western European countries, Australia, and Japan.) Another provision of the act eliminated U.S. licensing authority over many products exported to a COCOM country. Since COCOM destinations represent a large market for U.S. firms, the reduction in licensing burden will be dramatic. Further study of export policy may be appropriate after the effects of these changes in the law become clearer.

Restrictive Foreign Trade Practices

Restrictive trade practices take many forms—laws, regulations, and practices—with the objective of protecting a home market from foreign products. The following are some of the more frequently encountered practices:

- Tariffs and other import duties designed to protect a foreign country's domestic market rather than to raise revenues.
- Import licensing intended only to create uncertainty, delays, and discrimination for imported products.
- Procurement policies by foreign governments; e.g., requirements to buy preferentially national products.
- Export subsidies programs.
- Local or domestic content requirements (e.g., rules of origin) that prevent the import of new products.
- Nonsymmetrical access to government supported R&D.
- Market reserve policies that designate certain markets for domestic products only.
- Disregard of intellectual property rights by foreign governments which undermines the ability to exploit markets with new products.

Although most actions are sponsored by governments, business practice and social mores also may be significant. If they differ from those of the United States, they may act as significant trade barriers, especially if they are institutionalized. Emerging technologies are a particularly easy target because markets are not yet fully established and the protecting country thus has little to lose by erecting barriers to the introduction of new products.

6. Outlook

Emerging technologies offer the potential for substantial economic benefits. The economic growth of many nations, especially that of the United States, has been based on the development and successful introduction of emerging technologies (Appendix F). Lately, U.S. industry has been unsuccessful in capturing the majority of benefits from emerging technologies; at the same time, U.S. trading partners have demonstrated substantial economic growth through the marketing of products based on U.S.-developed technologies.

As a result, the present outlook for the success of U.S. high-technology industry in the global marketplace is of concern to many. This issue is receiving attention at the highest levels in industry, academia, and government.[1] A number of conferences, studies, and reports on this subject have generated considerable material but consensus on actions has not been reached as yet.

Nevertheless, there appears to be a strong interest in taking action to improve U.S. competitiveness. This report is intended to facilitate this process. New strategies can best emerge from a continuing dialogue among representatives from industry, labor, academia, and government. It is hoped that the information this report contains will serve to stimulate and assist in this dialogue. An in-depth exchange of ideas and information between all segments of our economic and technical community is a prerequisite for developing concerted actions. Actions are needed to maximize the benefits that we can derive, as a nation, from the opportunities offered by emerging technologies. If we succeed in stimulating improved competitiveness, then the outlook is good because this country remains strong in the generation of new science and technology options.

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[1] Current administration policy supports a Federal role in fostering and promoting R&D related to civilian technologies that may have major impact on the U.S. economy and its international competitiveness. As an illustration of this policy, the *National Action Plan on Superconductivity Research and Development*, prepared by the White House's Executive Office of the President, December 1989, states, "Superconductivity, along with other enabling technologies...will not be industry specific and, thus, warrants assistance where feasible and appropriate from the Government. The multidisciplinary nature of the technology and the fact that the benefits from commercialization will accrue over such a long term make it difficult for individual firms to justify capitalizing the basic R&D expenses for commercialization...With fierce international competition, time will be critical in transferring the technology into marketable products...The vertically integrated industrial entities that can spread the costs of R&D investments have a strategic advantage in capturing future markets."

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[1] It should be noted that [illegible] White House's Executive Office of the President, December 1987, states, "[illegible] will not be industry specific but, [illegible] appropriate from the Government. The [illegible] nature of the technology and the fact that the benefits from commercialization will accrue over such a long time make it difficult for individual firms to justify [illegible] the basic R&D expenses for commercialization. With fierce international competition, there will be [illegible] in transferring the technology into marketable products. The vertically integrated industrial [illegible] that can [illegible] the costs of R&D investments have a strategic advantage in capturing future markets."

APPENDICES

Appendix A Detailed List of Emerging Technologies

The following pages, one for each emerging technology, give more detailed technical and market information on the technologies. The name selected for each of the emerging technologies is one in general use, which is recognizable by the informed public. The specific item headings and their contents are of a more technical nature and are briefly described below.

