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May 27, 1998

MEMO TO: David Beier
Jim Kohlenberger
Tom Kalil
Lowell Weiss
Jeff Shesol
Henry Kelly

FROM: Jeff Smith

In the off chance that you don't already have it, attached, for your information, is a copy of a forthcoming Council on Competitiveness report, *Going Global, The New Shape of American Innovation*. It should be closely held. It is not scheduled for publication until later this year.

The introduction and the chapter on information technology may be of interest to those working on the MIT speech.

GOING GLOBAL

The New Shape of American Innovation

Council on Competitiveness

Table of Contents

Overview
Going Global: Lessons From Five Sectors

Is there any cause for concern about the nation's capacity for continued innovation at a time when the United States is so strong economically and technologically? The answer from a hundred heads of R&D at companies, universities and national laboratories representing over $70 billion in R&D is a resounding "yes."

The Council's survey of executives in the health, information technology, advanced materials, automotive and express package transport sectors conveys a clear and consistent message. Every company ranks the capacity to innovate—the transformation of knowledge and ideas into new products, processes and services—as a top priority. Innovative capacity plays a dominant, and probably decisive, role in determining who will prosper in the global arena. For companies, innovation creates strategic market advantage in a fiercely competitive economic environment. For countries, the ability to leverage innovation not only to achieve national goals (improved security, health, and environment) but to increase productivity and attract investment from an array of global sources is the key to continuous improvements in the standard of living and quality of life.

In no sector is there an immediate threat to U.S. leadership, but neither, according to these executives, is there any room for complacency. They are profoundly concerned that the unique set of conditions that propelled the United States to a position of world leadership may not be sufficient to keep us there.

The New Shape of Global Innovation

Global change brings tremendous challenges as well as opportunities. Changes in the global environment profoundly affect the way companies compete and how countries capture economic wealth.

A New Wave of Competition: Not so very long ago, it was nearly axiomatic that the industrialized world innovated while less industrialized countries supplied raw material, lower cost labor and low-end manufacturing. But, developing economies have learned a fundamental lesson—a model they have seen at work in the United States for a half-century and more. Investment in people, research and technology along with an innovation-friendly environment pays off in economic growth and higher-wage jobs. Some have already made the transition from imitator to innovator—and are demonstrating their new status in the U.S. patent system. From a negligible patent position in 1982, South Korea has increased its patents by 40,000 percent, surpassing the United Kingdom in its presence in the U.S. patent system and edging up on Germany. Others, such as Singapore, Malaysia and Hong Kong, have propelled themselves into a fast follower position and are capturing downstream jobs and wealth from innovative activity in the United States.

The Pace of Technology Churn: The line between global leader and also-ran has gotten very thin. The technology cycle times, particularly in information technologies, are so rapid that few industry executives are complacent about sustaining leadership. The rapid churn rate has a couple of implications for the United States. First, countries are leapfrogging generations of technology within the span of a single decade. Ten years ago, few Americans had ever heard of Bangalore, India, now a magnet for software investment. Taiwan figured prominently as a national security concern, not an economic competitor. Second, the pace of technological change provides ever more frequent entry opportunities for competitors. Leadership can shift within a few generations, and—especially in infotech—a generation can be as little as 2-3 years. Finally, with product cycles ranging from months to a few years, it is increasingly difficult for companies to allocate money to longer-term R&D that may not fit into a product window. Most R&D managers are investing in research with an eye on the bottomline, but more than a handful wonders from where the next generation of breakthrough technologies will come.

Globalization of Investment Choices: Information technology is changing the way everything is done and, more importantly for the U.S., where it can be done. The revolution in communications and information technology affords companies the ability to locate their wealth-creating investments wherever the markets offer the greatest opportunities and leverage—and without losing the cohesiveness of corporate strategy and communications. It is creating real choices for companies about where to invest.

Global Availability of Human Talent: In the past, workers in the developed and developing world didn't compete head-to-head. In a globalized economy, workers must directly compete not only on cost and productivity grounds, but in creativity and competence as well. In the knowledge-based economy, individual, corporate and national competitiveness will require both new and more extensive skill sets than have ever been required in the past. With the ability to manufacture anywhere in the world and sell it anywhere else, companies are investing wherever they find the best talent pool—and high quality talent pools are available globally. The education and training of American workers at all levels is one of the top priorities and chief sources of concern in every sector.

Globalization of Demand: For years, the sheer size of our market and the sophistication of consumer demand made the U.S. the launch market of choice for most hi-tech products—and the side benefits were enormous. Research, design, engineering and production teams tended to cluster in the United States as part of a first-market launch strategy. But, globalization of demand has evened out the playing field. Today, the fastest growing markets are overseas, and regional economic alliances offer just as attractive launch environments. These days, products are launched globally and almost simultaneously. Although the U.S. will always be an attractive market for new products, the need to position scientific and engineering talent here versus some other big launch market is just not as compelling.

Globalization of Research: It is tempting to believe that the U.S. is the default location for all the best investments in frontier research and technology. Unfortunately, that's no longer true. We hold an enormous stock of past investment, by foreign as well as domestic companies, that will fuel innovation here for years to come. But, a growing percentage of new R&D investments is going overseas for multiple reasons: to follow manufacturing, to provide full service operations to major customers overseas, to pay the entry price for market access, to benefit from an array of incentives and tax credits, and to take advantage of niche areas of competence, new ideas and pools of talent. No one foresees a wholesale shift of research outside the United States, but it is becoming clear that R&D investments at the margin are going offshore.

Impact of the End of the Cold War Era on Innovation: The loss of urgency of the Cold War mission has affected both the quantity of funding and the cutting-edge quality of a large portion of the public research investment in the United States. Technology base funding by the Department of Defense (DoD) is reaching a 35-year low. For universities, cutbacks in defense spending have resulted in a de facto reallocation of funding away from the physical sciences and engineering and shifted the focus of defense research away from the frontiers of knowledge-creation to more applied efforts. When DoD investments were pushing out the boundaries of the possible, universities could more easily attract the best and brightest scientific talent despite the salary premium in industry. For companies, defense procurements created first-buyer assurances at virtually any unit cost, encouraging them to take technology and investment risks that neither their management nor the capital markets would otherwise have supported. Defense fingerprints are all over many of the advanced technologies that have shaped the latter half of the 20th century. Although defense spending is clearly not the only viable mechanism to support frontier research and advanced technology, the United States has yet to find an alternative innovation paradigm to replace it.

Taken together, these changes are shaping a new and more competitive global environment for innovation. The United States remains the world's innovation powerhouse, bringing a unique combination of strengths to the table: the excellence of its R&D enterprise, a risk-taking entrepreneurial culture, efficient capital networks, and strong consumer demand for new products and services. But globalization is leveling the playing field, changing the rules of international competitiveness, and collapsing the margins of technological leadership. Our members are not convinced that the United States is preparing for success in a world in which many more countries will acquire a capacity to innovate.

Sources of Innovative Advantage: Sector Snapshots

The Council's R&D Advisory Committee examined global developments in five industry sectors with a view towards current competitiveness trends, innovation needs and priorities, and strengths and weaknesses in the U.S. environment for innovation. One of the crucial lessons learned is that there is no "one-size-fits-all" approach to innovation. Each industry, indeed each company, draws on the national platform in different ways to meet different needs. How they innovate largely determines what their national priorities are.

Innovation in **health and advanced materials** is intimately linked to improvements in basic science. It's no accident that their chief concerns center around the availability and adequacy of support for research, research equipment and research talent—and the sector executives see problems emerging in the U.S. research enterprise.

Federal support for basic research is clearly a priority concern. The percentage increase in funding for university research in the physical sciences (chemistry and physics) has been lower than in any other discipline by a considerable margin. In the better-funded life sciences, there are still early warning signs that changes in health care delivery are choking off funding for clinical research at academic medical centers, traditionally one of the most vibrant centers for innovation in

Study Approach

Step One: William Hambrecht, president of W.R. Hambrecht & Co., LLC, William Steere, chairman of Pfizer Inc, and William Brody, president of Johns Hopkins University, formed a Global R&D Advisory Committee—engaging research executives at leading companies, universities and national laboratories to advise and guide the project.

Step Two: The Advisory Committee examined current developments and R&D trends in five sectors—health, information technologies, advanced materials, automotive and express package transport and logistics. Members of the Advisory Committee took leadership of individual sectors and helped identify other key organizations, government agencies and companies to participate in the sector work. Advisors were selected for each sector to guide the research.

Step Three: Executives participating in the sector studies completec a three-part interview template that asked respondents to:

1. Describe where they invested their R&D dollars, what kind of R&D was performed there, and what attracted their investments offshore;
2. Rank the countries in which they performed R&D according to 10-15 characteristics, including the quality of the workforce, the caliber of research universities, the regulatory environment, etc.; and
3. Evaluate what the United States should be doing to improve the environment for innovation at home.

Step Four: The sector advisors reviewed published materials and data from a variety of sources to understand trends, developments and issues and to obtain objective information on specific aspects of the sector, such as investment patterns and innovative output.

Step Five: Study findings are synthesized and circulated among participants in each of the sectors for critique and review of findings and recommendations.

health care. Universities are feeling the pinch of rising laboratory costs; funding for state-of-the-art equipment has not kept pace, particularly for information technologies that have become the basis of modern research.

Problems in the people pipelines worry the executives as well. When funding for graduate research fellowships and cutting-edge research grows tight, it gets even harder to attract the best minds away from other career paths. The number of graduate students in the physical sciences and engineering has been static or declining for the past decade. Shortages of clinical investigators have been a long-term problem for biomedical research. University and industry executives alike believe that the United States has a relatively narrow window in which to address a root cause of the problem: a failing K-12 system that not only precludes a science track for many U.S. students, but barely achieves the minimum goals of literacy and numeracy.

Proximity to the best science in many fields matters to companies. Much of their breakthrough research is clustered in the United States. Because innovation occurs most often at the interface between disciplines, technologies and sectors, they stress the need for teaming internally and for multi- and interdisciplinary programs at universities, which they see as largely lacking today. This is particularly true for advanced materials where biology and chemistry departments and chemistry and chemical engineering departments remain worlds apart.

Partnerships, particularly with universities, are another key element of the innovation paradigm. Many company executives see potential dangers in the trend towards exclusive licensing of patented university research. In the health care field, exclusive licensing of genetic information, if access is denied or prohibitively expensive, is seen as potentially the greatest single threat to advances in fundamental understanding. In advanced materials and other sectors, industry executives are concerned that patenting practices could compromise the open and free exchange of basic research information, a hallmark of strength in the U.S. university system.

Heavy R&D spenders themselves, the companies emphasize national policies that bolster their investments: stability and better coverage of research tax credits and global protection for the intellectual property they generate.

For the **hardware, electronics and communications** parts of the infotech sector, enabling technologies and applied research are the more critical element of the innovation process. (This should not imply that underlying science is not important, only that the linkage to new products and services is less direct.) For these industries, the innovation challenge lies in marrying technological leadership with rapid product deployment. The global competition in infotech is getting stronger—in some cases, much stronger. Although most companies take advantage of improving competencies overseas in establishing world-wide networks for research and manufacturing, their core strategic technologies—the ones that give the United States an edge in infotech—are clustered here. Staying ahead of the competition hinges on four key capabilities:

- sustained research into breakthrough technologies
- fast diffusion of information through partnerships and strategic alliances
- a cadre of people trained in product realization
- rapid deployment of competitively priced products.

Public investment in breakthrough technologies is often critical in bridging the gap between scientific knowledge and technology application. The pace of technology churn is so rapid that company research tends to focus on relatively short-term windows of opportunity. Advances in science can be years and hundreds of millions of dollars away from viable technology. Although sustained investment in enabling technology is increasingly important, government funding sources, particularly at the federal level, are leery of supporting such research for fear of crossing a line into industrial policy. Concerns that federal support for applied research and enabling technologies constitute corporate welfare may be misplaced. Our findings suggest that the closer the technology comes to being product-ready, the more likely the companies are to eschew open collaboration and bring the research in-house for development.

Fast diffusion of information through public-private partnerships and strategic alliances turbocharges the learning process—and differentiated rates of learning separate the leaders in innovation from the rest of the world. Simplifying the partnering process, particularly with universities, is a key concern for larger companies. One electronics executive reports that, given the complexity of intellectual property arrangements, the company's preference is simply to hire talented professors away from the universities. Smaller and medium-sized companies find it difficult to establish research linkages with universities at all, effectively closing off an important channel of information diffusion to one of the most fertile grounds for innovation.

The pace of product deployment is another integral element of the innovation process for infotech. A painful lesson of the 1980s was that being the first mover was scant protection against fast followers. The ability of the competition to replicate our technology, even at the state-of-the-art, means that the production process must be as sophisticated as the product technology. The pace and quality of product deployment can be influenced by national support for research in production engineering—an area in which the United States has historically underinvested—and a cadre of people trained in product realization. The companies themselves have taken the lead, along with the NSF, in establishing the first center for training and research into product realization, but look to a time when product development becomes an integral part of the core curriculum at research universities

Innovation in **software**, by contrast, tends to be almost exclusively tied to the creativity of the workforce and the ability of companies to attract the best talent. The principal concerns of the companies are:

- a shortage of software engineers and declining enrollments in computer science
- the lack of network-based curricula at universities and excessively long lead times in getting new curricula approved (and in this rapidly changing field, the education could be obsolete by the time the new courses are approved)
- "in-your-face" government policies that slow their time to market and interfere with their reward mechanisms.

Although software companies invest heavily in R&D, their focus is more toward the "D" side. This tends to create a gap in fundamental research, particularly in software productivity. As demand for information technology explodes and information networks grow more complex, the need for progress in automating the software process will be critical. Local labor markets can never keep up with the growth in demand for software design—and an increasing amount of software development is already going offshore. Because advancements in software productivity would have multiple applications and users, this is seen to be a critical area for government investment software.

The **automobile** industry has some of the largest R&D spenders in the world, but their investments are directed largely at integrating thousands of parts into a machine that has to start on the first try every time, and work reliably in every kind of weather and over most terrain. For the kinds of breakthrough research that promises to transform a century-old technology (hybrid engines, fuel cells, electric powered vehicles) the industry relies on government research support and extensive partnerships with universities and national laboratories. The R&D tax credit is also an important consideration in an industry in which the margins of profit per unit are shrinking on average.

In the final analysis, the innovation drivers for the automotive industry have less to do with the availability of cutting-edge research or talented people than with local market conditions (consumer preferences, transportation infrastructure, price of fuel) and the legal and regulatory systems that govern safety, the environment and liability. The dilemma for the manufacturers is that the growth in demand for fuel-efficient or alternative fuel vehicles is mainly overseas; to be players in the global market, they must innovate. But, the lack of domestic demand for advanced technology vehicles—

and to the extent that fuel efficiency and low pollution are national objectives, the lack of government incentives to stimulate demand—is one of the largest stumbling blocks to innovation.

The **express package transport and logistics** business represents the marriage of information technologies (principally sensors, databases, and networks), electromechanical devices for materials handling in both vehicles and facilities, and decision-support design and analysis tools. Although the industry is highly technology intensive, even the most technically advanced do little research. The companies rely on the existing technology base and add value through integrating, demonstrating and deploying these technologies in complex systems. Proximity to the right kinds of enabling technologies is a plus, but the companies shop globally for the best available technology. Their principal concerns involve the availability of skilled people—ranging from workers with basic skills to trained engineers—and the regulatory environment, particularly abroad, that limits market access.

What Matters in Innovation

If innovation were simply a matter of inspired genius occasionally fertilized by government funding, the challenge of building a national innovation infrastructure would be relatively simple and straightforward. But executives from industry, universities and government describe a far richer and more complex spectrum of innovation-enablers. The availability of human talent and cutting-edge research, the regulatory, accounting, legal and capital conditions that facilitate the transition from ideas into wealth-creating products and services, access to international markets and protection for intellectual property that enable innovators to capture the returns on their investments are all essential parts of the process.. Weakness in any of these elements diminishes the others and, indeed, the entire platform for innovation.

The sector participants looked at what matters to their innovative capabilities and where the national platform for innovation is falling short.

People Matter: Long-term success requires access to the best and brightest globally. Without people to create, apply and exploit new ideas, there is no innovation process. Innovation demands not only a trained cadre of scientists and engineers to fuel the enterprise, but a literate and numerate population to run it.

The concerns:

- University and industry participants alike see K-12 as a flawed educational system, producing too many high school graduates who cannot read or add.
- Even our best students do not stack up well in international comparisons in math and science.
- U.S. students and teachers alike are not familiar enough with information tools and technologies.
- For fast moving fields, like computer sciences, university curricula cannot keep pace. By the time a new course is approved, typically over a couple of years, the technology base may have changed altogether, producing graduates with historical rather than current skill sets.
- The number of college degrees in the physical sciences and engineering has remained static or declined for a decade, while engineering graduates have doubled in Europe and increased even faster in Asia over the same period.
- Foreign students make up a majority enrollment in many schools, but an increasing number of foreign graduates are returning home as viable employment opportunities grow.

- Restrictive immigration laws make it difficult for universities and companies alike to recruit the best international talent, and particularly those Ph.D.'s that have received their degrees here.
- The scientist and engineering population does not reflect the diversity of the population at large, which threatens long-term public acceptance of the need for investment in science and the replenishment of the science and engineering talent pool.

Research Matters: For the past 50 years, most, if not all, of the technological advances have been directly or indirectly linked to improvements in fundamental understanding. Investment in discovery research creates the seedcorn for future innovation. Government at all levels is the mainstay of the nation's investment in science and engineering research and has the laboratory infrastructure to sustain it.

The concerns:

- Industry research as a percentage of the national total is rising, but the focus is increasingly short-term. Companies, in the global environment, no longer support "innovation by wandering around." Some research executives believe that their industries have gone beyond the danger point in cutbacks in fundamental research.
- Continued growth in federal support for university research is not assured under the current budget plan.
- Agency-funded research, with the exception of NSF and NIH, at universities is getting closer to the market, leading to concerns by both universities and companies about support for frontier research.
- Changing agency missions have resulted in a de facto reallocation of research resources, creating an unplanned shift in funding for university research away from chemistry, physics, mathematics and engineering.
- Static or declining research funding slows the availability of graduate fellowships—and, hence, diminishes the future talent pool—for the physical sciences and engineering.
- The cost of modern laboratory facilities and information infrastructure is increasing faster than the sources of support.

Partnerships Matter: Both the cost and complexity of the innovation process have greatly increased, making closer collaboration among firms, universities and government not just an option but a necessity. In complex technologies, innovation tends to occur at the interfaces between disciplines, technologies and industry sectors. The country that facilitates those linkages will gain innovative advantages through quicker information diffusion and leveraged funding and risk.

The concerns:

- Federal programs, like the Advanced Technology Program, which are as valuable for the linkages they catalyze as for the seedcorn they provide, are still contentious issues in public policy.
- The emphasis on patenting and licensing of university research is creating frictions at the interface of university-industry relationships and potential conflicts of interest between entrepreneurial and more traditional university missions.
- The lack of linkage between universities and small and medium-sized companies forecloses an important channel for innovation.

Manufacturing Matters: Manufacturing companies contribute nearly 75 percent of total industry R&D funding—a key national asset. Although high-tech service sector R&D is increasing, our limited sample in software and package transport indicates that the service industries focus far on D&D—development and demonstration—than they do on research. The U.S. investment in the infrastructure that supports manufacturing has traditionally been much lower than in countries like Japan, where process superiority often compensates for superior research and technology. Since company research is often clustered near manufacturing operations, the potential global dispersion of high-end manufacturing may ultimately diminish our overall innovative capacity.

The concerns:

- Manufacturing, particularly in the automobile, chemicals and electronics sectors, is increasingly global. Delinking U.S.-based research from manufacturing ultimately diminishes capabilities here because insight into process problems is a critical component of research.
- The United States has historically underinvested in the research infrastructure and trained workforce to support process technology and product realization.
- Science and engineering departments are almost always separated on university campuses, creating a chasm between scientific breakthrough and affordable deployment.

Regulatory and Legal Frameworks Matter: Cost and time-to-market are critical considerations for companies in an intensely competitive global environment—and a country's legal and regulatory system has a profound influence on both. Getting ideas to market affordably is an integral part of the innovation process, but the impact on innovation is rarely one of the yardsticks by which the regulations are assessed.

The concerns:

- The U.S. regulatory environment in many areas is still geared toward heavy industry and focused on the U.S. competitive environment. In many areas, regulations have not kept pace with fast changing technologies or global industries. The United States ranks well below foreign competitors in comparative evaluations of national regulatory environments.
- Harmonization of regulatory requirements should be a more visible government priority. Particularly in the health and automotive industries, it is needed to decrease costs and lower market barriers abroad.
- The lack of protection for proprietary data submitted to regulatory authorities in many parts of the world raises the effective costs (by lowering the revenue stream) of investment in innovation.