Major Technology Elements:

A listing of the more specific technology areas that describe the emerging technology. In most cases, more than one area is listed for each emerging technology since the advances tend to occur in several narrow fields at the same time.

What It Is:

A brief nontechnical description of the emerging technology and its importance.

Underlying Sciences:

A listing of the specific scientific or engineering competencies felt to be of critical importance for the development and marketing of products based on the emerging technology. Capability in the basic scientific areas, such as physics, chemistry, materials science, computer science, and engineering, is obviously required for all of the emerging technologies.

Engineering Barriers:

A listing of those technical impediments that must be eliminated or circumvented before products can be marketed based on the emerging technology.

What Is New or Better:

The specific improvements in processes, procedures, devices, or products that result from the introduction of the emerging technology.

Impact on What Products or Processes:

A listing of product and/or manufacturing areas that will directly benefit from the emerging technology.

Likely Markets or Industries:

A listing of those major market areas that will directly benefit from the emerging technology.

DOD Critical Technologies Comparison:

A listing of the DOD Critical Technologies thought to benefit directly by the development of the emerging technology. Using the DOD sequence numbering, the DOD list is taken from the Department of Defense Critical Technologies Plan (see Bibliography). This comparison is summarized in Appendix C.

Annual Sales by Year 2000:

An estimate of the total U.S. and world market size directly resulting from the emerging technology. The figures are taken from published studies, if a specific market study is available, and the reference given. If a market study does not exist, estimates were developed as follows: the U.S. Department of Labor Projections 2000 (Bulletin 2302, March 1988) was used as the source for a projected U.S. market size in the year 2000, medium estimate, at the 4-digit SIC code level. An adjustment to this projection was made by an estimate of the fraction of the total market resulting from the specific emerging technology.

ADVANCED MATERIALS

Major Technology Elements:

Structural and Functional Ceramics, Ceramic and Metal Matrix Composites, Intermetallic and Lightweight Alloys, Advanced Polymers, Surface-Modified Materials, Diamond Thin Films, Membranes, Biomaterials.

What It Is:

Advanced metals and alloys, ceramic and polymeric materials, and composites of these constituents used to produce devices and structures having improved performance characteristics and special functional attributes.

Underlying Science:

Solid-state physics and chemistry, interface and surface science, mechanics, fluid dynamics.

Engineering Barriers:

Rapid and reliable processing methods are needed; complex failure mechanisms need to be understood and related to processing and service-produced microstructures.

What Is New or Better:

Improved functional and structural properties like high-temperature strength, creep resistance, and corrosion resistance for ceramics and intermetallic alloys; composites offer high strength and stiffness combined with low weight, corrosion resistance, high dimensional stability; technology for controlling composition and processing that allows "designed in" properties.

Impact on What Products or Processes:

Devices and structures used at very high temperatures or special service applications; aircraft, aerospace, transportation, electronics, construction, wear resistant items.

Likely Markets and Industries:

Aerospace, construction, engines, electronics, manufacturing, energy.

DOD Critical Technologies Comparison:

20. High-Temperature/High-Strength/Lightweight Composite Materials

Annual Sales by Year 2000:

U.S.: $150B
World: $400B

ADVANCED SEMICONDUCTOR DEVICES

Major Technology Elements:

Silicon, Compound Semiconductors (GaAs), ULSI, Memory Chips, X-ray Lithography.

What It Is:

Improved materials, fabrication techniques, and advanced components and devices for use in electronic equipment of all kinds.

Underlying Science:

Solid-state physics and chemistry, surface and separation science, electrical and electronics engineering, electrical properties of materials. Optical, x-ray, ion-beam fabrication methods.

Engineering Barriers:

Difficulties in manufacturing at high volume, yield and quality but low cost. Must control contaminants and prepare high-purity gases and liquids.

What Is New or Better:

Improved speed, higher operating frequencies, reduced size, higher density, and multiple functions, lower cost, heat dissipation.

Impact on What Products or Processes:

Integrated circuits, smart power transistors, semiconductor materials, micromachines, solar cells, memory chips, microprocessors.

Likely Markets and Industries:

Electronics, television manufacturing, communications, computers, recording devices, medical and manufacturing equipment, toys and tools, aerospace—any area which requires significant use of electronics.

DOD Critical Technologies Comparison:

1. Microelectronic Circuits and Their Fabrication.
2. Preparation of Gallium Arsenide (GaAs) and Other Compound Semiconductors.