Capital Matters: The availability of patient and affordable capital is quite simply the basic fuel for innovation. Low savings rates in the United States and high entitlement payments are continuing sources of concern, but a range of federal policies affects the availability of funds for research, particularly for small companies.

The concerns:

- Small innovative companies, particularly in the advanced materials sector, have difficulty finding early stage capital.
- Government funding for the Small Business Innovative Research program is uncertain and inconsistent.

- Gains in market capitalization in the United States are compensating for underlying differences in the cost of capital internationally, but this may not survive a market downturn.
- Better research tax incentives are needed to bridge the gap between long development and payback periods and short-term financial market demands.

Conclusions

The platform for innovation is one of our most valuable – and least understood – national assets. It is both the main driver for and principal drag on future U.S. competitiveness, as measured by the success of U.S. companies in the global economy and improving standards of living for Americans.

The time to bolster our strengths and shore up our weakness is now, when the economy is strong and our margin of leadership is solid. The global environment that is emerging is likely to be unforgiving. Neither our capability for world class science and technology nor our ability to dominate international markets is insulated from global competition. If we inadvertently allow key parts of our innovation enterprise to erode, the growing numbers of innovative competitors will not be slow to fill the breach. Once lost, leadership will not be readily or inexpensively recaptured, if it can be recaptured at all.

DRAFT

A New Vision for Health Care Innovation
Executive Summary

Industry Chair: George Milne

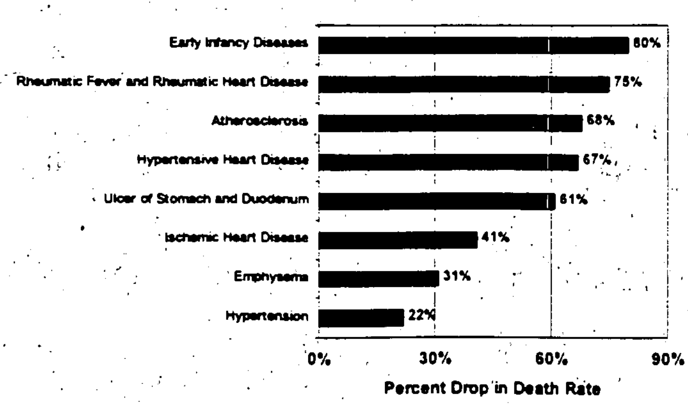
Sector Advisors: Stephen Yoder
Walter Kuemmerle

Health Care Innovation Is Vital to Us All

America's innovative leadership is nowhere more clearly represented than in health care, where the benefits are immediate and tangible. Average U.S. life expectancy has increased from 49 to 75 years since 1900 due to improved public health measures, childhood immunizations and better prevention, diagnosis and treatment of disease. Overall mortality from heart disease, stroke and, recently, cancer has declined, while old killers such as TB have been greatly reduced (Chart 1).[1] Real progress has been made in treating HIV infection. Small pox has been eliminated from the world; polio may follow by 2000. The burdens of pain and disability have been eased, directly improving the quality of life, not just its length.[2]

Better health has measurable economic benefits beyond the roughly $1 trillion the industry generates in economic growth, high wage jobs and trade. It means greater productivity in a society based on human capital. Increased longevity itself has an enormous impact on the economy. If life spans had not increased since 1900, the U.S. population would be about 135 million. Even assuming equal productivity per capita, U.S. GDP would be at half its current figure. Our society would be poorer literally and figuratively, without these advances.

Chart 1:
New Medicines Have Played an Important Role in Tackling Diseases
Drop in Death Rate for Diseases Treated with Pharmaceuticals, 1965-1995



Source: PhRMA. 1997. *Based on Boston Consulting Group (1993) and the U.S. National Center for Health Statistics (1996).*

A Never Ending War

These gains may now be threatened not only by issues facing the research infrastructure but by new medical challenges arising in the U.S. and around the world. Driving these challenges are epidemiological and demographic forces outside the control and scope of policymakers.

Aging of the population. The number of Americans aged 65 or older will expand from 12.5 percent of the population to 20 percent by 2025 as 76 million baby boomers reach retirement age. This can be expected to increase the proportion suffering from diseases such as Alzheimer's, cancer, heart disease and diabetes. Moreover, the economic, social and environmental changes in emerging markets are producing a shift of disease burden towards a mix much more like that now in the United States. The World Bank predicts that the 1990 world population of people aged 65 and older will triple to 1.4 billion by 2030, 80 percent of whom will live in countries that are poor today.[3]

Emerging infectious diseases. The emergence of new health threats, from HIV and other recently recognized viruses to antibiotic resistant bacteria, are raising the possibility that the medical advances of this century could now be jeopardized. A recent study suggests that infection as a cause of death in the U.S. actually increased between 1980 and 1992.[4] Disease does not stop at America's borders nor are we insulated from the horrible toll infectious and other diseases take in developing countries. In an increasingly global society, characterized by greater freedom of movement and economic interdependency, epidemics and rising disease burdens in other regions can be expected to have real impacts on our economy and health.

We are engaged in a never ending war on disease in which the targets are sometimes elusive and always shifting. Unless methods of disease prevention and health treatment improve, the security of the U.S. and the ability of the government to improve the general welfare of the citizenry could be threatened. Ironically, although the U.S. is the clear global leader in the biomedical research necessary to meet these threats, emerging vulnerabilities may weaken the long-term capabilities for innovation at a critical juncture. We may be in the process of effectively abdicating leadership responsibility, just when the needs are rising and opportunities for revolutionary new therapies are increasing.

Key Findings and Recommendations

Health Care Innovation Is Our Game to Lose

In heath care innovation, the U.S. is seen as the clear global leader, but this position is based largely on previous investment—and real concerns are being voiced about the future. Five key themes and areas for recommendations that emerged from the study are summarized here and detailed later in an action plan.

1. Implement proposed increases in federal funding for biomedical research and other basic sciences.

Basic research and education have been well supported in health-related fields, but not at the levels required to realize the potential of emerging scientific opportunities. Innovation in health care is directly linked to sustaining consistent and sufficient funding for basic research opportunities, supporting the education and training of young researchers that power the system, and maintaining an open system capable of attracting and retaining the world's best talent. Increasingly, innovation in health care is also linked to basic research in other fields ranging from chemistry, physics and engineering to computer and materials sciences.

2. Save Clinical Research

The vibrancy of academic medical centers (AMCs) constitutes a unique strength and source of momentum for health care innovation. But, ongoing changes in health delivery systems on the private side (managed care organizations) and potential changes on the public side (e.g. Medicare reform) could profoundly affect the funding base for research at AMCs. Better financing mechanisms for clinical research and training and integration of private payers into the innovation system represent key targets of opportunity.

3. Upgrade Physical and Information Infrastructure

Investment in physical facilities and laboratory equipment at universities and medical centers has been inadequate, with increased pressures for cost-sharing coming at a time when the institutions are already financially pinched. Shortcomings in the IT infrastructure and personnel threaten to slow the rate of research, innovation and education necessary to improve health care.

4. Improve Incentives for Innovation

The capacity for innovation can only be increased by addressing the discrepancies between rising requirements and shortening time windows for recouping returns on investment through protecting intellectual property, promoting a level playing field for competition, increasing regulatory efficiency and providing tax incentives for research. Steps must be taken to ensure that the research and application of novel technologies is not constrained by patenting and exclusive licensing of basic research tools.

5. Maintain public support for biomedical research

A critical concern is to maintain support for research by encouraging informed debate and preserving the public's trust and protection while avoiding precipitous decisions that could damage legitimate research.

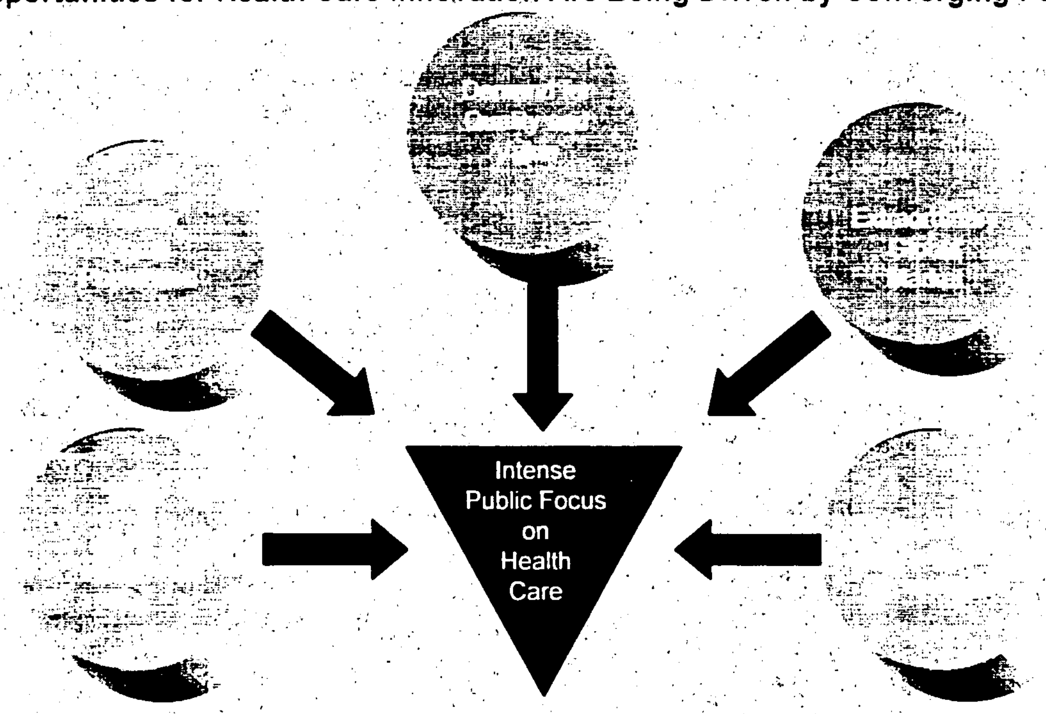
The U.S. has grown a complex ecosystem for health care innovation over the past half century, nourished by generous financial and public support and guided by farsighted political, academic and business leadership. Like most ecosystems, weakness or loss in any component of the innovation web will have ripple effects that adversely affect the others and the whole. The concerns raised by the study highlight key areas of vulnerability. Given the long time frames for health care innovation, we will have lost critical time and opportunities when these problems become visible.

In the meantime, other regions of the world are not standing still. They recognize the strategic importance of the sector and are making rapid strides to improve their competitive positions. In Europe, and the UK in particular, an emerging venture capital community and biotechnology industry is beginning to leverage historic scientific and technological strengths. Germany has great potential. Japan continues to make substantial investments in biomedical research. China is accelerating towards competing in the global medical products market, while emerging Asian technological powers show real promise. The rapid diffusion of information and researchers in what has become a global health care innovation ecosystem guarantees that offshore competition will become more important in the future even as the accelerating pace of scientific change and expanding markets offers new opportunities for catch up.

A New Vision for Health Care Innovation

The consequences of not addressing these issues would be the loss of innovative capabilities at a critical time in scientific and societal transformation. The world stands on the threshold of a health care revolution (Chart 2). The new tools offered by innovation represent the best way to deal with looming health care threats in this nation and around the world. Indeed, the possibility of missing this opportunity is perhaps the single strongest rationale for action.

Chart 2:
Opportunities for Health Care Innovation Are Being Driven by Converging Forces



Other nations' improving research capabilities in health care represent a win-win situation in a world in which exchange of information, ideas and people means greater progress for us all. The U.S. must maximize both its contribution and capacity to capitalize on the emerging global innovation ecosystem in health care. Obstacles towards reaching this goal should not be a source of discouragement but a context for prudent planning. We need to think proactively about creating a broader vision to transform science and our world.

This new vision for innovation is based on a comprehensive set of interlocking principles:

- **National and international security** is derived not only from military and economic power, but also from scientific and moral leadership. Innovation in health care serves international interests by promoting long-term prosperity and stability throughout the world.

- **Economic prosperity**, an increasingly important corollary to national security, is enhanced by a healthy and productive workforce—both at home and abroad.

- **Environmental sustainability** is important to better health. Emerging biotechnology applied to environmental needs may offer new ways to deal with pressing problems, such as managing pollution and improving agricultural technologies

- **Health care innovation** itself must be firmly grounded in achieving affordable care and enhanced quality of life by offering people more and better choices. The ultimate goals remain the prevention and alleviation of pain, suffering and disability along with the restoration of hope and health for all.

Reaching this vision will require leadership, creativity and investment. The growing public recognition of the critical role and scientific research, along with the need to back it up with adequate resources, is heartening. Translating this recognition into vision and action is the next crucial step.

Examining the Issues

Health care innovation means creating better tools—and using them appropriately.

Health care innovation has two fundamentally different forms, both of which offer great opportunities:

- **Product or technology innovation**, such as new medicines, vaccines, therapies, diagnostic technologies, and medical instruments and devices, provides new tools for care givers and patients to use in both disease prevention and health restoration, maintenance and improvement.

- **Process innovation** means doing things differently. It is best represented in health care by disease management, where clinical care delivery and organization are systematically integrated. This care is guided by evidence of best clinical outcomes from clinical trials, and enabled by using advanced information systems. Other important areas of process innovation include evaluation of health services and delivery.

Ultimately, these two types of innovation are synergistic, with new products or uses of products representing a crucial part of the process of reordering and improving health care. Both are necessary if rising customer and societal demands for high quality care and value are to be met (Charts 3 and 4).

Chart 3:
Innovation by New Products and Processes Improves Health Care

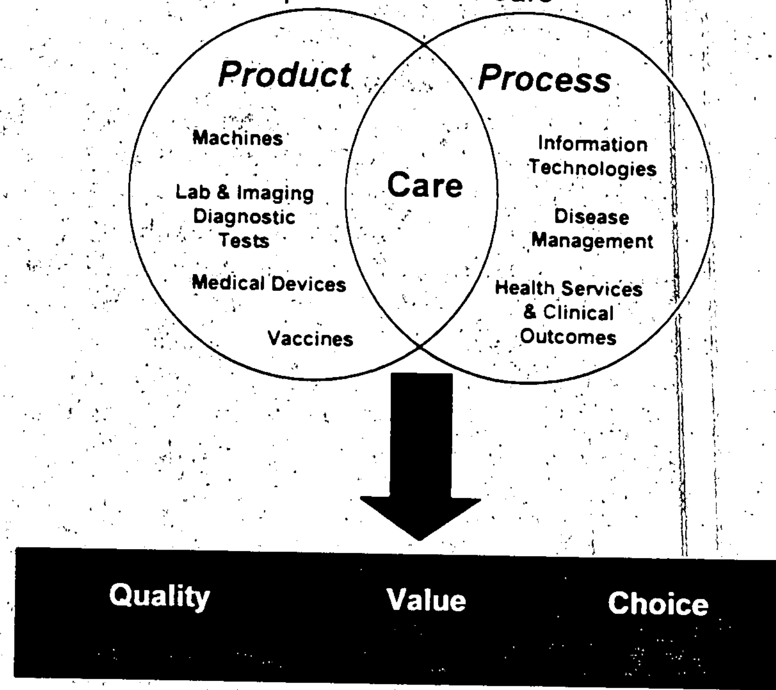


Chart 4:
New Medicines and Vaccines Offer Better Therapies for Patients

- **New oral drugs, such as lipid-lowering agents for heart patients with elevated cholesterol, selective serotonin reuptake inhibitors for depression and some other mental health conditions, and protease inhibitors--an important part of therapy for patients with AIDS.**

- **New protein drugs, like erythropoeitin for anemia and interferons for hepatitis and MS.**

- **Monoclonal antibodies have proved important for the study, diagnosis and, in some cases, treatment of illnesses.**

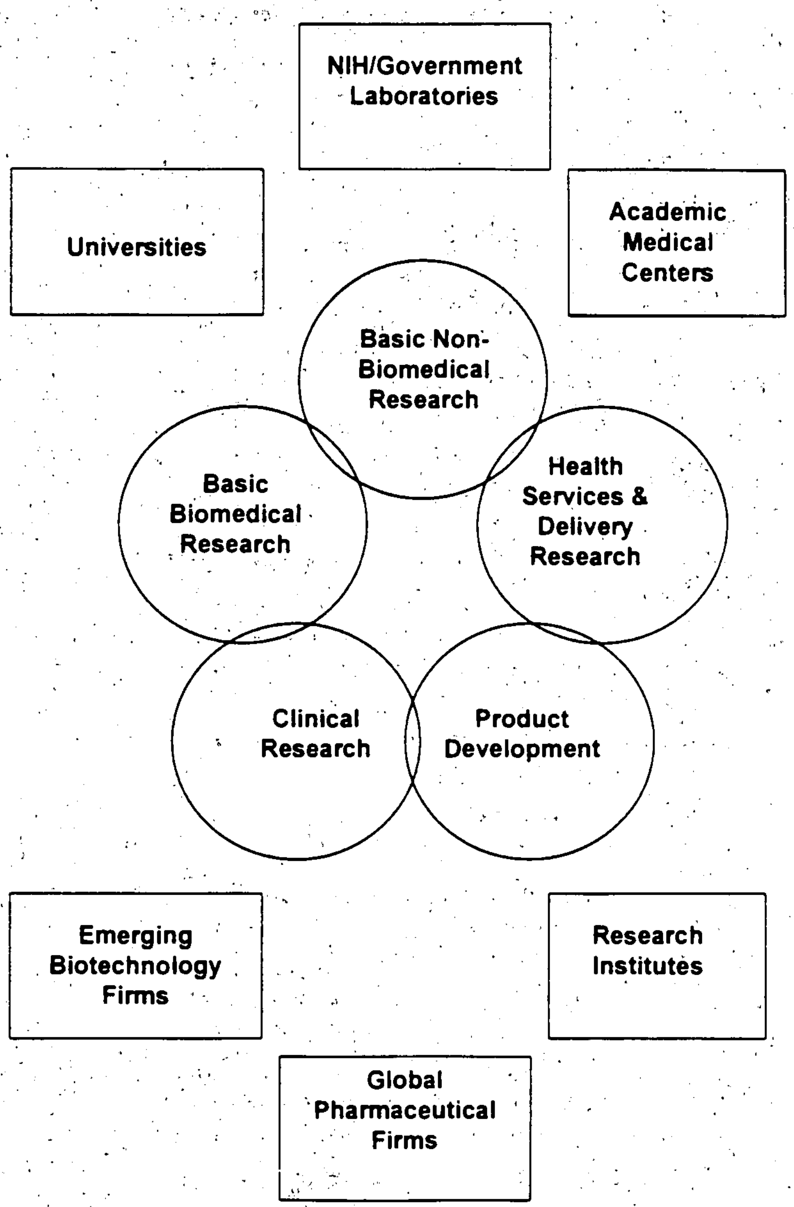
- **New and more effective vaccines have been based on recombinant DNA and new conjugation technologies.**

Health care innovation is a complex process that relies on collaboration and regular infusions from basic research.

The actual process of health care research and innovation is not a predictable linear progression from knowledge to development and application. Rather, it is an unpredictable, iterative process characterized by experimentation, feedback and adjustment performed by a variety of participants in many settings (Chart 5). Each participant plays an important role by adding pieces to the scientific puzzle; each has interests and objectives that can only be accomplished by establishing reciprocal relationships with others. While many of these participants may be located in a region or nation, health care R&D is increasingly global, particularly on the industrial side.

Collaborative exchange of information, people and resources in a series of partnerships is the hallmark of this process. Research by Rebecca Henderson and Ian Cockburn at MIT indicates that the pharmaceutical firms most connected to public research programs have the most productive drug discovery efforts, as measured by the number of important patents.[5] Work by Lou Galambos at Johns Hopkins and John Sturchio at Merck supports this correlation between cross-institutional collaboration and research productivity.[6] At the international level, analysis by Walter Kuemmerle at the Harvard Business School indicates that cross-national collaborations are increasingly important, with European companies increasing their presence in the U.S. research environment to a greater degree than U.S. companies are expanding abroad.[7] These collaborations ultimately form a web of biomedical innovation, a system where the total is greater than the sum of the parts.

Chart 5:
A Complex Ecosystem of Players in Health Care Innovation Has Emerged



Converging Revolutions in Biology and Information Technology will Transform Health Care.