Annual Sales by Year 2000:

U.S.: $75B
World: $200B

ULSI = Ultra large-scale integration
GaAs = gallium arsenide

ARTIFICIAL INTELLIGENCE

Major Technology Elements:

Intelligent Machines, Intelligent Processing of Materials and Chemicals, Expert Systems.

What It Is:

Electronic and electromechanical systems incorporating knowledge-based control systems.

Underlying Science:

Data structures, data management systems, software engineering, servo engineering, biological and cognitive sciences and engineering, numerical analysis, statistical physics.

Engineering Barriers:

Size of databases, computational speed, lack of formal tools for knowledge representation.

What Is New or Better:

Improved performance over current systems which are at most capable of a limited number of responses to events fully anticipated in advance. Improved graphical representation of results.

Impact on What Products or Processes:

Manufacturing of machine tools, robots, construction equipment. Materials and chemical processing; computer-aided design; signal and image processing. Analysis of medical tests or symptoms.

Likely Markets and Industries:

Manufacturing, mining, security, health care, construction, materials processing, communication and financial services.

DOD Critical Technologies Comparison:

5. Machine Intelligence/Robotics
9. Sensitive Radars
11. Automatic Target Recognition
13. Data Fusion

Annual Sales by Year 2000:

U.S.: $5B
World: $12B

BIOTECHNOLOGY

Major Technology Elements:
Bioprocessing, Drug Design, Genetic Engineering, Bioelectronics.

What It Is:
Production of high value-added biological products on a commercial scale. Modify the genetic machinery of living cells to produce useful biochemicals.

Underlying Science:
Genetic engineering, molecular biology, chemical engineering, biochemistry, biophysics.

Engineering Barriers:
Difficulty in controlling processes in large-scale bioreactors and making economical large-scale separations. Lack of measurement tools, data and knowledge to control cellular processes and to elucidate protein structure/function relationships for intelligent product and process design.

What Is New or Better:
Biosensors for on-line, real-time control; new and efficient separation and purification methods. New or better techniques to produce natural and/or new biochemicals; more efficient bioprocesses.

Impact on What Products or Processes:
Production of high value-added chemical products and new engineered chemicals.

Likely Markets and Industries:
Pharmaceutical and related products; foods, flavors, and fragrances; agrichemicals, commodities and fuels, pollution abatement.

DOD Critical Technologies Comparison:
22. Biotechnology Materials and Processing

Annual Sales by Year 2000:
U.S.: $15–40B (1989 U.S. Industrial Outlook, DOC, Jan. 1989)
World: $40B

DIGITAL IMAGING TECHNOLOGY

Major Technology Elements:

High Definition Systems, HDTV, Large Displays, Data Compression, Image Processing.

What It Is:

Use of digital technology to store, display, process, analyze and transmit images.

Underlying Science:

Electronics, artificial intelligence, communications engineering, surface science, solid state physics and chemistry.

Engineering Barriers:

Large, high-resolution (flat) displays, storage requirements for digital information, effective utilization of bandwidth, computer speed and memory, ability to recognize characteristic features in complex images.

What Is New or Better:

Advances in digital cameras, high-volume information storage and retrieval, high-speed computing (including parallel processing), higher resolution video display.

Impact on What Products or Processes:

Industrial processes in which the human eye or other detectors are used for inspection and monitoring, photography, printing, television, computer manufacture, process control systems, telecommunications.

Likely Markets and Industries:

Electronics, computers, process control and inspection, medical diagnostics, consumer electronics, telecommunications, broadcast television, satellite broadcast, data storage, defense industries, nondestructive inspection and evaluation.

DOD Critical Technologies Comparison:

9. Sensitive Radars
11. Automatic Target Recognition

Annual Sales by Year 2000:

U.S.: $3.3–4.3B (1989 estimate by the American Electronics Association)
World: $5B

HDTV = high-definition television

FLEXIBLE COMPUTER-INTEGRATED MANUFACTURING

Major Technology Elements:

CAD, CAE, CALS, CAM, CIM, FMS, PDES, Control Architectures, Adaptive-Process Control.