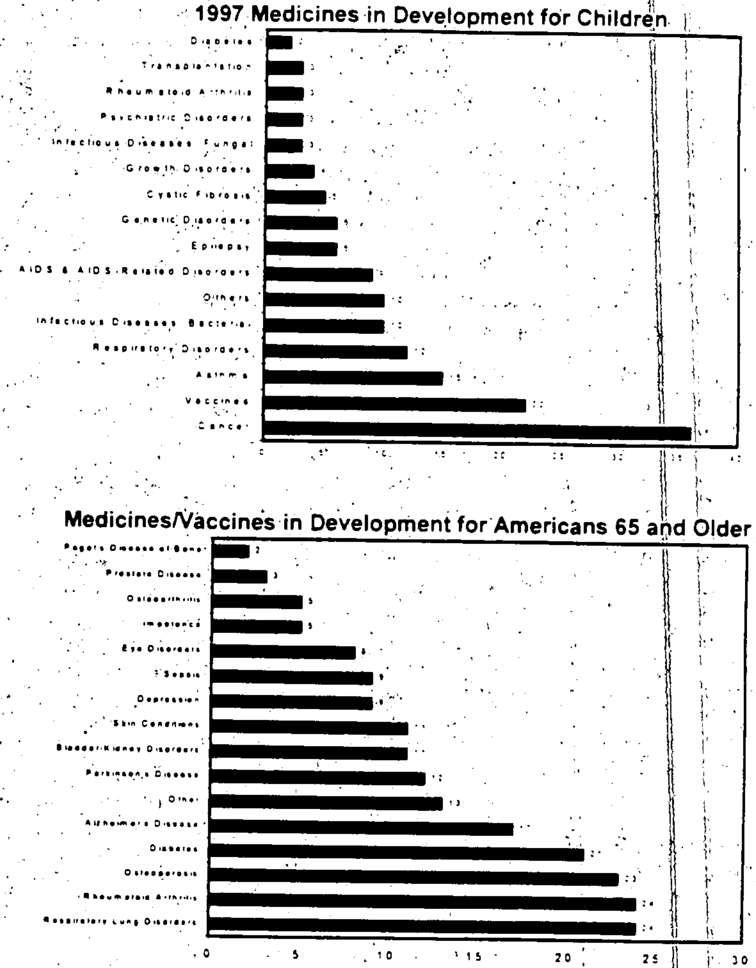
The output of this process has never appeared more promising. Many diagnostic and therapeutic methods that have recently been introduced or are under development will substantially improve care (Chart 6). More important, advances in molecular biology, coupled with advances in physical sciences, computers and information technology, have made the Human Genome Project a reality. By mapping and sequencing the human and several other organisms' genomes by 2005, this revolutionary project will provide the basis for a more systematic and fundamental understanding of biology. Deciphering the meaning of the genome is a task of enormous complexity that will require significant further investment both in the tools themselves and in their applications. The template it provides will be fleshed out in thousands of specific research projects over many years. Coupled with other advances in molecular biology, pathophysiology and epidemiology, such understanding will pioneer better methods to detect, treat and prevent illness.

The drug discovery process, which incorporates this information, is complex, integrative and increasingly multi-disciplinary (Chart 7). In addition to the biomedical sciences, it relies on input from a variety of other fields, ranging from chemistry, physics and computer sciences to engineering and materials. The emerging field of bioinformatics leverages IT advances to turn information into understanding; gene chips promise even further improvements.

A simultaneous revolution in clinical research will use computers and information systems to analyze patient databases and

Chart 6:

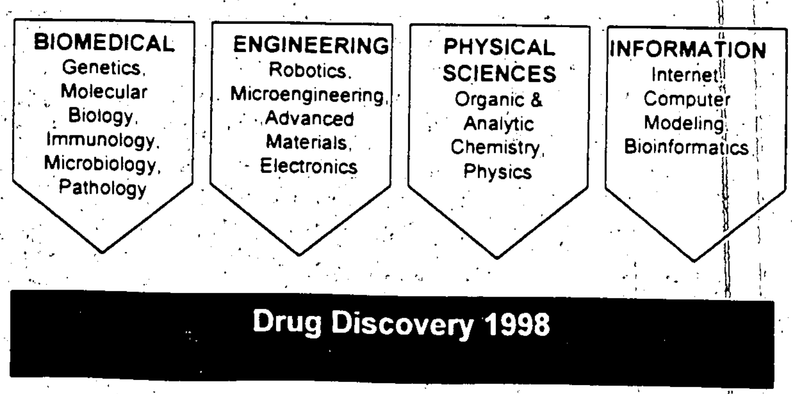
Many Medicines and Vaccines Are Being Developed for Both Children and the Elderly



Source: PhRMA. "Medicines in Development" Series. 1997.

Chart 7:

Finding New Medicines Is a Multidisciplinary Effort



model clinical and economic impacts on populations. This will facilitate more rational and evidence-based clinical decisions on how best to use existing and new technologies. Every clinical encounter could potentially become part of medical research. Information technologies will also enable more efficient and rapid clinical trials, while hopefully speeding diffusion of findings and best practices to physicians and patients. Remote telemedicine is opening new avenues of clinical investigation and care. Finally, IT advances will facilitate the wide variety of collaborations upon which health care innovation depends.

Combining these product and process innovations will accomplish the goals of better health quality with value.

Such an approach plays to areas of U.S strength. Innovation represents the best way to overcome rising disease burdens. Experience suggests that further investment in research and innovation produces high and increasingly positive rates of return in terms of health benefits—particularly when broad societal impacts, such as workplace productivity and spillover effects to other scientific fields and economic sectors, are considered. The unpalatable alternative is for society to face the increasing burdens of an aging population armed only with today's medical tools. The long-term result would be a stalled economy undermined by the need to devote increasing marginal resources to health care delivery.

This need not happen. New tools can and are being developed. The impact of this century's advances alone have been enormous. Further advances in molecular biology, genetics, engineering and other fields of science and technology are opening new vistas of opportunity. Collaboration between biomedical and physical sciences

Chart 8:

Advances in Treating Illnesses Have Had Large Economic Benefits for Society

- Current therapies for diabetic retinopathy, the leading cause of blindness in the U.S. among patients aged 20-71: $1.2-$1.6 billion in avoided disability costs.
- Treatment of pediatric acute lymphocytic leukemia (ALL): $1 billion due to restored lifetime earnings.
- Peptic ulcer disease curative eradication therapy for *H. pylori*: $760 million in avoided treatment costs.
- Estrogen replacement therapy decreasing hip fractures in women: $333 million due in part to avoided long-term care.
- Lithium for the treatment of manic-depressive illness: estimated to have saved $7 billion/year since intro in 1970.
- Conjugated hemophilus B (Hib) vaccine for two month-olds: $347-$462 million in avoided cases of infection annually.

Sources: HHS. *Cost Savings Resulting from NIH Support*. 2nd ed. Washington, D.C. 1993. The Ad Hoc Group for Medical Research Funding. *The National Institutes of Health—A Resource Guide*. Washington, D.C. 1997.

Chart 9:

Government Saves Money with Health Care Innovation

- Opportunities for cost-saving innovation in mental illness,estimated to result in $148 billion in annual direct and indirect costs, are enormous. Schizophrenia affects 5 million Americans and accounts for 25 percent of all federal disability payments.
- Today's improved medical care has resulted in Medicare savings of between $180-$219 billion since 1982, with as much as $25 billion estimated for 1995 alone.
- Innovation has helped reduce the rate of chronic disability and institutionalization by almost 15 percent from 1982-1994, saving an estimated 2.4 million patient years of institutional days costing $120 billion in 1997 dollars.

Sources: The Ad Hoc Group for Medical Research Funding. *The National Institutes of Health—A Resource Guide*. Washington, D.C. 1997; Center for Demographic Studies, Duke University.

will not only provide better medicines, it will also create new ways of diagnosing and managing illness using imaging and gene testing technologies able to target clinical therapies for better results.

Health care innovation not only leads to longer and healthier lives, it also brings substantial economic benefits (Charts 8 and 9, previous page). Using new and better therapies reduces the costs of illness and expensive interventions, like surgery or hospitalization, which is of direct interest to patients, insurers, employers as well as the government. Economic calculations do not include the qualitative value that individuals and society place on longer, healthier lives. Innovation also gives patients and providers more choices.

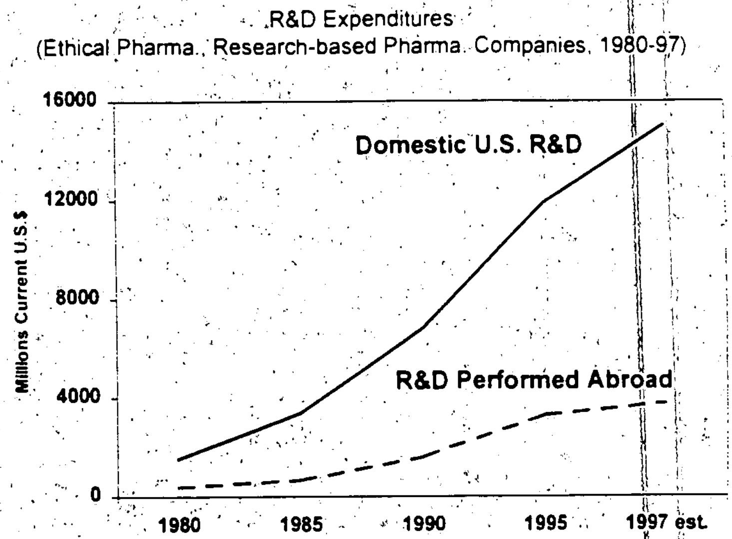
Where We Stand

Given the importance of health care innovation to society, where does the U.S. stand? Sector study participants saw the United States as the clear global leader in the biomedical research and innovation processes so crucial to achieving better health care (Chart 11). But we didn't get there by luck or accident. Our current leadership position stems from across-the-board strengths in all key innovation elements:

1. *Excellent researchers who push the boundaries of science.*
2. *Support for basic biomedical, and clinical research, along with non-medical basic research by governments, not-for-profit organizations, and industry.*
3. *Outstanding universities, academic medical centers, research institutes, and government and industry laboratories that combine to form the research network for innovation.*

Chart 10:

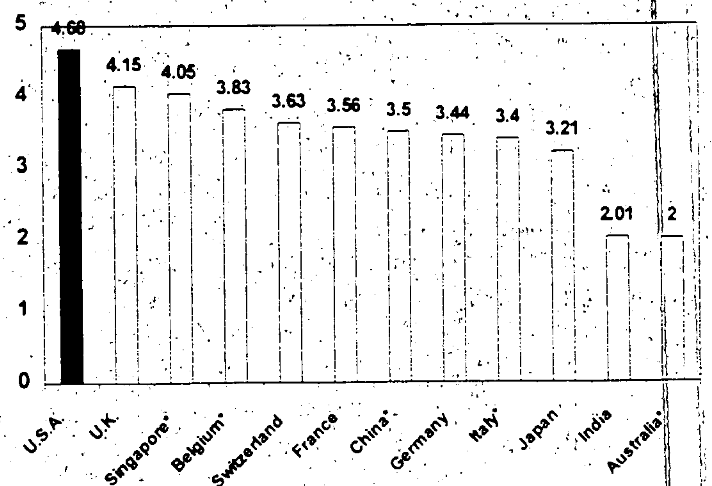
Pharmaceutical Company R&D Expenditures Have Grown Rapidly—with a Stable Portion Conducted Abroad



Source: PhRMA, *Annual Survey*, 1997.

Chart 11:

The United States Received the Best Overall Rating for Health Care Innovation



5 = this country provides a highly favorable environment for innovation in health care.
1 = this country provides a highly unfavorable environment for innovation in health care.
* ratings rely on a small number of data points and are indicative rather than reliable in a statistical sense.

Source: Council on Competitiveness and Prof. Walter Kuemmerle, Harvard Business School, 1997 Survey.

4. *An entrepreneurial culture and market-oriented system which facilitate the translation of scientific observations into products.*

5. *A concerned and aware public that has strongly supported biomedical research.*

Sector participants ranked the United States vis-à-vis other countries on each of these elements. Collectively, the rankings enable an overall assessment of the climate for innovation and indicate that while strengths vary for some positions, the U.S. offers the most favorable overall environment for health care research.

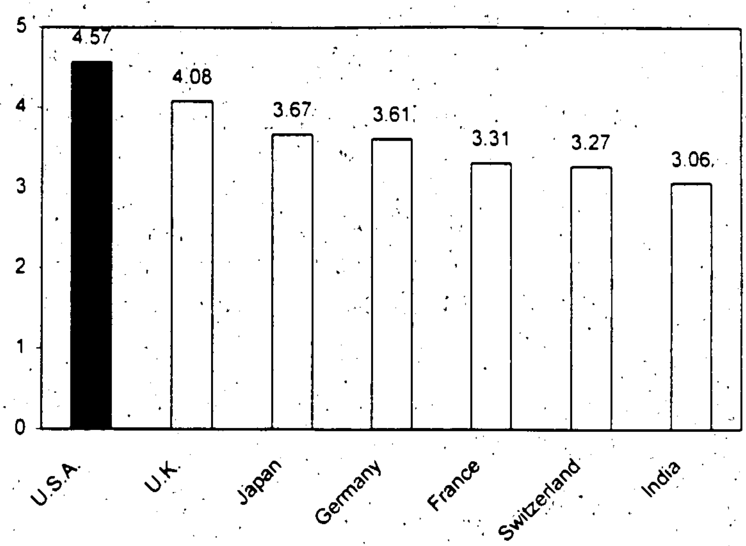
1. Excellent researchers who push the boundaries of science.

U.S. universities and research institutes historically have been able to attract, train and retain the best biomedical science students from around the world (Chart 12). They have been drawn here by first-class educational and research opportunities—a direct result of sustained support of research by government, universities, industry and society. These students create the pool of basic and clinical researchers willing to take risks. Their ideas and findings fuel the process of innovation in both academic and industry settings, forming the basis of U.S. leadership in this field. However, sector study participants voiced real concerns that support for training of both basic and clinical investigators is inadequate, while declining research career opportunities are leading students and investigators to avoid or leave these fields.

2. Support for basic biomedical and clinical research and non-medical basic research.

The federal government's support for basic biomedical research, principally via the NIH and NSF, lays the groundwork for health care innovation (Chart 13). Over 80 percent

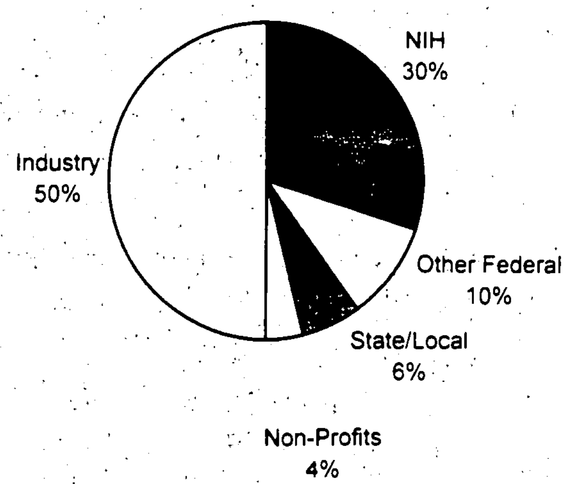
Chart 12:
The United States Has the Highest Quality Health Care Scientists



Source: Council on Competitiveness and Prof. Walter Kuemmerle, Harvard Business School. 1997 Survey.

Chart 13:
U.S. Biomedical Research Funding Comes from a Variety of Sources

Sources of U.S. Biomedical Research Funding, 1995



Source: Barfield, C. and Smith, B. *The Future of Biomedical Research*. 1997. AEI Press. Chapter 1.

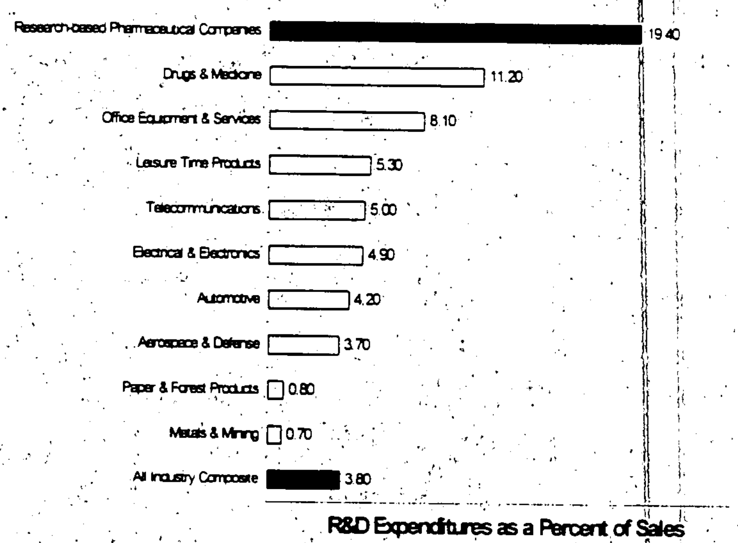
of the 1997 NIH budget of $12.7 billion was used for investigator-initiated grants—peer reviewed and competitively awarded to individual researchers. Private not-for-profit organizations, such as the Howard Hughes Medical Institute, are another important funding source for flexible, investigator-focused, long-term research so necessary for high-risk, innovative work. State and local governments have played a vital role in supporting public university infrastructure. U.S.-based pharmaceutical companies, biotechnology firms and other subsidiaries spend more on R&D as a percentage of sales than any other industry, and their total investment has risen dramatically over the past two decades (Chart 14). A relatively small part of this industry spending supports work in academic settings through an increasing number and diversity of partnerships and collaborations; most industry spending is internal and focused on applied research and clinical development.

While noting these strengths, study participants voiced serious concerns about inadequate levels of basic research funding in the face of enormous opportunities, declining non-biomedical basic research support, and the belief that industry cannot and should not fill public funding shortfalls for basic research.

3. Outstanding universities, academic medical centers, research institutes, government and industry laboratories.

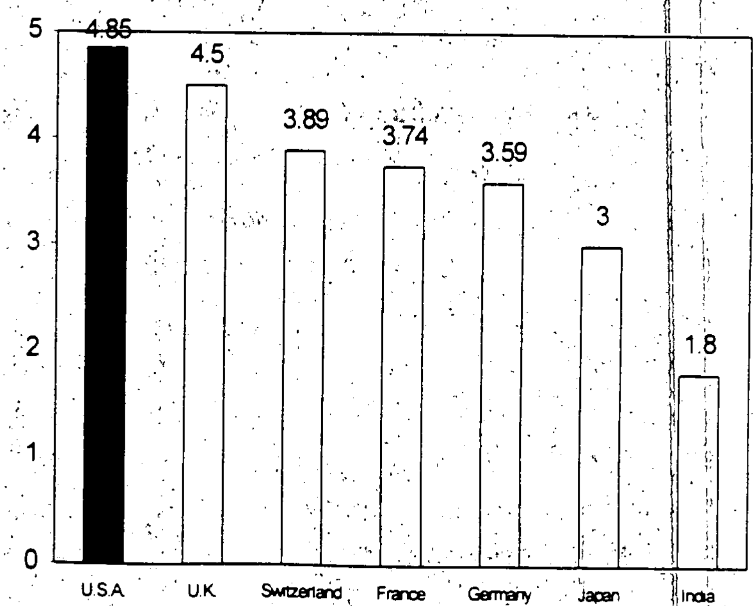
The U.S. university system oversees the education and training for future researchers, as well as the conduct of basic research. Academic medical centers associated with the medical schools of many of these leading universities fill teaching and investigative roles while also providing patient care—creating a critical nexus between basic and clinical research (Chart 15). They are NIH's largest partner in creating new knowledge

Chart 14:
The Pharmaceutical Industry's Contribution Reflects Much Higher Relative Spending vs. Other Sectors



Source: PhRMA. 1997. Based on data from *Annual Survey* and Standard & Poor's Compustat (a division of McGraw-Hill, 1997).

Chart 15:
Excellent Academic Medical Centers Are Critical to U.S. Success...



Source: Council on Competitiveness and Prof. Walter Kuemmerle, Harvard Business School, 1997 Survey.

and receive about half of all NIH extramural funding. Government laboratories, including the NIH intramural research program, are able to conduct cutting-edge science that is unencumbered by the many pressures and short timeframes experienced elsewhere; research institutes have a similar focus. These institutions provide the means to develop talent and conduct research, spawning most of the new biotechnology firms that have been so important to U.S. leadership (Chart 16). They also form a research network with industry counterpart.

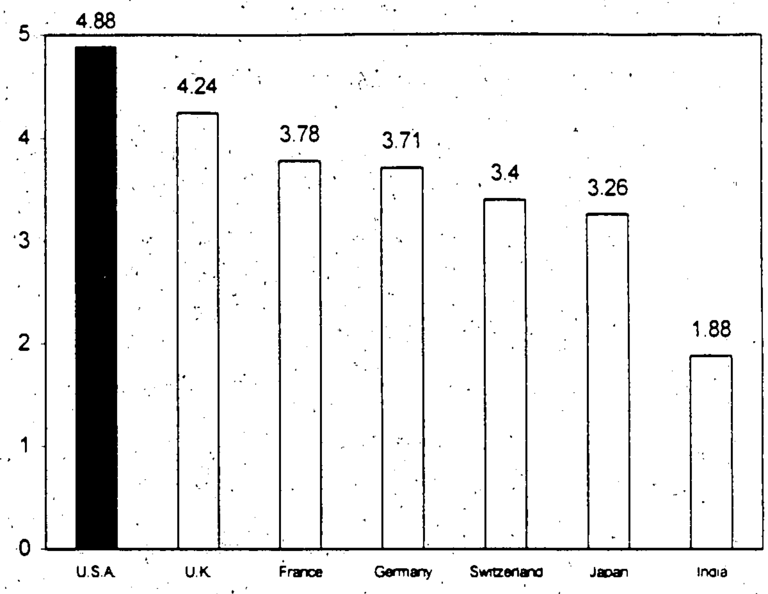
Deficiencies in the underlying physical and information technology infrastructure, however, were reported to hamper research; while academic medical centers face severe funding pressures in a changing health care system.

4. An entrepreneurial culture and market-oriented system.

The U.S. has a climate uniquely conducive to applying basic science to societal needs while creating economic value (Chart 17). Receptive financial markets and a well-developed venture capital community are critical to providing the means for translating research into new firms and products. A U.S. environment offering competition and choice, along with reasonable returns for risk taking, creates the engine for innovation. Strong intellectual property protection, coupled with high regulatory standards and improving processes, are also crucial (Chart 18, next page). State and local governments play an important role in fostering regional initiatives that promote collaborations between universities and industry. Increasing collaborations between emerging companies (usually called biotechnology firms) and integrated global pharmaceutical companies that now use all of the same new genetic and molecular technologies

Chart 16:

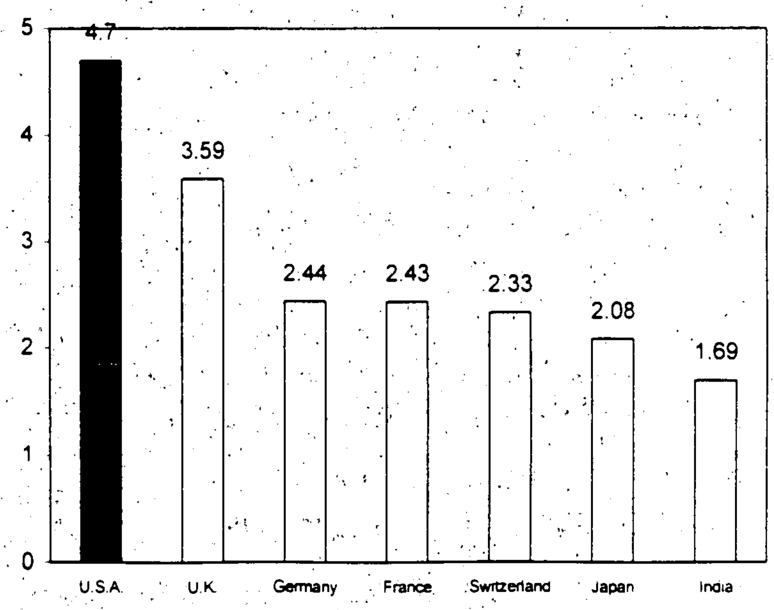
...As Are Strong National Research Institutes



Source: Council on Competitiveness and Prof. Walter Kuemmerle, Harvard Business School, 1997 Survey.

Chart 17:

Investment Climate for Entrepreneurs Is Best in the United States



Source: Council on Competitiveness and Prof. Walter Kuemmerle, Harvard Business School, 1997 Survey.

associated with "biotechnology" are another vital aspect of this system (Chart 19).

Despite these strengths, participants felt that current incentives have not kept pace with the rising costs and risks of health care innovation.

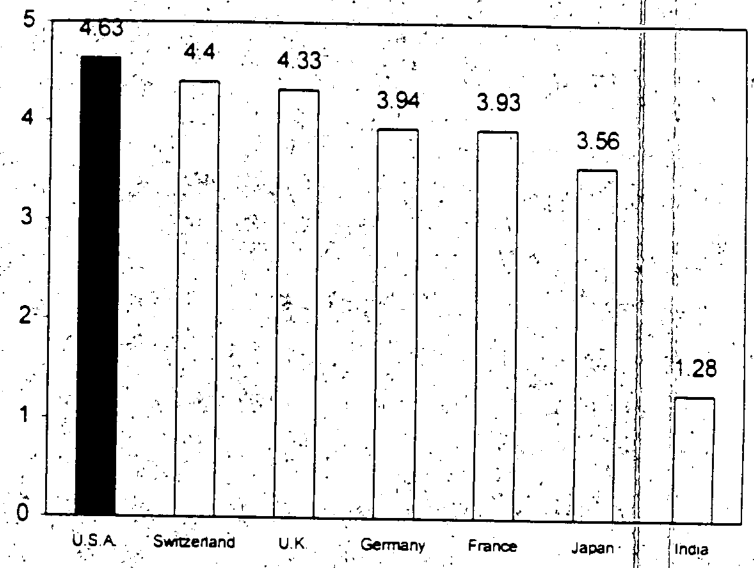
5. A concerned and aware public that has strongly supported biomedical research.

The U.S. public has a keen interest in health care and has strongly supported research. This includes long-term public support for investment in research programs and facilities by federal, state, and local governments, participation in the process as patients in clinical trials, and acceptance of the new products that result from innovation. A recent Research! America survey indicated levels of support for public biomedical research investment at over 80 percent.[8]

Concerns were expressed that this historic support could be undermined by rapid technological change that is now raising public fears about the potential misuse of biomedical advances.

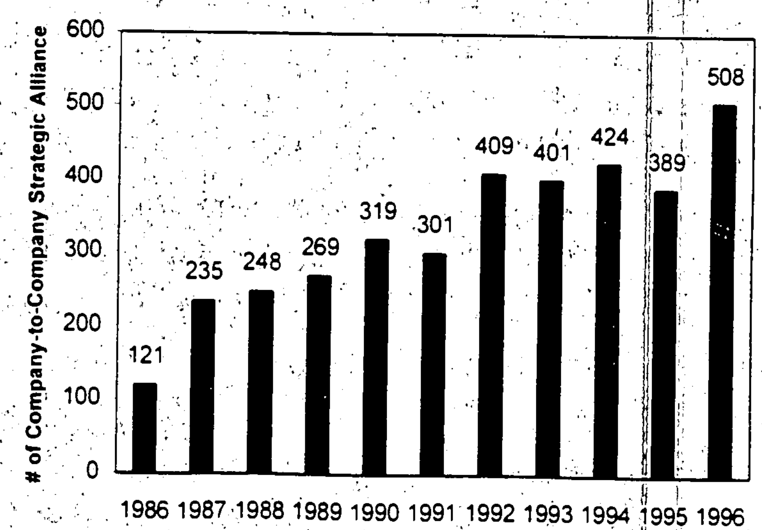
Together, these elements form a highly developed and complex web of collaboration between the major stakeholders in the research and innovation process. This interdependence among players, along with competitive, investigator-initiated research funded by a variety of sources, distinguishes the U.S. from other regions. The highly flexible, bottoms-up approach, coupled with market-driven, competitive incentives for innovation, has allowed the U.S. to respond rapidly to changes and opportunities. This stands in marked contrast with centralized, top-down planning which has stifled initiative in other nations. This complex, flourishing ecosystem of interdependent yet

Chart 18:
Intellectual Property Receives the Greatest Protection in the United States



Source: Council on Competitiveness and Prof. Walter Kuemmerle, Harvard Business School, 1997 Survey.

Chart 19:
Increasing Strategic Alliances between Companies Have Been Important to the U.S. System



Source: *Windhover's Pharmaceutical Strategic Alliances*, 1997 competitive players has led to great scientific and commercial success. The ecosystem is not self-contained: one of its great strengths is its openness to ideas, people and resources globally.

Rating the Competition

Europe shows real potential for health care innovation. European nations in aggregate possess biomedical research assets comparable to those of the U.S. Several leading global pharmaceutical firms are based in the U.K., Switzerland, Germany, Scandinavia and France, most of which have a substantial presence in the U.S. The U.K. was noted to have an environment particularly conducive to biomedical innovation. Significant public investment in research via the Medical Research Council is complemented by the Wellcome Trust, which represents the single largest private supporter of biomedical research in the world. An emerging European and international venture community and increasingly receptive financial markets are supporting a growing number of promising biotechnology firms, which now number over 180 for the U.K alone. Some of these firms are establishing collaborations with global pharmaceutical firms.

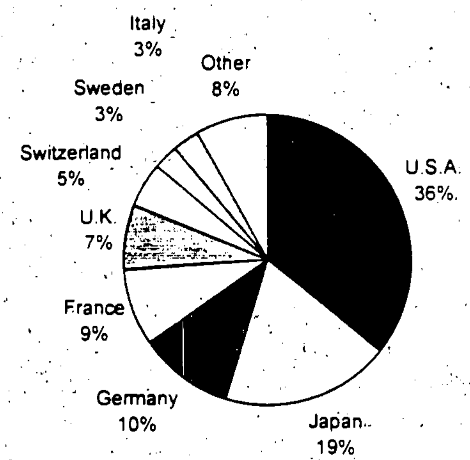
On the European continent, recent and ongoing liberalization of laws restricting genetic-oriented research are improving the environment for innovation. Public resistance to new biomedical technologies may be moderating, while academic attitudes against industry collaborations and commercialization of research may also be shifting.

Germany has made large strides recently with the government-sponsored BioRegio campaign playing an important role.[9] Although France has a history of excellent

Chart 20:

The United States Leads in Pharmaceutical R&D

Company-Financed Pharmaceutical R&D, by Country, 1995

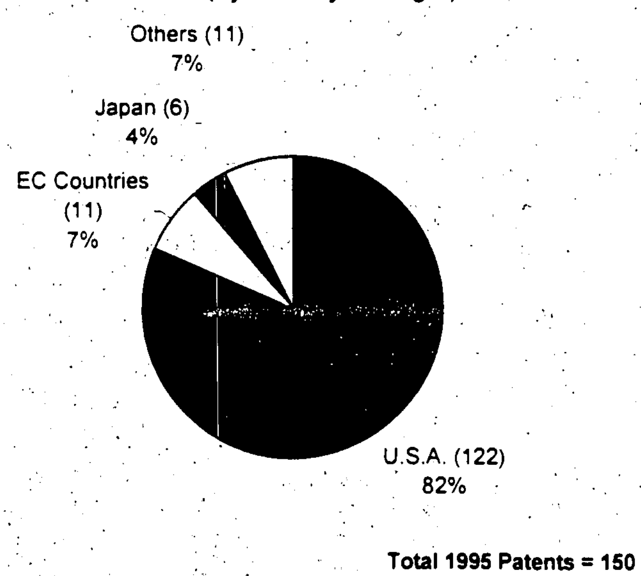


Source: Centre for Medicines Research, U.K. 1997.

Chart 21:

The United States Dominates Genetic-Related Pharmaceutical/Health Care Patents

U.S. Genetic Engineering Pharmaceutical/Health Care 1995 Patents (by country of origin)



Source: PhRMA, *Annual Patents Survey*, 1997.

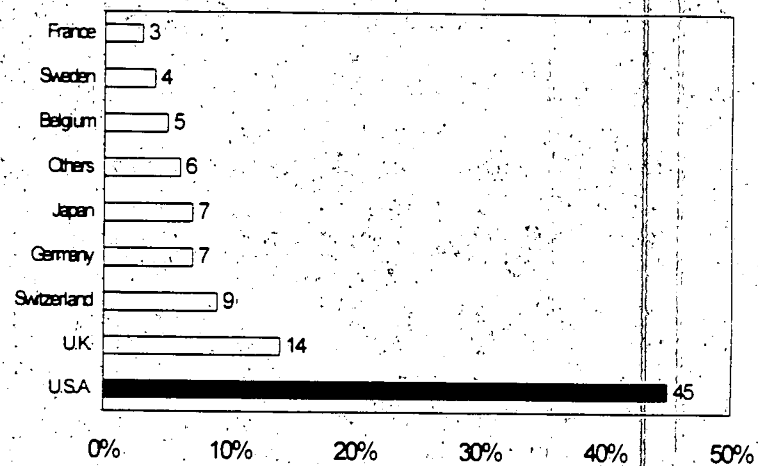
health care science, it was thought to be still somewhat shackled by a centralized, top-down system of research funding and control.[10] E.U. scientific funding and strategy also tends to be overly centralized.[11] Even so, the participants believe that Europe represents an area of great potential for health care innovation, provided that recent improvements in the investment climate continue.

Japan has strengths but lacks critical elements for leadership. Japan represents the second largest national pharmaceutical market in the world after the U.S. dominated by Japanese firms who have been less successful in foreign markets than their U.S. and European counterparts.[12] Japan's investment in basic biomedical research is substantial, yet this has led to the creation of only 20 to 30 biotech firms versus approximately 1300 for the U.S. and over 700 for the E.U. This may be due in large part to the absence of a strong entrepreneurial and venture capital community and a regulatory and reimbursement system that historically has rewarded incremental rather than truly innovative advances. Japanese firms are increasingly reaching to establish collaborations with U.S. biotechnology and pharmaceutical firms.

Emerging regions may be a force to be considered in the future. Other nations vary widely in their climates for health care innovation. Some, such as Singapore, are illustrative of progress made after enacting specific policy changes. Several, such as India, have potential but are plagued by intellectual property protection issues. Others are nursing emerging industries and can be expected to be forces in the future. At this time, their role in biomedical research is relatively small.

Chart 22:
Almost Half of Major New Drugs Have U.S. Origins

Development of 152 Global Drugs by Country of Origin, 1975-1994



Source: Barral, P.E. *20 Years of Pharmaceutical Research Results Throughout the World*. Rhône-Poulenc Rorer Foundation, 1996.

How U.S. Health Care innovation Leadership Pays Off

Facts bear out the study participants' perception of American biomedical leadership:

- 93 NIH-supported scientists have won Nobel Prizes, including current NIH Director Dr. Harold Varmus.
- Overall citations of U.S.-authored scientific journal papers tripled from 1987-1993, with these citations heavily weighted towards biomedical subjects, a substantial percentage of which were supported by NIH grants.[13]
- 82 percent of biotech patents issued by the U.S. Patent Office in 1995 for genetic engineering, health care and pharmaceutical products were to U.S. firms (Chart 21).
- A 1992 analysis of 11 high-tech industries by the General Accounting Office singled out pharmaceuticals as the one industry in which the international competitiveness of U.S. firms did not decline in the 1980s.[14]
- From 1975-1994, 45 percent of all the world's important global drugs originated in the U.S. (Chart 22).
- Research-based pharmaceutical firms generated an estimated $106 billion in prescription medicine sales in 1997--$66 billion in the U.S. and $40 billion abroad.[15]
- In 1996, these companies employed 203,000 in the U.S. and 164,000 abroad.[16]
- The U.S. is home to two thirds (about 1300) of the world's biotechnology firms, most of which are biomedically-oriented.
- U.S. biotechnology firms employ 118,000 people in 1996.[17]
- Pharmaceutical products have consistently generated a trade surplus of approximately $1 billion.[18]
- U.S. biomedical technology represents an international magnet. The U.S. attracted an estimated 75 percent of world investment in biotechnology in 1997.[19] All major non-U.S. pharmaceutical firms have collaborations with U.S. biotech companies, and most of these firms also have substantial internal research efforts based in the U.S.

Major Concerns Threaten the U.S. Health Care Ecosystem

Despite this record of past successes, study participants voiced significant concerns about the future. These concerns coalesced around five major themes.

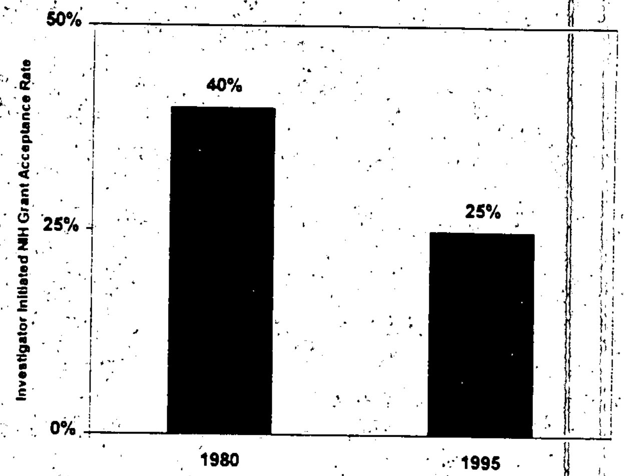
1. Basic research and education have been relatively well-supported but not at the levels required to realize the potential of emerging scientific opportunities.

Biomedical basic research funding has not kept pace with the increased number of new scientific opportunities: Basic research provides the substrate of fundamental knowledge from which all modern medical technology has come. Essential understanding of how cells and organs function and malfunction, diseases progress, bacteria and viruses act, and how genetics, the environment and other risk factors interact to produce illness, provide the tools for further investigations while giving clues on how to detect, treat and, ideally, prevent disease. Most of this work is conducted in universities, research institutes and government labs and funded largely by the federal government—principally through the NIH, via investigator-initiated grants.

NIH funding has continued to grow over the past decade, but not at a pace commensurate with both rising research opportunities and accompanying costs. The investigator-initiated NIH grant acceptance rate has fallen from approximately 40 percent in 1980 to less than 25 percent in 1995 (Chart 23). While the reasons behind this drop are likely complex, heightened competition and reduced grant lengths have raised investigator anxieties, leading to lower risk, "safer" proposals. Shorter funding cycles have also decreased research efficiency, with

Chart 23:

The Acceptance Rate of NIH Investigator-Initiated Grants Has Fallen



Source: NIH.

greater amounts of time dedicated to seeking support rather than actually performing research. Concern was also expressed that specific earmarked funding for diseases. motivated by political advocacy rather than pursuit of the best scientific opportunities. could distort research priorities.

Graduate biomedical education has weaknesses that could extinguish the creative source of basic research: Funding support for graduate scientific education is increasingly constrained. raising the key challenge of how to attract the best young minds. Providing the type of cross-disciplinary education necessary for excellence in today and tomorrow's environment is limited by funding and institutional rigidity. Coupled with underlying weaknesses in K-12 scientific and mathematical education. such factors threaten the development of future U.S. biomedical research talent.

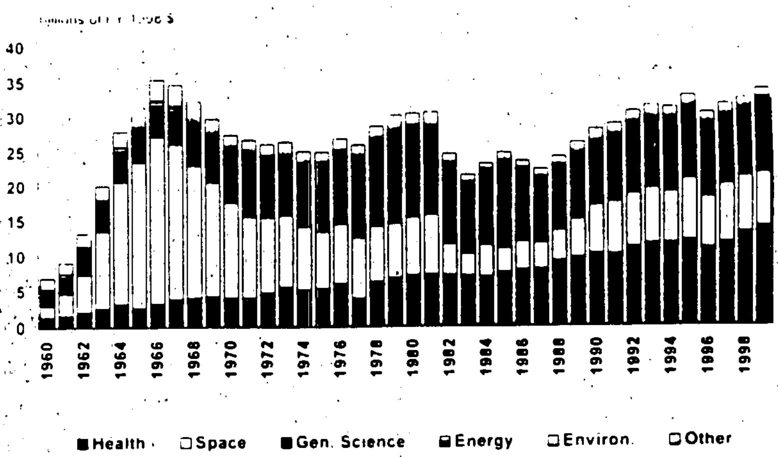
Fortunately. the U.S. has been able to attract the best students worldwide for biomedical graduate education: approximately one quarter of Ph.D. students in the life science fields is of international origin.[20] However. concerns about decreasing academic opportunities here and emerging commercial opportunities in other regions may hamper retention. Current immigration restrictions for students desiring to stay. as well as researchers seeking to enter the U.S. on a permanent or temporary basis. exacerbate this situation.

Funding for non-biomedical basic research and education has declined over the past decade, seriously threatening future prospects for health care innovation: While basic research in the biomedical sciences has continued to grow over the past decade. other fields have not been so fortunate. Government funding for the physical

Chart 24:

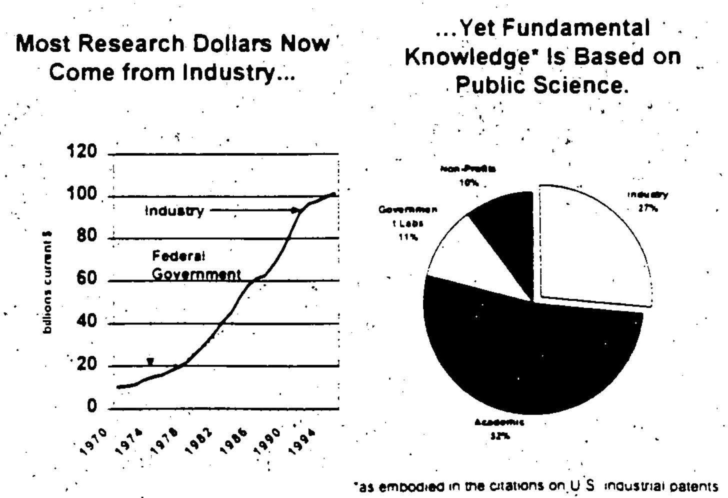
Funding for Non-Biomedical R&D Is Flat

Trends in Nondefense R&D by Function, FY 1960-99
Outlays for the Conduct of R&D, Constant FY 1998 $ Billions



Source: AAAS.