What It Is:

A new approach to manufacturing and construction requiring not only technology but management and engineering adjustments. Use of computers, robots, and intelligent machines in the total manufacturing and construction enterprise. Integration of both the materials handling and processing systems as well as the planning, logistics, and business systems.

Underlying Science:

Control theory; operations research; electrical, mechanical, manufacturing, and industrial engineering; business and management science.

Engineering Barriers:

Need for data structures to describe product and process. Concurrent engineering to integrate design and manufacture. More reliable machines, automated process planning, "smarter" robots, more accurate and inexpensive sensors.

What Is New or Better:

Reduce cost and time to manufacture, improve quality; permit competition by scope and variety of product line; reduce inventory, manufacture to order rather than to plan.

Impact on What Products or Processes:

Manufacturing discrete and batch parts; economical small lot manufacture; continuous and adaptive processes; chemicals, pharmaceuticals, steel, paper, textiles; residential and commercial construction, public works.

Likely Markets and Industries:

High-tech manufacturing, automotive, construction, home appliance, computers, office machines, machine tools, aerospace.

DOD Critical Technologies Comparison:

5. Machine Intelligence/Robotics

Annual Sales by Year 2000:

U.S.: $10–20B
World: $20–40B

CAD = computer-aided design
CAE = computer-aided engineering
CALS = computer-aided logistics support
CAM = computer-aided manufacturing
CIM = computer-integrated manufacturing
FMS = flexible manufacturing systems
PDES = product data exchange specification

HIGH-DENSITY DATA STORAGE

Major Technology Elements:

High-Density Magnetic Storage (including perpendicular recording), Magneto-Optical Storage.

What It Is:

Erasable (read/write) data storage offering several orders of magnitude improvement in information storage density.

Underlying Science:

Optical physics, surface science, magnetics, solid-state physics, mechanical engineering, fluid dynamics (aerodynamics).

Engineering Barriers:

Magnetic disk and tape: interaction between read-write head and magnetic media surface; crosstalk; size of information cells (domains); flatness (of disks); error detection. *Magneto-optical disk:* mass of read head that slows access time; relaxation effects; spacing of tracks; tracking; size of information cells.

What Is New or Better:

Magnetic disks with thin-layer technology: steady increases in information density (doubles about every 3 years); reduced access time (mean time to get to data from random location on disk or tape).

Magneto-optical disks: Very high information densities; reduced danger of contact with storage media and lower cleanliness requirement offer potential of high reliability and provide removable media.

Impact on What Products or Processes:

Data storage devices, home and studio audio and video, computers, communications, television, consumer cameras (with magnetic disks instead of film), office information storage systems. Information now stored on paper and film.

Likely Markets and Industries:

Computers (super to PC), office equipment, recording systems, cameras.

DOD Critical Technologies Comparison:

7. Integrated optics

Annual Sales by Year 2000:

U.S.: $15B–100B
World: $30B

(Note: The larger estimate of $100B assumes that a significant portion of the paper and microfilm market is captured.)

HIGH-PERFORMANCE COMPUTING

Major Technology Elements:
Modular/Transportable Software, Numerical Simulation, Neural Networks.

What It Is:
Design and development of architectures for rapid and efficient processing; development of ways to program large systems to perform complex tasks.

Underlying Science:
Software engineering, microelectronics, optoelectronics, data structures and algorithms, numeric and symbolic methods, computational science and technology.

Engineering Barriers:
Reliability, accuracy, and automated development are deficient. Software is difficult to specify and to design; development is costly and time consuming, and it is difficult to test for failures that might occur during use.

What Is New or Better:
High-performance computers can address large problems of numerical and scientific computing such as weather forecasting, hydrodynamics, aerodynamics, weapons research, prototyping of products and facilities, and high-energy physics.

Impact on What Products or Processes:
Computer and communications systems of all sizes, networking, word processing, information retrieval and distribution, database management, manufacturing processes, engineering design, science, research and development in all fields.

Likely Markets and Industries:
Manufacturing, business, service industries, research organizations, product, process, plant prototyping.

DOD Critical Technologies Comparison:
3. Software Producibility
4. Parallel Computer Architectures
6. Simulation and Modeling
13. Data Fusion
15. Computational Fluid Dynamics

Annual Sales by Year 2000:
U.S.: $50–100B
World: $100B

MEDICAL DEVICES AND DIAGNOSTICS

Major Technology Elements:

Cellular-Level Sensors, Medical Imaging, In-Vitro and In-Vivo Analysis, Targeted Pharmaceuticals, Fiber Optic Probes.