Chart 25:



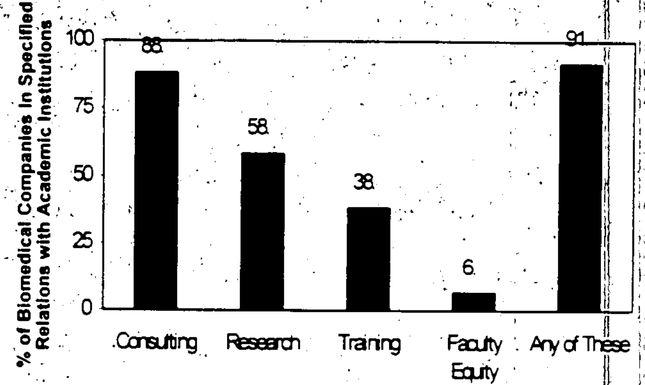
Source: *The New York Times*. May 13. 1997. Based on data from the National Science Foundation and CHI Research. Inc.

sciences, engineering and IT has declined significantly since the end of the Cold War. Yet with science becoming increasingly multidisciplinary, the best prospects often lie at the interfaces of fields. Biomedical research is dependent on a wide variety of non-biomedical fields, from chemistry and physics to engineering and advanced materials. The genomic and molecular biology revolutions would have been impossible without the use of computers and new information technologies to process, analyze, share and store enormous quantities of data. All of these technologies were derived from basic research, and the promising advances now expected in health care would not have been possible without them. By the same token, advances in biomedical sciences, particularly genetics, offers real promise for applications in chemistry, environmental science, materials and agriculture. Research is a positive—not a zero-sum—game, offering benefits to everyone. Declines in any one area diminishes all, with society the ultimate loser.

Industry money is not the solution to basic research funding issues: While the pharmaceutical and biotechnology industries invest heavily in applied research and development (Chart 10), these firms generally do not engage in high levels of basic research that produces fundamental knowledge. Industry does contribute substantially to the basic research process through scientific interactions with academic investigators; educational support and infrastructure sharing. Firms are establishing an increasing number and variety of collaborations with universities to bolster their innovation efforts (Chart 26). A 1996 study by Blumenthal *et. al.* indicated that 90 percent of biomedical firms had collaborations with academic institutions, with industry financial support contributing

Chart 26:

Life Science Companies Have a Variety of Collaborations with Academic Institutions



Source: The New England Journal of Medicine, February 8, 1996.

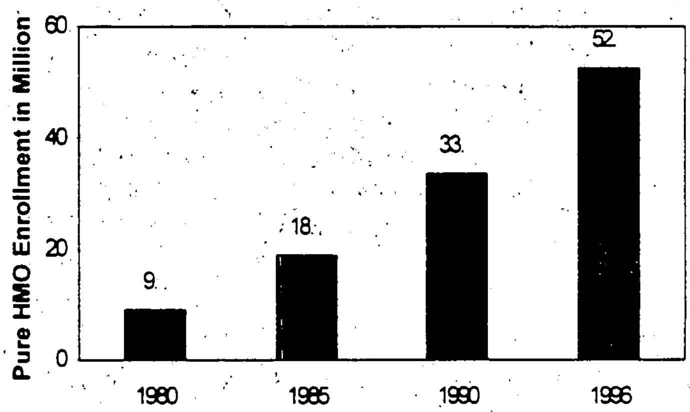
12 percent of these institutions' R&D financing.[21]

Although increased collaboration between academia and industry provides more resources and non-financial benefits, like information exchange, industry support is not a substitute for adequate public funding of basic research. From academia's perspective, such a development could decrease the free exchange of information critical to scientific progress. It could also divert universities from their core missions of fundamental research and education towards short-term applied research/ development and job training. Sector study participants from industry share these concerns, noting that prospects for innovation would be impoverished in the long run. Participants believed that applied science, development and risk-bearing were industry's role. Industry-university collaboration must carefully balance these considerations to produce mutual benefits while preserving complementary activities. The proposed 1999 federal scientific budgets were seen as a much-preferred solution to academic basic research funding issues.

2. Clinical research capabilities are threatened by ongoing changes in the U.S. health care system

The U.S. health care delivery system is in a state of flux: The U.S. health care system, though considered the envy of the world, has experienced rapid and accelerating changes over the last decade, particularly in the past five years. While complex, the central feature of these changes has been a shift away from fee-for-service to a predetermined rate per person (capitation) financing of care delivery directed by managed care organizations (Chart 27). Ongoing shifts in government health care spending through Medicare and Medicaid

Chart 27:
Managed Care Has Grown Rapidly in the United States



Source: Interstudy Publications, 1997.

can be expected to have further impacts. These changes are driven by real and pressing concerns about escalating costs. Widespread shifts in how, where and by whom health care is provided have altered reimbursement rates and cash flows to the professionals and hospitals providing this care. Detailing these changes or making any recommendations related to them is beyond the scope of this report. However, because clinical research is embedded within the health care delivery system, these changes have significant impact on research and innovation, and therefore, warrant consideration.

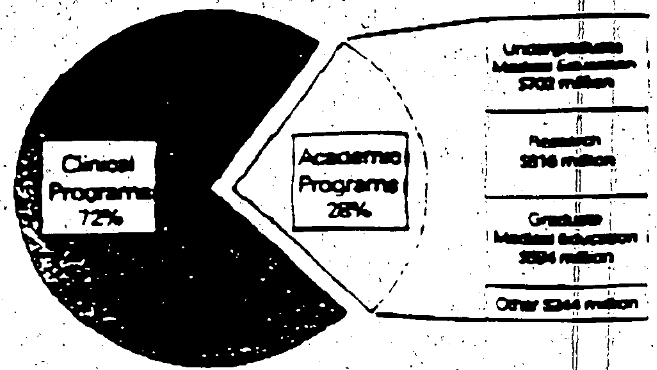
Academic medical centers are pressured by changes in the health care delivery system: Although the changes in health care delivery have helped moderate rapid increases in health care spending, they have also produced unintended consequences for clinical research. Many academic medical centers (AMCs) have been particularly affected. These institutions represent a unique nexus of basic and clinical research critical to the multi-disciplinary, interactive nature of the research ecosystem: they are the workshops of health care innovation. Their multiple missions of teaching, research and patient care greatly facilitate the innovation process, yet also place them at a cost disadvantage (estimated 10-40 percent) in an increasingly competitive market.[22] These factors have triggered large-scale and necessary restructuring, yet they have also curtailed a substantial source of funding for clinical research.[23] This is due to diversion of patients from AMCs to lower cost community hospitals and refusals by insurers to pay part of clinical research costs previously covered under fee-for-service reimbursement.

Decreased clinical revenues have meant less flexible and discretionary funds available for

Chart 28:

A Large Portion of AMC Clinical Care Revenues Have Supported Research and Education

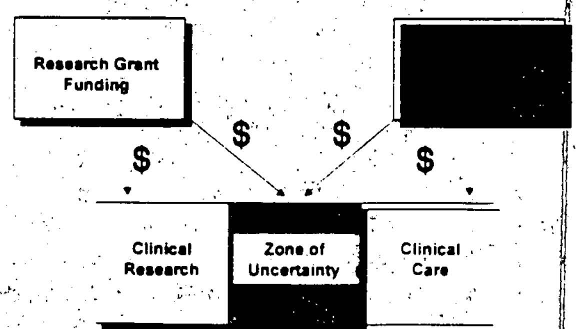
Estimated Faculty Practice Plan Support of Academic Programs, 1992-93
(Faculty Practice Plan Revenue = $8.3 billion)



Source: AAMC. *The Financing of Medical Schools—A Report of the AAMC Task Force on Medical School Financing*. Washington, D.C. 1996.

Chart 29:

Funding "Uncertainties" May Occur When Patient Care Meets Research



Source: Mechanic, Robert, Allen Dobson, Ph.D. Sylvia Y. *The Impact of Managed Care on Clinical Research: A Preliminary Investigation.* Final Report. Public Health Service. National Center for Research Resources. http://www.ncrr.nih.gov/newspub/mancare.htm.

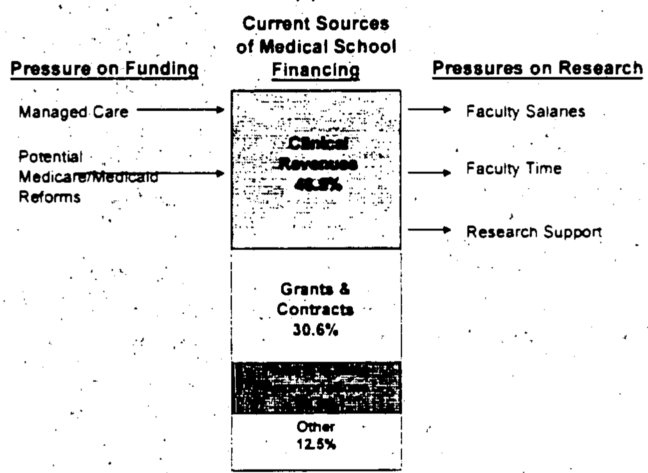
research, which is particularly detrimental for studies not sponsored by NIH or other grant sources. Unsponsored work is often important in bridging the gap between basic and clinical research and is responsible for a large proportion of studies published in medical journals. It also supports academic studies in clinical outcomes, health services and epidemiology crucial to developing methodologies for evidence-based medicine.

A second impact of the changing health care delivery system is the loss of patients and their data for clinical research. Many potential research subjects are being diverted from AMCs due to cost considerations. Clinical data is frequently locked up in proprietary databases of managed care organizations. Exacerbating these difficulties is competition from private contract research organizations (CROs) that are able to organize and conduct more rapid and less expensive clinical trials for biotechnology and pharmaceutical firms. In some cases, these trials are performed outside the traditional AMC setting.[24] The net effect is fewer resources and patients that are available for academic clinical research.

Clinical investigators at these institutions are leaving the field, diminishing basic and applied biomedical research and development capabilities: These developments have increased pressures on clinical researchers who perform their work in AMCs. Physician-investigators provide unique creativity and insight because they bridge science and clinical application. Insufficient training and numbers of such investigators have been recognized as a long-standing problem in the U.S. biomedical research system. This is now particularly important in light of the revolution in genetic and molecular biology requiring translation into understanding

Chart 30:

Pressure on AMC Clinical Revenue May Affect Institutional Support for Research



Source: Mechanic, Robert. Allen Dobson, Ph.D. Sylvia Yu. *The Impact of Managed Care on Clinical Research: A Preliminary Investigation*. Final Report. Public Health Service. National Center for Research Resources. http://www.ncrr.nih.gov/newspub/mancare.htm.

disease states, as well as the ability to conduct research into clinical outcomes, health service delivery, and epidemiology needed to achieve quality care.

AMC investigators now feel pressured to shift time away from research to clinical care in order to make up revenue shortfalls. Time and resources for clinical research training are also decreasing. While changes in the U.S. health care system are recent and the time course for research is long, two recently published studies suggest that both exert significant impact. The first suggests that institutions in areas of high managed care penetration have a trend towards less investment in research, as measured by decreased dollar growth, compared to those in low managed care markets (Charts 31a and 31b).[25] The same study shows an outright decline in number of investigator-initiated grant awards to clinical department in affected institutions. A second study indicates that young clinical researchers in high vs. low managed care markets published fewer scientific articles, while perceiving greater levels of departmental conflict and decreased cooperation and community.[26] These changes also threaten the formerly close bonds between clinical and basic researchers at AMCs, disrupting a human interaction so necessary to research. While these studies' findings are suggestive rather than conclusive, they could be considered a warning for the future given the early stage of health care change. Study participants reported that many of these investigators are now leaving clinical research. Such a loss would prevent the U.S. from realizing the benefits promised by innovation.

Payers are generally not an integral part of the innovation process: This loss would directly impact those organizations financing care. As noted, the U.S. health care system is experiencing

Charts 31a and 31b:

Research Activity May Be Affected by Managed Care

Chart 31a: NIH Awards to Medical Schools in Different Managed Care Markets from 1986 to 1995, based on Constant Dollars

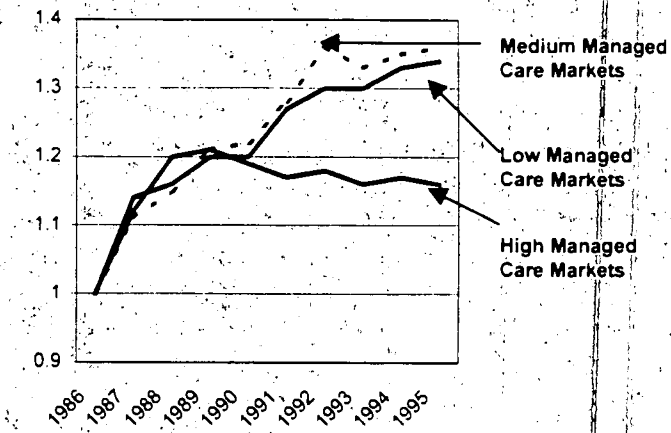
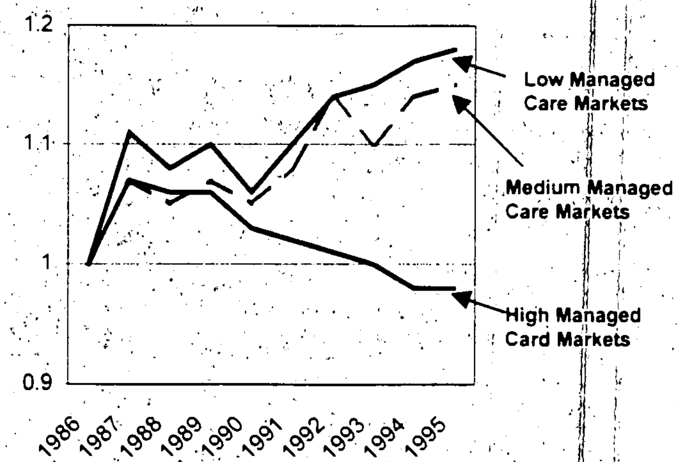


Chart 31b: R01 Awards to Medical Schools in Different Managed Card Markets from 1986 to 1995, based on Constant Dollars



Source: Moy et al. Unpublished data.

rapid changes and dislocations as it continues to reform and restructure. Managed care organizations (MCOs) have now become dominant players, yet evolution will continue and new forms of financing and delivering care can be expected to emerge. Driven by budgetary pressures, the role of federal and state governments as payers will also change as the shift of Medicare and Medicaid patients toward managed care accelerates. Regardless of what forms and functions payers take in the future, demands for quality of care will remain. With some notable exceptions, most private payers have not been heavily involved in the innovation process. Some organizations have internal research efforts and assets; improvements in the numbers and capabilities of MCO researchers offer new opportunities.[27] As the basis for competition shifts from cost to quality, payers also will have a long-term interest in innovation. Participants noted that MCOs have assets, such as patient access and clinical data, that are critical to conducting health services and outcomes research. The key challenges noted were how to bring them into the web of innovation, while at the same time allowing AMCs to make fundamental changes necessary to adapt to the rapidly evolving health care system. The success of some AMCs in adopting to changing market forces is encouraging. However, changes must occur in ways that do not compromise innovative capabilities.

3. **The physical and informational technology infrastructure for research, along with IT training, is inadequate for meeting today and tomorrow's needs.**

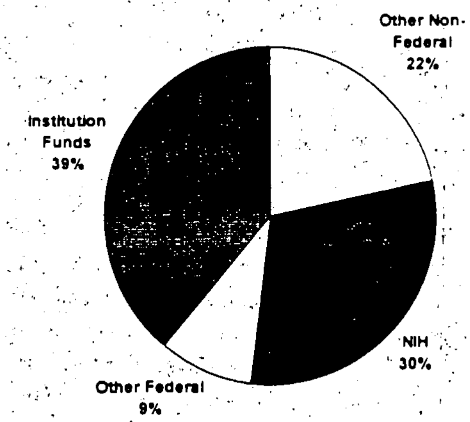
Recent investment in academic research facilities and equipment has been insufficient: If scientists provide the intellect for basic and clinical research while universities: research institutes, government laboratories, and private firms provide the funding and sites, infrastructure provides the actual means to conduct this work. Study participants reported that investment in physical facilities and equipment at universities and medical centers has been inadequate, with increased pressures for cost-sharing coming at a time when these institutions are financially pinched. Rapid scientific advances are also changing and raising resource requirements. NIH and other federal research project grants have not adequately reimbursed institutions for overhead expenses. Industry collaborations similarly have been project-oriented. Some specific programs, such as the 75 general clinical research centers (GCRS) located at various universities have been funded at levels below those approved by the National Center for Research Resources Advisory Council. State governments providing large amounts support for the public university infrastructure have also been unable to keep pace with rising facility and instrument/equipment expenses of increasingly complex, multi-disciplinary science. A long-term strategy for physical infrastructure support is necessary.

Health care information technology infrastructure, resources, and training are inadequate for today and tomorrow's needs: Equally important as buildings and equipment is the information technology (IT) infrastructure and personnel that support research efforts. The information technology revolution is raising new opportunities for health care innovation and education. Examples include the sharing of genomic databases by centers around the world, the use of computerized data in clinical trials and FDA submissions, analysis of clinical data for epidemiology and health services research, and high quality health information now available on the Internet. Coupled with emerging advances in

Chart 32:

Source of Funds for the Purchase of Academic Research Instruments in the Biological Sciences: 1993

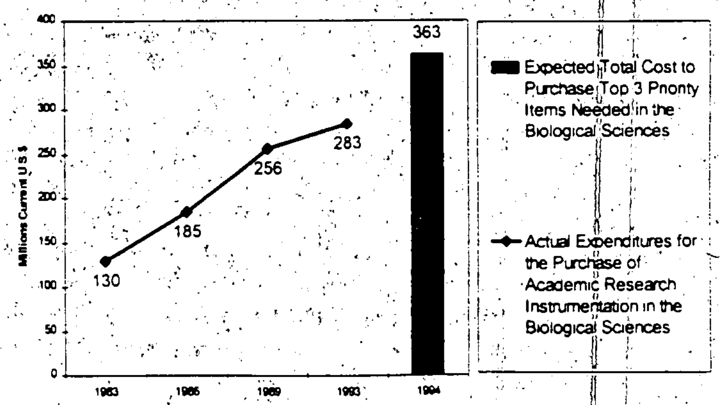
Total Amount: $283 million



Source: Academic Research Instruments and Instrumentation Needs in the Biological Sciences. National Institutes of Health. 1994.

Chart 33:

Current Expenditures on Instrumentation Not on Track to Meet Top 3 Priority Items in the Biological Sciences



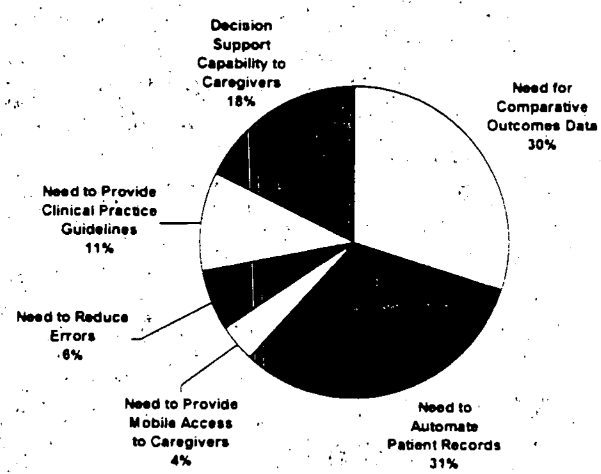
Source: Academic Research Instrumentation and Instrumentation Needs in the Biological Sciences. National Institutes of Health. 1994.

diagnostic technologies such as gene chips. IT has tremendous potential for improving health care quality.

Health care, however, has been a laggard compared to other sectors in leveraging the IT revolution.[28] Study participants reported several shortcomings. Pharmaceutical and biotechnology companies struggle with enormous volumes of data related to gene sequences, molecular biology, and potential medicines (bioinformatics). Clinical health services and epidemiology researchers are often not able to access, analyze and share information from databases that is necessary to develop evidence-based medicine. This is due to databases' often proprietary nature, lack of accepted standards and metrics for reporting clinical data, and incompatible software systems. Inadequate investment and understanding of information technologies by many providers is another issue. Insufficient numbers of the best IT personnel in health care vs. finance and other fields represent a critical bottleneck, with the need for more education and training cited as critically important. Finally, much health information available to the public via the Internet is from questionable sources and of dubious validity[29]—and developing methods to evaluate such information is difficult.[30]

These IT shortcomings threaten to slow the rate of research, innovation and education necessary to improve health care. They also undermine the potential to export health services innovation, missing an emerging opportunity for further U.S. leadership in innovation. Finally, poor quality medical information disseminated via the Internet could undermine the ability of patients to act as better partners in maintaining their own health.