What It Is:

Health-care diagnosis and treatment equipment and supplies based on new sensors, biotechnology processes and imaging devices.

Underlying Science:

Immunology, microbiology, biology, electronics engineering.

Engineering Barriers:

Need to design instruments with little or no invasion of the human body. Cellular level devices and diagnostics will require miniaturization, capabilities not presently available.

What Is New or Better:

The capability to detect and understand defects at cellular level. Opportunity to harness biomolecules as sensitive probes. Minimize trauma during treatment and diagnoses. Improved diagnostic and therapeutic systems.

Impact on What Products or Processes:

Diagnostics and treatment equipment, health-care products, including diagnostic instrumentation such as magnetic resonance imaging and CAT scanning, clinical analyzers, radiation treatment.

Likely Markets and Industries:

Health-care, instrumentation, pharmaceutical, medicine.

DOD Critical Technologies Comparison:

22. Biotechnology Materials and Processing

Annual Sales by Year 2000:

U.S.: $8B
World: $16B

CAT = computer-aided tomography

OPTOELECTRONICS

Major Technology Elements:

Integrated Optical Circuitry, Optical Fibers, Optical Computing, Solid-State Lasers, Optical Sensors.

What It Is:

The use of light (visible, IR, UV radiation) as the means to transmit, process, and store information.

Underlying Science:

Optical physics and engineering, solid-state physics, surface science, electronic engineering.

Engineering Barriers:

Device speed; integration of components with electronic devices; laser performance; materials limitations.

What Is New or Better:

Improved information handling capacity and signal quality, reduced sensitivity to interference, increased processing speed and data storage capacity.

Impact on What Products or Processes:

Long-distance and local fiber optic systems; electrical, mechanical, and thermal sensors; computers; chemical and mechanical manufacturing processes.

Likely Markets and Industries:

Telephone, television, teleconferencing, on-demand audio and video programming, telecommunications, electric power, computers, manufacturing, medical diagnostics and therapy.

DOD Critical Technologies Comparison:

7. Integrated Optics
8. Fiber Optics

Annual Sales by Year 2000:

U.S.:	$4.6B	(U.S. Department of Commerce, International Trade Administration, "International Competitiveness Study of the Fiber Optics Industry," p. 25, September 1988. Optical fiber communication components only—optical sensors alone add $1B worldwide.)
World:	$10.8B	

IR = infrared
UV = ultraviolet

SENSOR TECHNOLOGY

Major Technology Elements:

Active/Passive Sensors, Feedback and Process Control, Nondestructive Evaluation, Industrial and Atmospheric Environmental Monitoring and Control.

What It Is:

Devices that provide a signal (generally optical, electrical, or acoustical) that accurately reflects some process parameter in real time.

Underlying Science:

Electronics, nondestructive evaluation, control theory, mechanical and industrial engineering.

Engineering Barriers:

Currently, sensors lack one or more of the following characteristics: range, stability, precision, resistance to harsh environment, selectivity, sensitivity. Integration of sensors and signal processing.

What Is New or Better:

New sensors measure parameters more accurately and in real-time under a wider range of conditions due largely to better materials, fabrication techniques, and more complex electronics and data processing.

Impact on What Products or Processes:

Continuous process industries like materials, food and beverage, pharmaceutical, chemical, biochemical, smelting and refining; waste management, construction, manufacturing.

Likely Markets and Industries:

Chemical smelting and refining, pharmaceutical, food and beverage, electric power, materials.

DOD Critical Technologies Comparison:

5. Machine Intelligence/Robotics
10. Passive Sensors

Annual Sales by Year 2000:

U.S.: $5B
World: $12B

SUPERCONDUCTORS

Major Technology Elements:

High-Temperature Ceramic Conductors, Advanced Low-Temperature Conductors.

What It Is:

(1) Superconducting materials having critical transition temperatures (T_c) above 77 K (boiling point of liquid nitrogen).

(2) Low-temperature superconductors with improved performance characteristics and materials properties.

Underlying Science:

Solid-state physics, ceramic processing science, electronic engineering, surface science.

Engineering Barriers:

Low current densities and strengths in bulk forms. Composition and environmental stability. Integrated circuit fabrication technology. Economical refrigeration techniques.

What Is New or Better:

T_c above 77 K significantly reduces cost by eliminating liquid helium as coolant. Low-temperature superconductors yielding sophisticated integrated devices, even first microprocessors. Powerful magnets for research and medical diagnostics, magnetically levitated trains.

Impact on What Products or Processes:

Electronics; electrical transmission, switching, motors, and controls; electric power generators; medical diagnostic equipment; rail and ship transportation; computers; particle accelerators.

Likely Markets and Industries:

Electronics and data processing, electric power equipment, medical diagnostics, transportation equipment, high-energy physics.

DOD Critical Technologies Comparison:

21. Superconductivity

Annual Sales by Year 2000:

U.S.: $3–5B (1989 U.S. Industrial Outlook, DOC, Jan. 1989)
World: $8–12B

Appendix B Comparison of the 1990 and 1987 DOC Emerging Technologies Reports

Comparison of Emerging Technologies

1990	1987
Advanced Materials	Advanced Materials A. Ceramics B. Polymer Composites C. Metals
	Thin Layer Technology A. Surfaces & Interfaces B. Membranes
Advanced Semiconductor Devices	Electronics A. Advanced Microelectronics
Artificial Intelligence	Computing B. AI Techniques
Biotechnology	Biotechnology A. Genetic Engineering B. Biochemical Processing
Digital Imaging Technology	(None)
Flexible Computer-Integrated Manufacturing	Automation A. Manufacturing
High-Density Data Storage	Automation C. Technical Services
High-Performance Computing	Computing A. Computing Equipment
Medical Devices and Diagnostics	Medical Technology A. Drugs B. Instruments & Devices
(none)	Electronics C. Millimeter Wave
Optoelectronics	Electronics B. Optoelectronics
Sensor Technology	(None)
Superconductors	(None)
(None)	Automation B. Business & Office Systems

Comparison of 1990 Opportunities for Change and 1987 Barriers

1990	1987
The Cost of Research & Market Introduction	High Cost of Capital/Tax Incentives
Engineering Training and Education	(Not identified separately)
Integration of R&D, Design, and Manufacturing	(Same)
Improving the Quality of Products and Services	(Not identified separately)
Improving the Technology Infrastructure	(Not identified separately)
Dependence on Domestic Technologies and Market	(Same)
Industrial Cooperation	Antitrust restrictions
Protecting Intellectual Property Rights	(Same)
Laws of Product Liability	(Same)
Regulatory Constraints	(Same)
Export Policy	(Same)
Restrictive Foreign Trade Practices	(Same)
Product and Interface Standards	(Not identified separately)

Appendix C Comparison of the Emerging Technologies with the Critical Technologies of the Department of Defense[1]

DOC Emerging Technologies	DOD Critical Technologies
Advanced Materials	(20) High-Temperature/High Strength/Lightweight Composite Materials
Advanced Semiconductor Devices	(1) Microelectronic Circuits & their Fabrication (2) Preparation of GaAs and other Compound Semiconductors
Artificial Intelligence	(5) Machine Intelligence/Robotics (9) Sensitive Radars (11) Automatic Target Recognition (13) Data Fusion
Biotechnology	(22) Biotechnology Materials & Processing
Digital Imaging Technology	(9) Sensitive Radars (11) Automatic Target Recognition
Flexible Computer-Integrated Manufacturing	(5) Machine Intelligence Robotics
High-Density Data Storage	(7) Integrated Optics
High-Performance Computing	(3) Software Producibility (4) Parallel Computer Architectures (6) Simulation and Modeling (13) Data Fusion (15) Computational Fluid Dynamics
Medical Devices and Diagnostics	(22) Biotechnology Materials & Processing
Optoelectronics	(7) Integrated Optics (8) Fiber Optics
Sensor Technology	(5) Machine Intelligence/Robotics (10) Passive Sensors
Superconductors	(21) Superconductivity
	Also Listed: (12) Phased Arrays (14) Signature Control (16) Air Breathing Propulsion (17) High Power Microwaves (18) Pulsed Power (19) Hypervelocity Projectiles

[1] "The Department of Defense Critical Technologies Plan," Department of Defense (DOD), Washington, DC May 1989. The numbers in the table refer to the numbers used in the DOD document.