Chart 34:
Multiple Factors Are Driving Health Care IT



Source: 1996 Annual HIMSS/Hewlett-Packard Leadership Survey.

4. The incentives and environment for investment in innovation have not kept pace with rising costs and risks

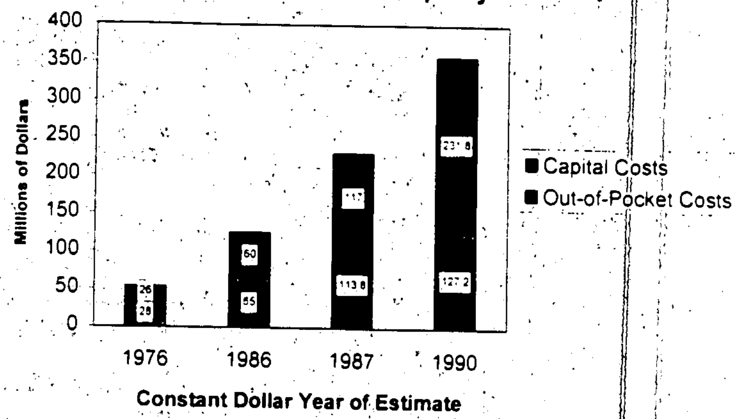
The costs and risks of research and innovation are rising: While people and institutions provide the source and means for innovation, proper incentives ensure that scientific and technological advances are applied to real health care needs in ways desired by society. The U.S. has had a favorable environment supporting such applications, yet study participants expressed concern that policies have not kept up with the rising costs and risks of innovation and commercialization (Charts 35 and 36). Several forces are driving increased costs and risks of pharmaceutical R&D and commercialization:

- Greater number and complexity of underlying technologies such as genomics and combinatorial chemistry now used to discover new medicines
- More complicated, chronic diseases are now targeted, with longer trials involving more patients
- Data requirements for regulatory approval have increased
- Greater branded and generic competition, with shorter effective product lives during which to recoup investment
- Rising investment requirements for the global commercialization of products

Rising costs and risks of R&D coupled with a more competitive international commercial environment have altered the risk/return ratio. The wave of consolidation sweeping the pharmaceutical industry is evidence of the changing underlying economics (Chart 37, next page). This trend highlights the importance of continued innovation for survival. If companies are unable to develop innovative new medicines that create the

Chart 35:

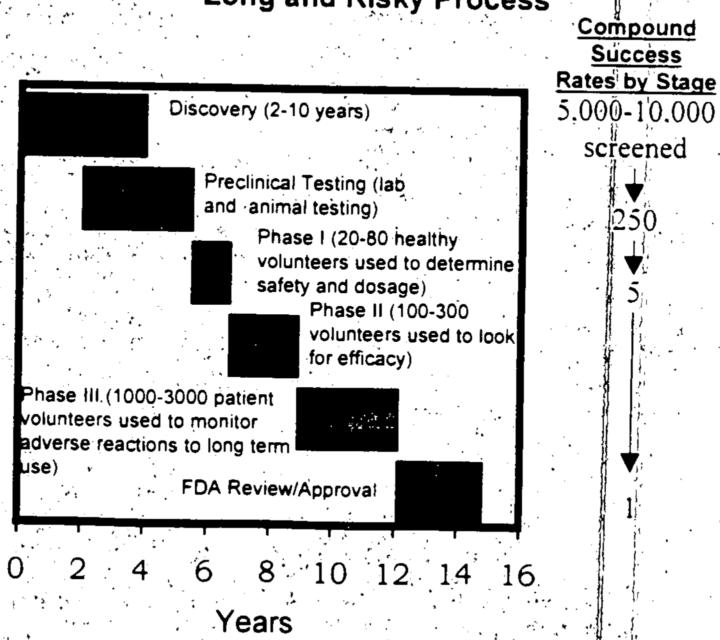
The Cost of Developing Medicines Has Grown Rapidly



Note: costs are in yearly current dollars, and durg development costs have likely increased further in real terms.
Source: Hansen, 1979. Wiggins, 1987. DiMasi, 1991; Office of Tecnology Assessment, 1993.

Chart 36:

Bringing Medicines to Patients Is a Long and Risky Process



Source: PhRMA, based on data from the Center for the Study of Drug Development, Tufts University, 1995.

revenue base to support further research, they may be forced into cost-cutting mergers. Several study participants felt that research would suffer, U.S. firms would be adversely impacted, and society would lose valuable benefits unless key aspects of the U.S. and global innovation milieu are addressed.

Intellectual property developments could make scientific investigation more difficult while decreasing investment returns at a time of rising costs and risks: Developments in patenting practices and enforcement were noted to have powerful effects on research and innovation. One key issue is the patenting and exclusive licensing of basic research tools not specifically related to products. The granting of broad patents relevant to basic research tools such as gene sequences could slow or potentially block whole areas of research if access is unreasonably denied or restricted. Such developments could also substantially raise infringement risks and costs of product development in related areas, to the point of stopping research altogether.

A decreased window for recouping investment is another concern. Conditions have changed markedly since enactment of the Hatch-Waxman Act in 1984. Effective product patent lives are shorter due to longer development times and more rapid and intense branded-generic competition (Chart 39, next page). At the same time, investment requirements and risks have increased.

Finally, the lack of effective patent protection for pharmaceutical products in many emerging nations, from inadequate enforcement to outright piracy, is a key challenge. The total lack of protection for proprietary data submitted to regulatory authorities in most countries of the world, and the often-inadequate periods of

Chart 37:

Pharmaceutical Industry Consolidation Continues

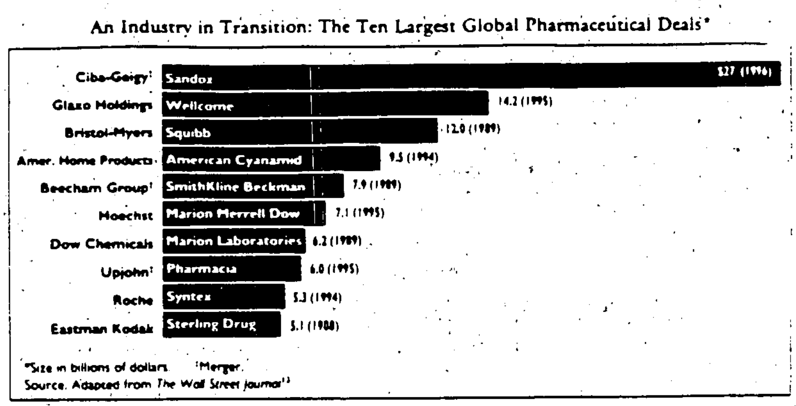
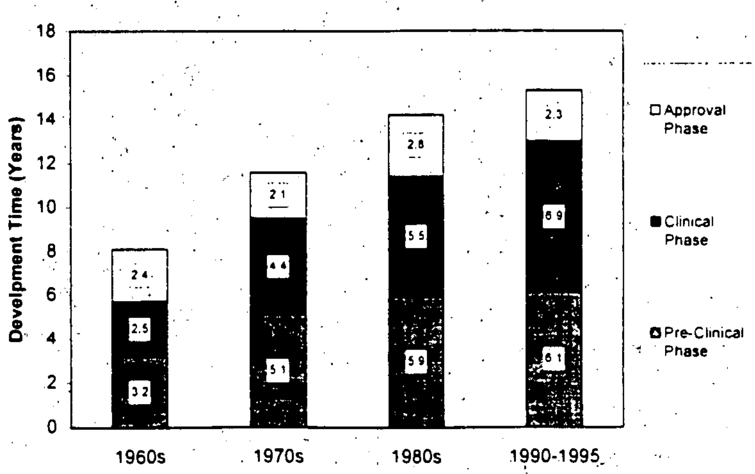


Fig 5. In the past 8 years alone, over $200 billion has shifted as mergers and acquisitions have occurred in the pharmaceutical industry

Source: Adapted from the *Wall Street Journal.*

Chart 38:

The Time Required to Develop New Medicines Has Increased



Source: Tufts Center for the Study of Drug Development, 1997.

registration data exclusivity (where it is provided at all) are impediments to innovation. Along with other trade barriers, these deficiencies have been estimated by the Pharmaceutical Research and Manufacturing Association to cost U.S. pharmaceutical firms $5 billion in lost additional revenues annually.

Regulatory issues add further risk and uncertainty to innovation: The recent passage of the FDA Modernization Act of 1997 was seen as a major event addressing several longstanding issues (Chart 40). Concerns of study participants centered on successfully implementing its measures to preserve and extend the benefits of more efficient processes, while ensuring that the FDA has adequate resources in areas such as IT. Some participants reported continued issues in non-pharmaceutical technologies, particularly with medical devices, where unpredictability in current regulatory practices was reported to discourage innovation. The need to find balance between maintaining high standards that encourage excellence, while avoiding inhibition of investment, is a shared sector objective.

Rising global opportunities, coupled with the need to recoup investment over a shorter time frame, were cited as reasons to continue pursuing international harmonization of regulatory requirements and processes. Having common criteria and procedures for the development, registration and manufacturing of medicines would decrease redundancy and costs, speed development of new therapies, and lower barriers to accessing international markets. Sharing data would also further these goals.

Tax incentives and trade policies related to innovation must be improved: Study participants noted that a major problem facing health care innovation

Chart 39:

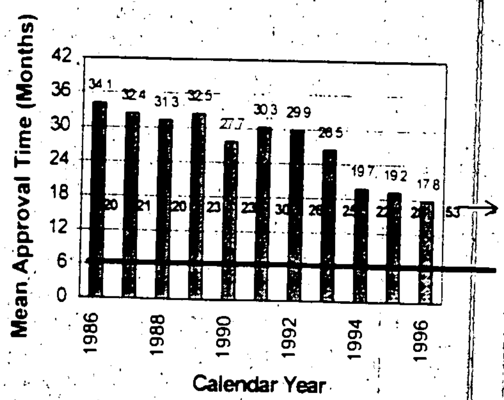
Patent Life Remains Below Historic Levels

Source:

Chart 40:

Regulatory Review Times Have Decreased

Mean Approval Times for New Drugs



Source: U.S. Food and Drug Administration, 1997.

is the fundamental conflict between long development and pay back time requirements vs. short-term financial market demands from investors. Tax incentives provide a means to address this conflict, with the R&D tax credit particularly helpful. Despite its importance, the R&D tax credit has been temporary, requiring periodic repassage. Study participants felt that making the R&D tax credit permanent would decrease uncertainty and increase research investment. A recently released study by Coopers and Lybrand predicts that a permanent R&D tax credit would add $3.8 billion in 1998 dollars to research investment by pharmaceutical companies over the next 12 years.[31] Removing disincentives in the current tax code for U.S.-based firms to conduct R&D in the U.S. was also cited as desirable.

5. Public support for legitimate biomedical research and its clinical applications may be undermined by rapid technological changes that are raising fears of misuse

Recent developments have raised the public's anxieties about emerging biomedical technologies: Support by the American public has long been essential to medical research and innovation. Americans have supported public and private funding of research, participated as patients in clinical trials, and accepted new therapies. This support will be even more important in a future when empowered patients face increasingly complex technologies that offer more choices.

Recent public reactions to developments in biomedical technology could undercut support for research. The most acute concern has been over the potential extension from animal cloning technologies to creating new human beings. Fears of potential genetic and other medical information-based discrimination for employment and insurance are another concern. Patient confidentiality is also becoming an important issue with the increasing use of electronic databases and pending availability of genetic and other potential markers for disease. Patients fearing misuse of information may avoid participating in clinical trials. Unless these concerns are addressed in a way that maintains public trust in researchers and care providers, the conduct and application of biomedical research will be jeopardized. The enormous positive potential of these new technologies to improve diagnosis and treatment of disease could be lost if they are overshadowed by fear. These fears are worsened by a generally poor understanding of the biomedical research process and its specific content, which also threatens the role of patients as informed partners in their own health care.[32]

Governments are considering responses that could threaten legitimate research: Reflecting the concerns of their constituents, public officials at federal and state levels have reacted to recent developments by drafting and pushing legislation intended to prevent potential abuses of science. The possibility of cloning of human beings has attracted the most attention, but genetic discrimination and patient confidentiality are also areas of legislative attention. While seeking to prevent the real abuse of cloning entire human beings, the effect of some anti-cloning legislation could be to prevent important cell and tissue research needed for developing new therapies. Areas of research and development ranging from understanding degenerative diseases to developing skin implants for burn patients could be affected or even prevented. A recent letter from the American Society for Cell Biology, signed by 27 Nobel laureates, stressed the risks that such legislation poses to legitimate basic biomedical research. Similarly, while the confidentiality of specific patient-identifiable information must be maintained, failure to use medical records and tissue samples in important disease, epidemiology and health services research could prevent development of better treatments and evidence-based medicine. Fears of genetic discrimination could derail clinical use of information that could improve prevention and help guide treatment. The key question guiding any policy response is how to best address the public's concerns about misuse while preserving legitimate research and clinical applications.

These concerns are not overstated. Germany is just now emerging from the impact of anti-genetic technology laws that seriously retarded its biotechnology research and commercialization for two decades. These laws were passed in response to past abuses of science and fears that emerging technologies posed new dangers. Similar concerns were voiced in the United States in the 1970's about recombinant DNA technology. Fortunately, guidelines were developed and restrictive legislation avoided, allowing the great progress that produced benefits for patients. Today's situation calls for similar prudent and carefully considered responses to issues raised by rapid technological advances.

Final Thoughts

Concerns about health care innovation and its application within the United States should not obscure two basic points. Health care innovation has tremendous power to improve our lives, and the U.S. is operating from a position of strength. Change by doing things better is the only answer to health care and related problems, and American leadership in the global health care innovation ecosystem is required to find solutions. This report offers some preliminary recommendations to frame the debate for change. Yet the specific responses to challenges noted in this study must be guided by a broader vision for innovation, a vision founded on the hopes for the society that we want for our generation and those that succeed us. Thoughtful policies and farsighted investment so grounded can strengthen and extend our innovative capabilities. Such responses will speed the development of new ways of improving health, producing individual and social gain while preserving and enhancing basic human values. Provided that the right steps are taken at this critical crossroads of scientific and social change, the case for our future is bright.

Recommendations

Action is Necessary to Secure the Future

These recommendations represent a starting point for discussion. They are directed and apply to all levels of government, academia and industry because each must play a role in improving the U.S. health care research and innovation system.

1. Increase Support for Basic Research

The Federal Government should:

- Implement proposed increases in federal funding for NIH to meet the twin challenges of increased research opportunities and looming long-term health care problems.

- Increase federal funding for other basic sciences and engineering both for their intrinsic contributions to the science base and their importance to health care innovation

- Revise immigration practices to allow the U.S. to attract and retain the best students and researchers globally and to promote cross-border collaborations and facilitate a free exchange of ideas

Universities should:

- Increase multidisciplinary education to realize the potential of emerging technologies

Industry should:

- Create more opportunities for exposure to industrial R&D for researchers-in-training to provide an enhanced educational experience and produce more innovative researchers

In collaboration, government, industry and academia should:

- Improve primary and secondary education in science and math to provide continued new talent for research careers

- Increase support for internships, graduate or post-doctoral positions and fellowships in interdisciplinary fields to provide the human resource necessary to develop and apply emerging technologies

2. Save Clinical Research

The federal and state governments should:

- Increase support for training of clinical researchers to sustain the capacity to develop and apply innovation in health care
- Carefully evaluate the impact of health care system policies (e.g. Medicare reform) on innovative capabilities to avoid or manage unintended and adverse consequences for clinical research
- Provide compensatory funding mechanisms for income lost from eroding cross-subsidies from clinical care at AMCs to research to ensure the continuation of superior clinical research
- Explore ways to develop more transparent and flexible public funding mechanisms for clinical research to increase efficiency and accountability while maintaining necessary levels of support

Academic Medical Centers should:

- Continue ongoing restructuring efforts to improve the efficiency of AMC care delivery to adopt to changing market needs and economic realities

In collaboration, government, industry, academia and managed care organizations should:

- Engage in collaborative clinical and outcomes research to leverage all parties' capabilities while addressing the core interests of each
- Develop personnel exchange programs between MCOs, AMCs and industry to transfer learning and promote mutual understanding
- Explore joint programs for the development of clinical researchers to provide important future resources to conduct necessary translation and outcomes research

3. Upgrade Physical and Information Infrastructure

The federal and state governments should:

- Work with universities to develop better methods to provide adequate reimbursement for overhead in public grants such a peer-reviewed grants specifically to fund research infrastructure

- Work with AMCs and research institutes to develop multi-use research facilities to address constrained instrumentation and overhead resources

- Incent unrestricted industry grants for academic infrastructure through tax incentives or other means

The federal government and industry should:

- Increase training for health care information workers through support of academic programs and continued education to ensure that new technologies can be applied

- Support public and private funding of gene research (pharmacogenetics) and other lab tests that provide information to facilitate clinical research and targeting of medicines to improve the speed and efficiency of research and actual patient care while decreasing costs

In collaboration, federal and state governments, industry, MCOs, AMCs should:

- Provide high quality, credible information to the public via new electronic media to allow for informed discussion of issue and improved patient involvement in their own care

- Jointly develop standards for basic research and clinical information sharing to ensure compatibility and to promote sharing and use of data for important research applications while maintaining adequate data security and patient confidentiality

4. Improve Incentives for Innovation

The federal government should:

- Continually assess whether the patent life of innovative medicines is sufficient to warrant significant incentives for investment in long-term, high risk R&D, particularly in light of dramatic changes in the health care environment since past laws were enacted

- Pursue enactment and enforcement of international patent protection and of registration data exclusivity to allow recouping of investment necessary in an era of escalating technology development costs

- Promote a global business environment that provides for free market competition to provide a level playing where the competition is based on real innovation and value

- Continue regulatory reform (fast-tracking clinical trial requirements) to extend recent FDA reform benefits

- Continue dedicated FDA user fee funds to continue improving the efficiency of review of new treatments and getting them to patients sooner

- Pursue international regulatory harmonization to improve overall speed, efficiency and costs of developing new therapies

- Pass a permanent U.S. R&D tax credit to provide an incentive for needed innovation

Universities should:

- Remove disincentives for faculty to participate in the innovation process (conflict of interest and disclosure ambiguities) to facilitate more rapid technology transfer

Industry should:

- Work in collaboration with government and universities on efforts to improve the efficiency of technology applications.

5. Maintain Public Support for Biomedical Research

Federal and state governments should:

- Avoid enacting restrictive laws governing medical research which could seriously slow or even prevent basic advances being made or translated into needed new treatments while, at the same time maintaining public protections

In collaboration, industry, academia, governments, and MCOs should:

- Provide the public with factual, balanced and high quality information in order to have a meaningful and informed discussion of issues related to the application of new technologies, including genetics

- Improve primary and secondary education in science and math to improve general public understanding of, and participation in emerging biomedical science issues and critical evaluation of information sources such as those available on the Internet

- Jointly develop research guidelines for information which safeguards patient identifiable information but preserves the ability to conduct important biomedical research in order to maintain public trust and support of biomedical research

- Strengthen the peer review process to preserve rigor, accountability and public trust

Health Sector Biographies

Industry Chair:

Dr. George M. Milne, Jr., President of Pfizer Central Research and Animal Health and Vice President of **Pfizer Inc**, is responsible for guiding the company's worldwide pharmaceutical drug discovery and development efforts. He also oversees research collaborations with the entrepreneurial and academic research communities. Dr. Milne received his B.S. in chemistry from Yale University and his Ph.D. from MIT. He attended Stanford University for post-doctoral study in chemistry and the Medical College of Virginia for pharmacology postgraduate training.

Sector Leaders:

Dr. Stephen E. Yoder is Director, Corporate Strategic Planning at Pfizer Inc in the Corporate Strategic Planning & Policy Division, where his activities focus on issues related to research and innovation. He received a B.S. in Biology from Bucknell University and a M.D. from the University of Virginia. After completing a residency at Pennsylvania Hospital in Philadelphia, he served there as an attending physician for the resident's teaching service prior to entering the Wharton School, where he received an MBA with a major in health care management.

Dr. Walter Kuemmerle is an Assistant Professor of business administration at the Harvard Graduate School of Business. An alumnus of the Harvard Graduate School of Business, the Koblenz School of Corporate Management, and the École Supèrieure de Commerce de Lyon, Dr. Kuemmerle's research interests include the management of technology and innovation in the United States, Japan and Europe. He has published extensively on the globalization of R&D, with an emphasis on the pharmaceutical and biotechnology sectors and has worked for several international health industry leaders.