Appendix D National Security Concerns*

The defense industrial base generally comprises the same manufacturers that produce goods for the general public. Few industries rely primarily or completely on the Department of Defense as their principal market. However, the Department depends on virtually every sector of the manufacturing base for material. Ninety-five percent of the manufactured goods purchased by the Department of Defense come from a broad spectrum of 215 industries. In 1985, the Department spent almost $165 billion within these industries. This represented 4.1 percent of America's total gross national product and 21 percent of the manufacturing gross national product. However, while the Department of Defense is a major purchaser of manufactured goods, we recognize that in many important sectors, such as electronics, we purchase only a small portion of total output. Even so, our market share (even in the electronics industry) can provide us with substantial leverage if properly managed.

In addition to meeting requirements for the production of today's weapon systems, the Department's investment in the industrial base must encourage the research and development for advanced technologies that are key to the next generation of weapon systems. These include technologies such as infrared focal plane arrays, microwave devices, advanced sensors, exotic alloys requiring powdered metallurgy technology, high temperature ceramic composites, and high temperature superconductors. Additionally, advanced manufacturing strategies, such as flexible computer integrated manufacturing, must be developed for and integrated into the entire industrial base.

As a nation and as a continent, we no longer are totally self-sufficient in all essential materials or industries required to maintain a strong national defense. Consequently, we must identify requirements carefully and assess them against our industrial base capabilities. We must develop strategies that enable us to meet security needs with available resources. For those essential products the United States does not manufacture, we must rely on offshore sources or stockpiles. We can, however, offer incentives to establish domestic manufacturing industries for these products.

Clearly, the Department of Defense cannot provide massive financial assistance for every American industry characterized by a lack of international competitiveness, nor can we effectively provide incentives for every manufacturing industry critical to our defense. The issue of competitiveness is one that requires continuing creativity and innovation within the private sector. There are numerous factors that industries themselves must come to grips with if they are to remain competitive in the international market place. There are also national issues, such as our tax code and antitrust laws, that warrant our attention. Our education system has been cited as providing a less than adequate technically trained labor force for the future. To the extent that these and other national issues affect the industrial base, the Department of Defense intends to stimulate, when warranted, appropriate activities throughout the Government to address them.

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*This text is taken from the first part of the summary of *Bolstering Defense Industrial Competitiveness* (see Bibliography).

Within the Department of Defense acquisition process we have identified several areas that are impediments to efficient defense production. Frequent policy changes, emerging technologies, changing military requirements, the defense budgeting process, and program and budget instability make long-term planning difficult. Typically, small volume purchases and program stretch-outs contribute to an environment in which defense contractors have little incentive to make long-term investments in facilities with advanced capabilities that could yield higher quality and more competitive products.

Commercial market rewards for performance are lacking in the defense market. Unit cost reductions, quality improvement, shortened delivery times, etc., neither stimulate demand for additional units nor provide greater market share; nor do unit cost reductions result in increased profit. Emphasis on lowest bid cost may result in inadequate attention to life cycle costs, quality, and past performance.

The Department of Defense reliance upon detailed product and process specifications can be counterproductive. Outdated specifications frequently reduce innovation, inhibit improvements, and result in excessive administrative processes required to implement, monitor, waive, or modify specifications. Procurement processes focus mainly on prime contractors, even though materials and components purchased by prime contractors from lower-tier industries represent 50 to 85 percent of our total expenditures. Historically, the Department has had limited direct influence on the performance of subtier contractors because of considerable administrative difficulty in passing performance incentives through prime contractors to multiple levels of subcontractors and suppliers.

Finally, layers of bureaucracy and somewhat cumbersome contract administration processes add to the costs of doing business with the Department of Defense. Government emphasis on oversight activities can lead business managers to focus more on meeting inspection requirements than on improving quality and productivity.

This Department of Defense report is designed to provide both a strategy and specific initiatives to address this concern. Integral to this strategy is a recognition that the Department's influence is, at the same time, significant and limited. The strategy suggests exploiting the Department's leadership and leverage potential to strengthen the industrial base, but not to the exclusion of other Departmental priorities such as a well equipped force structure. On the other hand, it is neither possible nor desirable for the Department to solve all the ills of the commercial manufacturing sector.

The cornerstone of this effort is cooperation with domestic industry and our allies. The United States could not build fortress America, even if this were a desirable objective. Nor can the Department of Defense reverse worldwide economic trends, such as the internationalization of manufacturing. To maximize domestic industry's potential, cooperative relationships must flourish among the Department of Defense, large corporations, and the lower-tier manufacturing industries that are the foundation of our industrial base.

Appendix E Investment in R&D and Consortia by Japan, EC and U.S.

The intensity and diversity of cooperative research is a reflection of the importance accorded to emerging technologies; the majority of cooperative projects (probably at least 75 percent of total expenditures) deals with emerging technologies.

	R&D as % of GNP (1985) Total	Civilian	Gov't. Share of Total	Consortia As % of Total	Gov't. Share of Consortia
JAPAN	2.6%	2.5% (est)	19%	≈4%	≈50%
EC	1.9%	1.4%	45%	≈4%	≈50%
U.S.	2.8%	1.9%	47%	<1%	<20%

JAPAN — Most R&D (>70%) is performed in private industry. Consortia are significant within Government R&D funding (≈10% of total). Focus is on consumer application.

EC — Industry probably carries out less than half of all R&D. Consortia are important within Government R&D funding (≈5% of total). Focus is on civilian applications.

U.S. — Most R&D (>70%) is performed in private industry. Consortia are relatively insignificant within Government R&D funding (<0.5% of total). Focus is on national security.

Listed below are only those projects which have significant involvement by the respective Governments. Privately operated consortia are not listed; for example, the National Cooperative Research Act of 1984 relaxed antitrust provisions for cooperative research ventures. More than 150 such ventures have registered including SEMATECH; most of these do not involve Government funding.

JAPAN
- 8 large-scale projects (MITI)
- Friend 21 (MITI)
- 3 next-generation industry projects
- 9 ERATO projects (STA)
- 20 Japan research development corporation projects (STA)
- 62 key technology center consortia
- 119 KTC lending projects
- SIGMA software project
- 6 superconductivity projects
- Human frontier science plan
- International frontier research plan

EC
- >200 ESPRIT projects
- >200 EUREKA projects
- 100 BRITE projects
- 50 RACE projects
- JESSI project (under discussion)
- EURAM program

U.S.
- Variety of cooperative efforts, primarily sponsored by DOD (in particular DARPA).
- SEMATECH
- AISI/DOE steel technology program

Sources: *Economic Report of the President*, 1988
First Report on the State of Science and Technology in Europe, 1988
MITI White Paper: *Trends and Future Tasks in Industrial Technology*, 1988

Appendix F Comparison of Industry Growth Rates

Intensive use of technology and industrial growth are correlated. The table below compares the 10 SIC (Standard Industrial Classification) industries experiencing the highest growth rates over the past 16 years (1972–88) with the 10 industries having the lowest growth rates during this period. The top 10 are all technology-based industries, whereas the last 10 have pursued strategies that are much less technology dependent.

Relative Shipments Growth, 1972–88
(1988 shipments as a percentage of 1972 shipments)
(1982 $)

SIC	TOP 10	RATE	SIC	LAST 10	RATE
3573	Computing Equipment*	8823	3211	Turbine Generator Sets	17
3674	Semiconductor Devices*	6072	2793	Photoengraving	23
3832	Optical Devices/Lenses	940	2121	Cigars	35
3693	X-ray Apparatus	537	2386	Leather/lined Clothing	38
2795	Lithographic Services	394	3743	Railroad Equipment	42
2831	Biological Products	387	2661	Bldg Paper/Board Mills	42
3678	Electronic Connectors	356	3333	Primary Zinc	44
2833	Medicinals & Botanicals	347	3552	Textile Machinery	48
3842	Surgical Appliances	337	3021	Rubber/Plastic Footwear	50
3841	Surgical & Medical Inst	327	2517	Wood TV, Radio Cabinets	50

*The growth rates of these two technologies have been adjusted for technical change as well as price change.
Source: Department of Commerce, *U.S. Industrial Outlook*, 1988

Appendix G Bibliography

The following list is not intended to be comprehensive. Rather, it is meant to provide additional information, complementing and supplementing this report.

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