Health Sector Study

Industry Chair

George M. Milne, Jr.
Pfizer Inc

Sector Leaders

Stephen E. Yoder
Pfizer Inc

Walter Kuemmerle
Harvard Business School

Members

Steve Fodor
Affymetrix, Inc.

Gordon Binder
Amgen Inc.

David Ebsworth
Bayer Corporation

Leon Rosenberg
Bristol-Myers Squibb (retired)

Karl J. Hittelman
University of California, San Francisco

James Blair
Domain

Charles E. Putman
Duke University

Diana MacArthur
Dynamac Corporation

August M. Watanabe
Eli Lilly and Company

Dennis Henner
Genentech, Inc.

James E. Neidel
Glaxo Wellcome plc

Dennis Purcell
Hambrecht & Quist

Thomas Hofstaetter
Hoechst Marion Roussel Inc.

Purnell W. Choppin
Howard Hughes Medical Institute

Randal W. Scott
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David J. Skorton
University of Iowa

William Brody
Johns Hopkins University

Robert Z. Gussin
Johnson & Johnson

J. Patrick Fitch
Lawrence Livermore National Laboratory

Sandra Zink
Los Alamos National Laboratory

Hans Frauenfelder
Los Alamos National Laboratory

André L. Lamotte
Medical Science Partners

Bennett Shapiro
Merck & Co., Inc.

Lana Skirboll
National Institutes of Health

Paul Herrling
Novartis Pharma Ltd.

Frederick W. Telling
Pfizer Inc

Edwin L. Behrens
The Procter & Gamble Company

Barbara A. Piette
Schroeder Ventures Life Sciences

Richard Lerner
The Scripps Research Institute

Kevin Kinsella
Sequana Therapeutics, Inc.

George Poste
SmithKline Beecham

Gerald R. Fink
The Whitehead Institute for Biomedical Research

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Going Global: Information Technology

DRAFT

Industry Co-Chairs: Maurice Holmes
Paul Horn

Sector Advisor: Don Smith

Information technology (IT) industries have tremendous importance, not only in their own right, but also to the future of the U.S. economic enterprise. It's not just that the industry—computers, electronics, communications, software and services—represents a tremendously large and growing fraction of high wage jobs, exports and national wealth (Charts 1 and 2). Rather, information technologies are irrevocably transforming lives and jobs in virtually every sector of the economy.

Everything from computers to cars to coke dispensers is potentially an info-machine—not only controlled by information technologies but also linked to a global information network. The time when coke machines can communicate their inventory needs directly to suppliers and cars can be remotely diagnosed (perhaps even remotely repaired) is fast approaching. Throat swabs will identify germs genetically and transmit a patient's information directly to a pharmacy's computer. So pervasive and profound are the opportunities that the Information Revolution is difficult to conceptualize, much less summarize.

National leadership in the technologies and applications that drive the Information Revolution is critical. The perception among participants in the sector study, however, is that the foundations of strength in the United States are not as solid as they must be to sustain IT preeminence. The emergence of world-class competition, the pace of technology churn, and the inadequacy of the national investment in IT-related research and human talent are creating some longer-term vulnerabilities. The global environment for IT is likely to be unforgiving; if lost,

Chart 1:

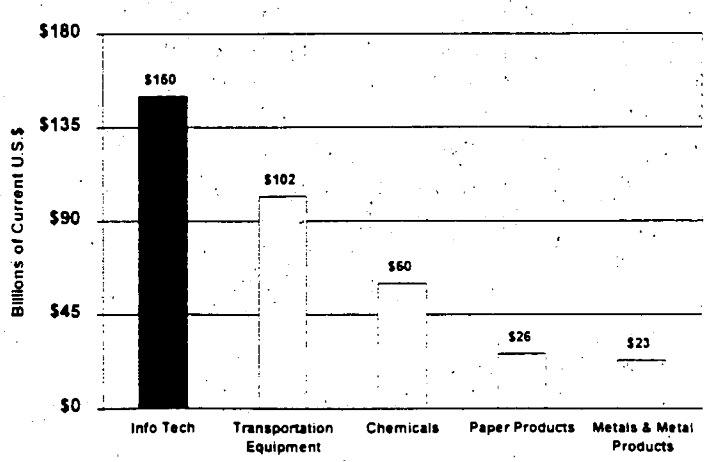
IT Has Enormous Economic Impact

- **The U.S. IT Industry Represented 6.1 Percent of U.S. GDP in 1996.**
- **The U.S. IT Industry Employed 4.3 Million Workers in 1996.**
- **The U.S. IT Industry Created Close to 250,000 New Jobs between 1995 and 1996.**
- **The IT Industry's 1996 Average Wage Was 73 Percent Higher Than the Average Private Sector Wage.**

Source: AEA and NASDAQ. *Cybernation*. 1997.

Chart 2:

Information Technologies Lead U.S. Exports



Source: AEA and NASDAQ. *Cybernation*. 1997. P. 61.

neither U.S. leadership nor jobs will be readily recaptured.

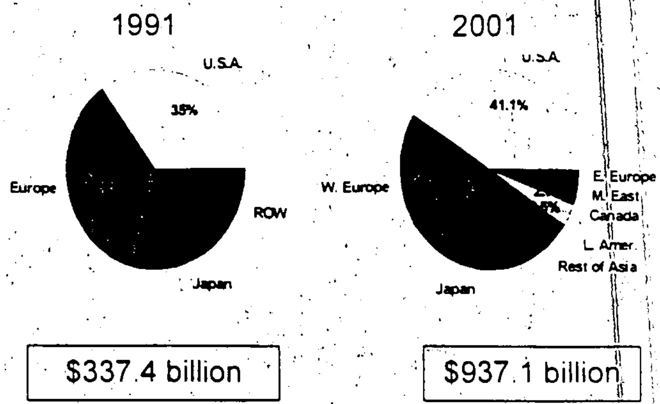
WHERE WE STAND

There is no end in sight to growth in global demand for hardware, software, applications and services. Total spending on IT is large and growing around the world in total dollars and as a percentage of GDP (Charts 3 and 4). For example, the total worldwide market for software alone is predicted to double between 1996 and 2001—from $105 to $203 billion.[1] Worldwide spending on personal computers/single-user systems is expected to grow from $203 billion to $300 billion between 1996 and 2000.[2]

Although exports are large and growing, the U.S. IT trade deficit starkly highlights the fact that we do not stand apart from the competition to capture wealth-creating investments in IT technologies, manufacturing and services (Chart 5): European countries are investing strongly in both regional R&D consortia and in national IT infrastructures. Throughout Asia, emerging economies are targeting information technology as a key industry for development (Chart 6, next page).

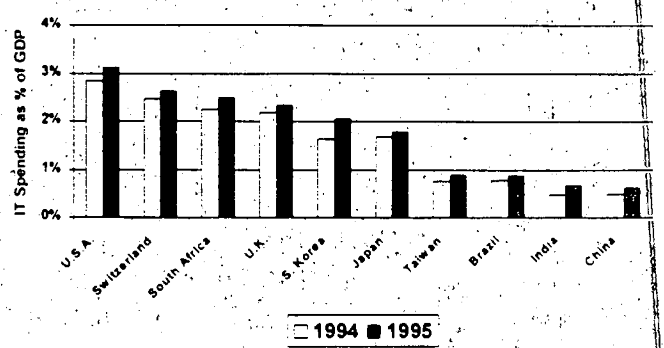
The barriers to entry and growth of non-U.S. players are likely to be smaller in the future than they were in the past. Investment requirements are lower than they were for hardware products. Technology churn is faster, providing more frequent entry opportunities. Intellectual talent is available globally. The Year 2000 challenge is likely to provide creative insight into software applications, traditionally a key U.S. advantage, to the emerging centers of excellence around the world that are rewriting codes.

Chart 3:
Worldwide IT Spending by Region Is Exploding



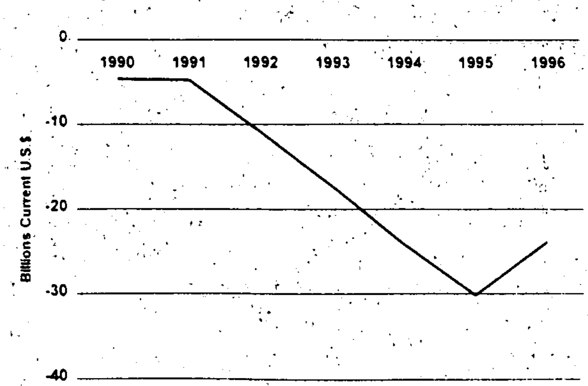
Source: *The Gray Sheet*. International Data Corporation. 1997.

Chart 4:
Many Countries Are Targeting IT as a Key Sector



Source: *The Gray Sheet*. International Data Corporation. 1997.

Chart 5:
Despite its Leadership, U.S. IT Trade Is in Deficit



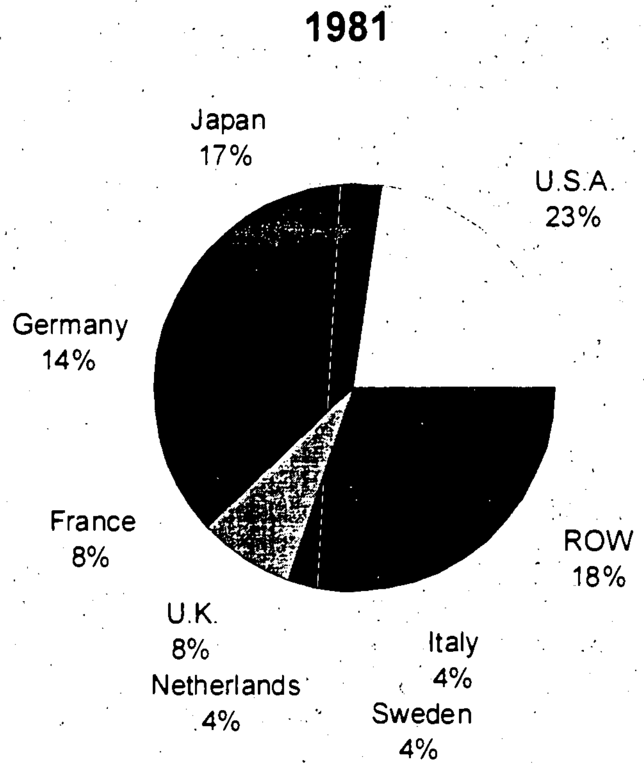
Source: AEA and NASDAQ. *Cybernation*.

TO LOCATE

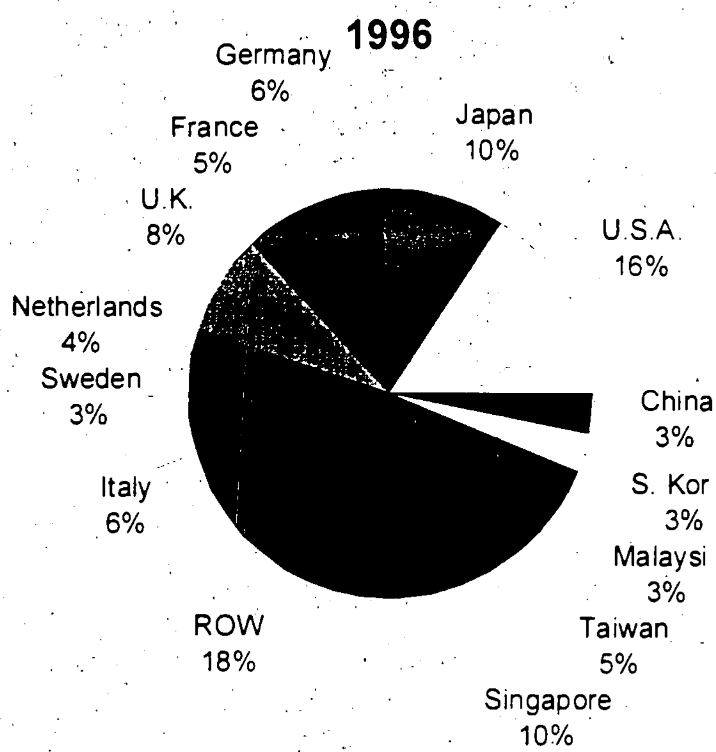
[2] International Data Corporation. *The Gray Sheet*. January 15, 1997. Vol. 31. No. 21. P. 3.

Chart 6

The United States Still Holds the Largest Single Share in Hardware, Equipment and Communications Exports—But the Global IT Market Is Exploding and Barriers to Entry Are Falling.



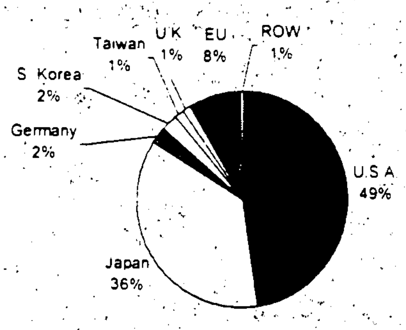
$43.1 Billion



$303.5 Billion

Chart 7:

United States Dominates IT Patents

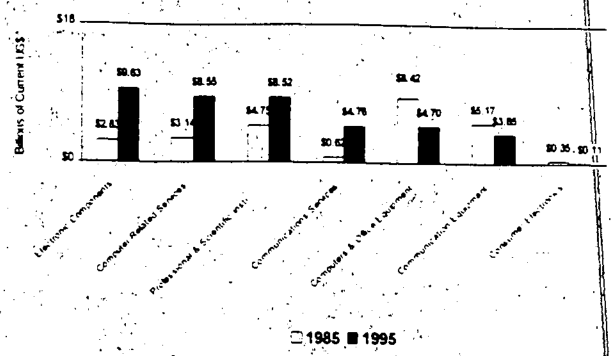


Total IT Patents, 1992-1996: 65,583

Source: CHI Research, Inc.

Chart 8

On Balance. U.S. Company Funds for IT R&D Are Increasing



Source: The Gray Sheet. International Data Corporation. 1997.

Chart 9:

Top 20 IT Firms by R&D Expenditures, 1995 (billions U.S.$)

Chart 10:

Top 20 IT Firms by R&D Intensity, 1995 (R&D as a percent of sales)

Siemens	Germany	$2.075	**Adobe Systems**	USA	18.2%
Hitachi	Japan	$1.945	**Cray Research**	USA	18.2%
AT&T	**USA**	$1.518	**Novell**	USA	18.0%
Matsushita Electric Industrial	Japan	$1.496	**Advanced Micro Devices**	USA	16.4%
IBM	**USA**	$1.383	**Lotus Development**	USA	16 4%
Nippon Telegraph & Telephone	Japan	$1.242	SAP	Germany	16.3%
Toshiba	Japan	$1.196	Ericsson	Sweden	15.3%
NEC	Japan	$1.053	Northern Telecom	Canada	14.8%
Sony	Japan	$.946	**Microsoft**	USA	14.5%
Ericsson	Sweden	$.929	**Analog Devices**	USA	14.3%
Alcatel Alsthom	France	$.909	**Tandem Computers**	USA	14.2%
Motorola	**USA**	$.897	**DSC Communications**	USA	13.4%
Mitsubishi Electric	Japan	$.655	**National Semiconductor**	USA	11.9%
Northern Telecom	Canada	$.644	**Silicon Graphics**	USA	11.1%
Robert Bosch	Germany	$.643	**Storage Technology**	USA	10.5%
Bell Canada	Canada	$.638	**Teradyne**	USA	10.4%
General Electric	**USA**	$.530	**Bay Networks**	USA	10.4%
Canon	Japan	$.495	**Amdahl**	USA	9 9%
Intel	**USA**	$.453	**3Com**	USA	9.8%
Sharp	Japan	$.453	**Intel**	USA	9 6%

Source: OECD. *Information Technology Outlook 1997*. Tables 1.23 and 1.24. P. 64.

Nonetheless, the widely held sentiment among sector study participants is that the United States remains at the top of the innovation chain in information technology. In sheer numbers of patents, our information technology sector dominates the world, accounting for nearly 50 percent of all IT patents filed in the United States (Chart 7, previous page).[3] The IT industry, led by electronic components, invested over $40 billion in R&D in 1995, more than a third of the nation's total business investment (Chart 8, previous page). U.S. IT companies rank the highest in the world in R&D intensity (Charts 9 and 10, previous page). These companies also dominate many segments of the global market and still account for 16 percent of total world exports in computers and office equipment, semiconductors and electrical components, and communications equipment (see Chart 6).

There are a number of factors that contribute to U.S. competitiveness:

Software and IT Services Leadership

Software is an industry in which the United States holds a particularly strong advantage. The software and computer services industries created more than 450,000 new jobs between 1990 and 1996.[4]

Hardware used to comprise the lion's share of the U.S. IT market but has declined as a portion of the market—a reflection of the steadily increasing demand for software and support (Chart 11). Industry respondents point out that software drives IT innovation. Hence, the U.S. lead translates into advantages for other sectors as well (See Express Transport and Logistics).

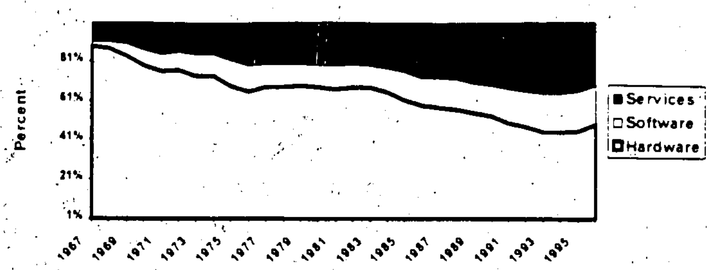
Entrepreneurial Culture

The United States features the premier innovation culture globally. Entrepreneurial

Chart 11:

Software and Services Are Gaining Share

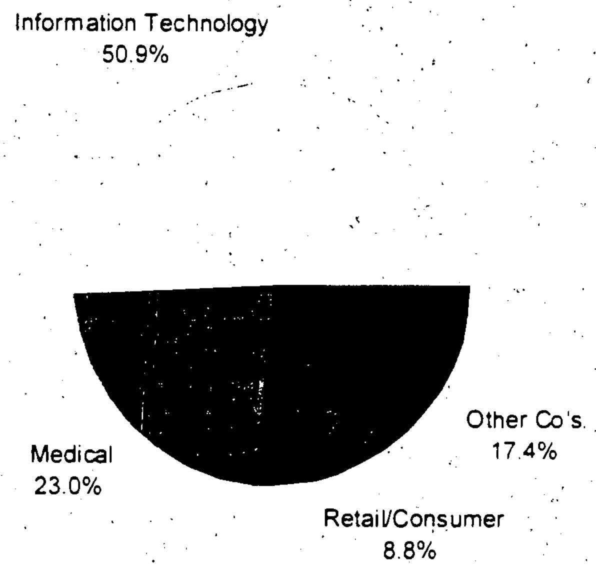
U.S. IT Spending



Source: *The Gray Sheet*, International Data Corporation.

Chart 12:

IT Dominates Venture Capital Investments



1997 Market Value = $12.2 billion

Source: Coopers & Lybrand L.L.P. *Money Tree Report 1997 Results*. P. 1.

[3] CHI Research, Inc. *Technological Competitiveness Analysis for Five Technologies in 15 Countries*. October 29, 1997. Table 1, p. 30.
[4] AEA and NASDAQ, *Cybernation*. 1997. P. 12.

talent, creativity and risk-tolerance provide the grease for the U.S. innovation machine. An integral part of this culture is our unique venture capital (VC) industry that helps to pull ideas out of universities and existing companies into new technology ventures. The majority of VC investment, in turn, is in the information sector (Chart 12, previous page).

Venture capital creates the reward mechanism through which innovators profit from their activity. This profit incentive, augmented by the financial discipline imposed by the VC process, drives a more rapid commercialization of new technologies.

Although other countries have tried to imitate the venture capital system prevalent in the United States, the lack of a tradition of private ownership in many countries inhibits successful transplantation of the VC model.

Market Size and Sophistication

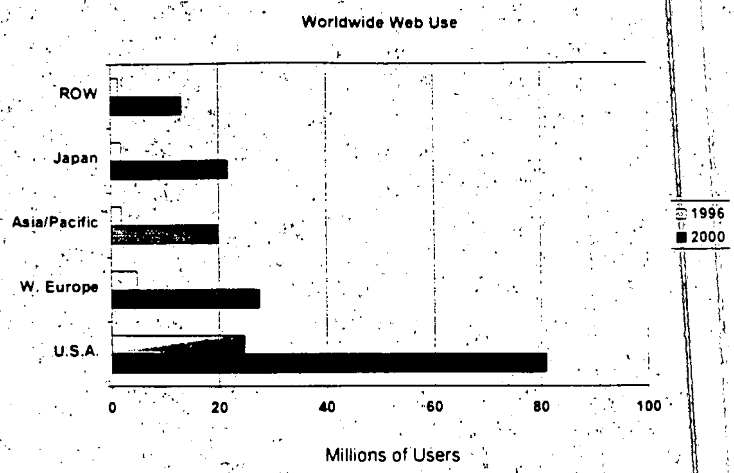
The fact that the United States constitutes the largest single market for IT products and services is a key draw for talent and investment. Both U.S. and foreign firms in the IT sector feel the need to have a presence in this market. Our large and demanding consumer markets provide abundant demand and opportunities for new information technology products and services (Chart 13).

World's Best Talent/ University Training

The U.S. ability to generate and attract the best technical talent from all over the world provides a key competitive edge. The talent pool is driven by the fact that the bulk of the industry is located in the United States along with world class universities that attract, train and graduate the best and brightest internationally (Chart 14). International competitors that have improved their positions vis-à-vis the United States have

Chart 13:

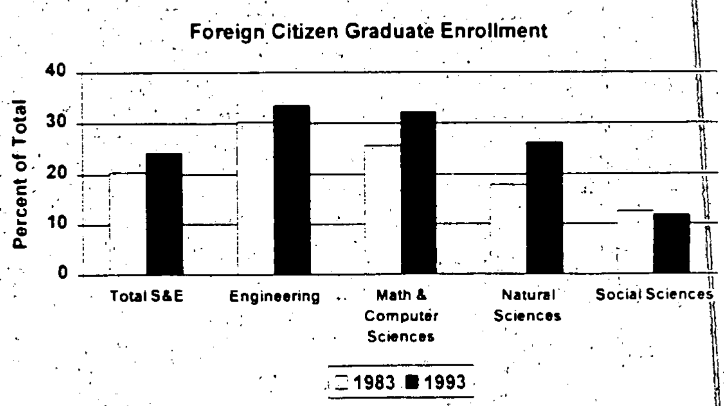
The United States Leads the World in Demand for IT



Source: *The Gray Sheet*. International Data Corporation. 1997

Chart 14:

U.S. Universities Attract Foreign Students



Source: NSF. *Science & Engineering Indicators—1996*.

done so primarily through the development of highly skilled human capital.

World's Best Research Universities

The ability to attract the best human talent to the United States is surely a function of the strength of the research platform and caliber of research.

The United States is one of the few countries in which research and education are combined—enhancing both the preparation of the students and the quality of the research. The diversity of world-class institutions creates a virtuous cycle of competition to expand the frontiers of knowledge.

Silicon Valley

Silicon Valley is unique globally, both in the presence of major competitors in the IT industry and in its ability to support innovative product development. Through its combination of industry scale and scope, strong universities, abundant VC and a risk taking culture, Silicon Valley is arguably the most important region for IT innovation anywhere in the world (Chart 15).

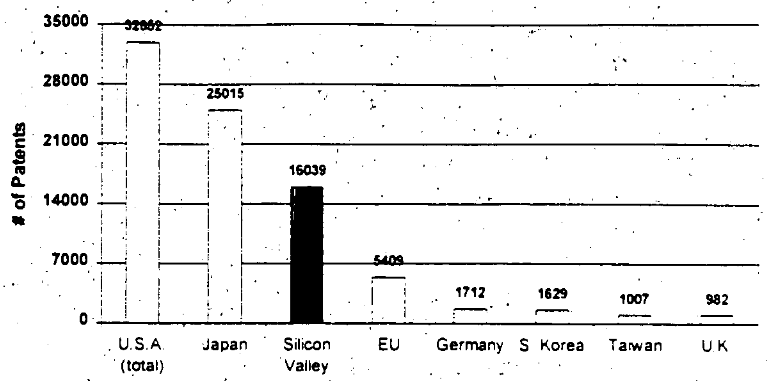
WHY INNOVATION MATTERS

There is a widespread sense that the U.S. lead, while strong, is not unassailable. In the global environment, the fundamentals of innovation are changing profoundly. The creation and application of knowledge are truly global for the first time. Companies have gained the tools to combine people, research and products into worldwide networks and operations.

Countries are leapfrogging generations of technological development in a matter of years. The pace of technology churn in the industry is so rapid that no industry leaders are complacent about sustaining an edge (Chart 16). Leadership can shift in a matter of generations—and in this industry, a generation can be less than 2 years.

Chart 15:

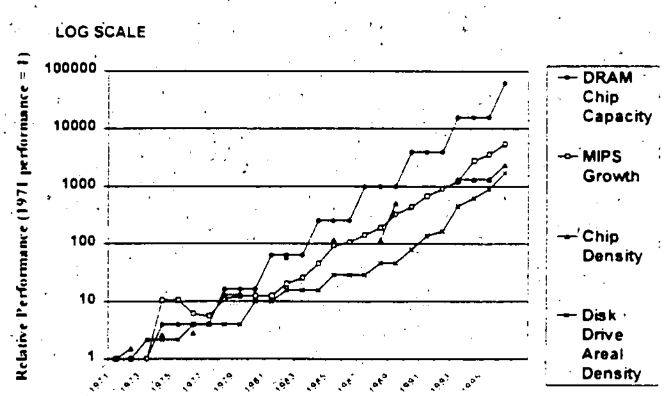
Silicon Valley Outperforms Many Countries in Patent Production



Sources: CHI Research, Inc. and U.S. Patent and Trademark Office.

Chart 16:

The Pace of Technological Change is Accelerating



Sources: The Gray Sheet, International Data Corporation, 1997; and, IBM internal data on disk drive areal density.

Moreover, the globalization of the IT industry has had a profound impact on where and how new products are introduced (Charts 17 and 18, next page). Even five years ago, the United States was the launch market of choice for virtually all IT products and services. This created an enormous strategic advantage since it drew product development and research teams into the United States from around the world. Today, product launches are beginning to be global and simultaneous; there are less compelling reasons for key personnel to be located in the United States.

Further, as IT industry operations disperse globally, job opportunities for the best and brightest are increasing overseas (Chart 19). There is less attraction for foreign graduates trained in the United States to work here when they can get a similar job at home. A growing number of U.S. trained scientists and engineers are opting to return home.

These changes do not diminish America's powerful advantages in IT, but they do point to some potential, emerging vulnerabilities.

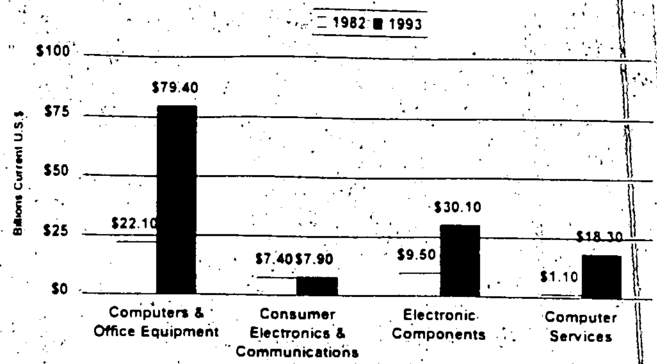
Emergence of New Competitors

According to the sector participants, the largest threat to the U.S. competitive position in IT is not that any one country will soon surpass it but, rather, that the number and sophistication of competing countries is growing. It is clear that a few competitors, South Korea and Taiwan in particular, are making the transition from imitator to innovator. Taiwanese IT patents filed in the United States increased 8,292 percent between 1986-1996, while South Korean patents increased by a staggering 40,625 percent during the same time (Chart 20, next page). At this rate of growth, these countries have already overtaken the UK in their presence in the U.S. patent system and are edging close to Germany.

At the same, other countries can threaten U.S. leadership by capturing the

Chart 17:

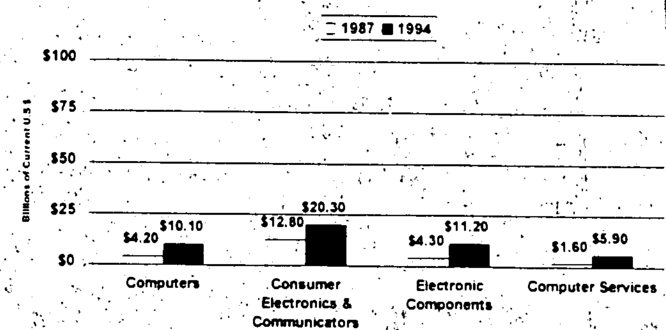
Sales of U.S. IT Affiliates Abroad Have Grown More Rapidly Than...



Source: OECD. *Information Technology Outlook*. 1997. P. 80.

Chart 18:

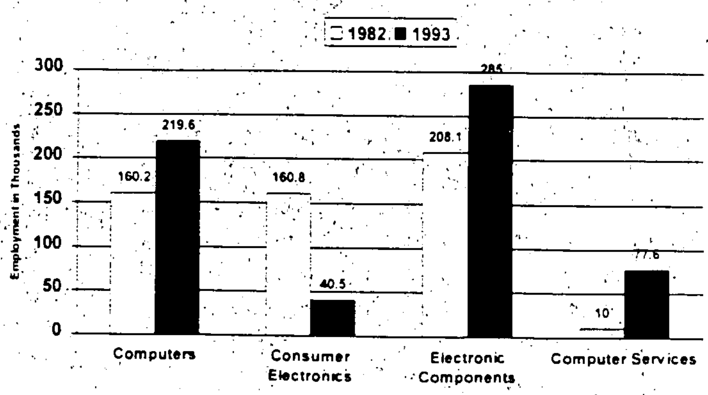
...Sales of Foreign IT Affiliates in the United States



Source: OECD. *Information Technology Outlook*. 1997. P. 84.

Chart 19:

Employment in Majority-Owned U.S. Affiliates Abroad Is Growing



downstream jobs and profits from innovative activity in the United States. The ability to innovate may be less important in some countries than the capacity to imitate—and a number of Asian countries are able to be fast-followers, even at the state-of-the-art. One of their advantages is cost (Chart 21). And, this kind of differential extends to manufacturing labor and scientists and engineers as well. Moreover, respondents to the industry survey indicated that the presence of incentives—R&D tax credits, incentives for investment in plant and equipment, worker training credits and one-stop regulatory shopping—were key elements in the decision to locate facilities overseas.

As manufacturing moves offshore, there is a growing tendency to co-locate certain types of research with manufacturing. The diminution of the U.S. IT manufacturing base has potentially far-ranging repercussions in two ways. First, there is concern that design superiority in electronics and software applications cannot be sustained in the absence of a strong and cutting-edge manufacturing capability. Second, U.S. manufacturing companies account for the vast majority of business research, about 73 percent. Service sector companies, which have much lower rates of investment in research, tend to focus on development and demonstration (D&D) rather than R&D. As manufacturing disperses globally, the amount and quality of R&D conducted in the United States may be adversely affected.

Short Term R&D Investment Focus

Although the industry's investment in R&D is increasing, there is concern that product development is overshadowing its investment in long-term research. This should not be surprising given the rate of technology churn in the industry. With product cycles ranging from months to a few years, it is difficult to allocate money to longer term R&D that may not fit into a

Chart 20:

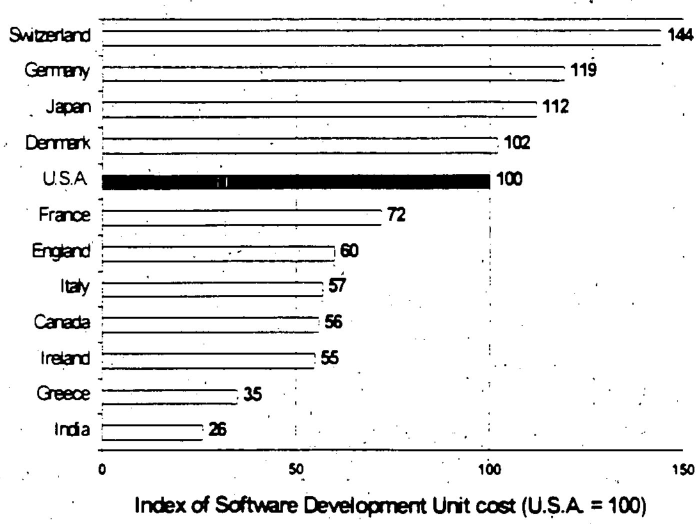
Emerging Economies Make the Transition from Imitator to Innovator

COUNTRY	# of IT patents filed in U.S.A., 1982-86	# of IT patents filed in U.S.A., 1992-96	% INCREASE
Germany	1304	1712	31%
EU	3373	5409	60%
UK	575	921	71%
Australia	37	80	116%
U.S.A.	13202	32852	149%
Japan	7012	25015	257%
Israel	53	258	387%
Singapore	1	82	8,200%
Taiwan	12	1007	8,292%
South Korea	4	1629	40,625%

Source: CHI Research, Inc. *Technological Competitiveness Analysis for Five Technologies in 15 Countries*. October 1997.

Chart 21:

The United States Faces Stiff Cost Competition in Software Development



Source: National Software Alliance. *Software Workers for the New Millennium*. January 1998. P. 2-17. Figure 2-8.

Chart 22:

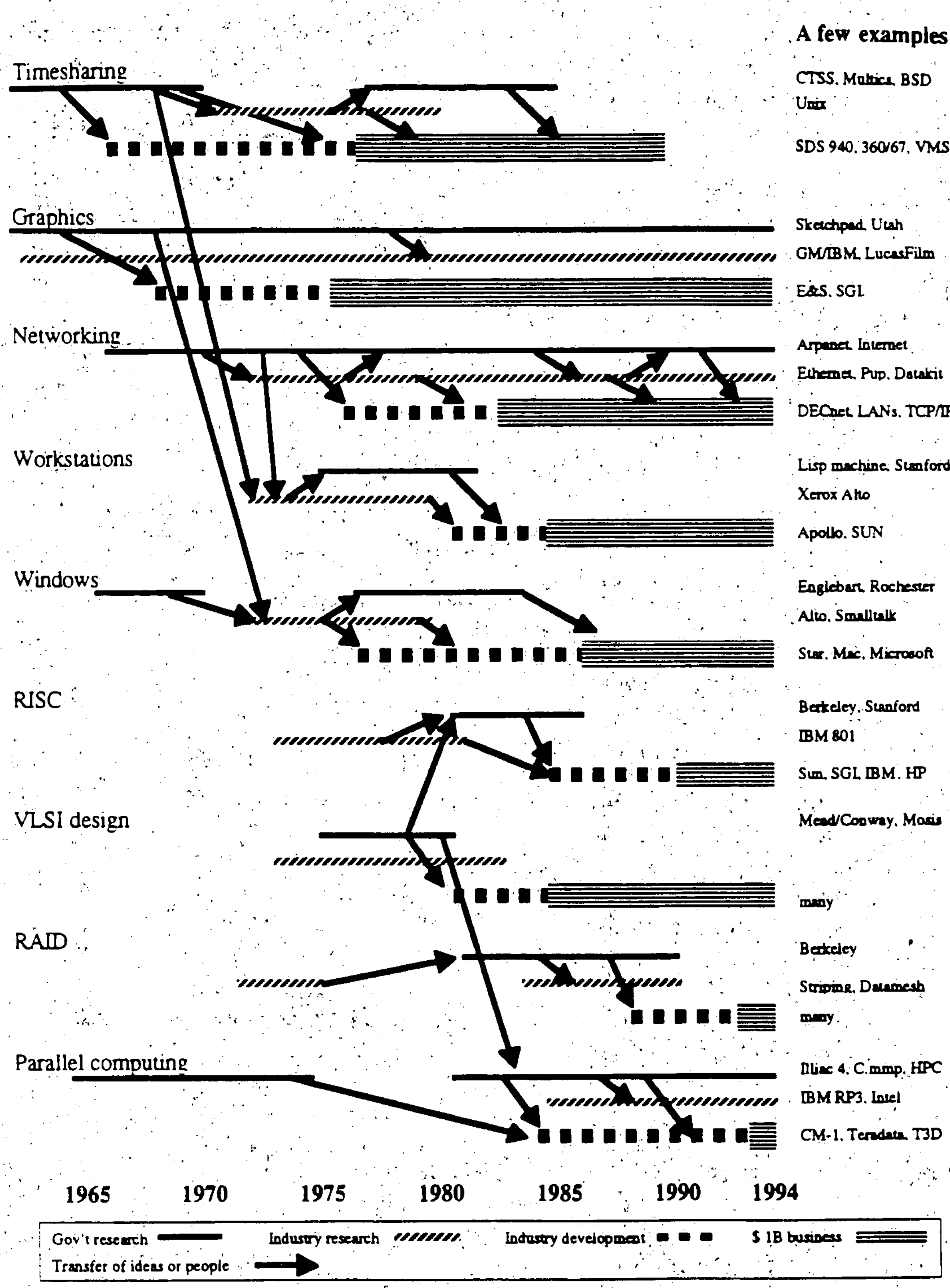


FIGURE ES.1 Government-sponsored computing research and development stimulates creation of innovative ideas and industries. Dates apply to horizontal bars, but not to arrows showing transfer of ideas and people.

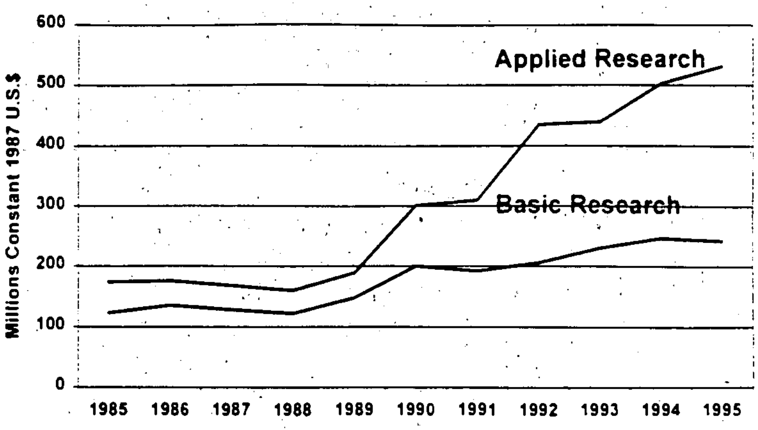
product window. Very few companies are able to invest for a payoff that is 10 years away. Moreover, many advances in IT are broad in their applicability and complex enough to take several engineering iterations to get right. No single company can be assured of recouping such research investments.

Government funding traditionally provided the impetus for fundamental advances in information technologies, either through direct funding of R&D at universities and federal laboratories or through the technology pull of the procurement budgets. (For example, although development of the integrated circuit was funded by the private sector, the knowledge that the government would purchase the product at any unit cost created the environment for companies to invest in the technology.) Virtually every major advance in IT has some federal money in the picture. Networking, computer graphics, workstation technology, windows and mouse user interfaces, parallel computing, and digital libraries were all born from federal funding for research (see attached chart 22). Although the casual observer might assume that the usefulness of government investments to the commercial IT sector ended in the 1960s, ongoing investments like the ASCI project in massively parallel processing continue to push the outer edges of the technology envelope.

There is a more recent concern that the government has also shifted its funding focus away from frontier research (Charts 23 and 24). Universities traditionally were able to attract top-notch scientists willing to forgo higher salaries in industry for the more intriguing research in academia. As one university executive noted, given the given cutbacks in funding for cutting-edge challenges, the research universities are having an increasingly difficult time differentiating their research environment.

Chart 23:

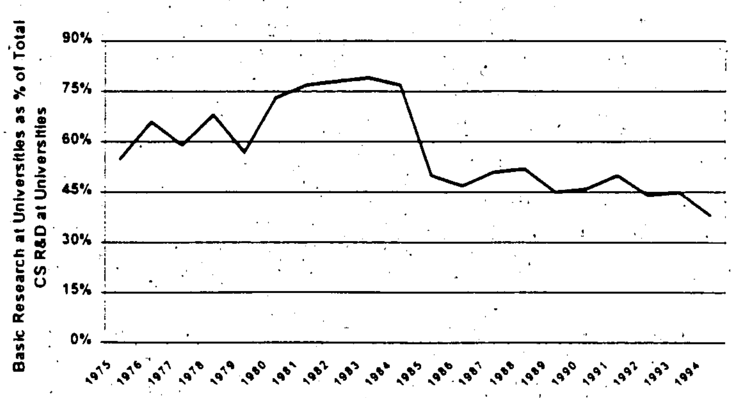
Federal Funding for Applied Research in Computer Science Outpacing Basic Research



Source: National Science Foundation. *Science & Engineering Indicators—1996*. Appendix Tables 4-22 and 4-23. Appendix pp. 138 and 140.

Chart 24:

DoD Funding for University Research in Computer Sciences is Falling



Source: National Science Foundation. SRS.

A number of industry respondents in the IT sector are worried that universities are being drawn towards research that is closer and close to the market—which diverts attention away from their traditional focus on discovery research. Many universities, but particularly public universities, have been tied more closely into regional economic development programs where the metrics of success tend to be jobs and businesses created. There are growing pressures for universities to get involved in research parks, technology incubators and small business assistance programs. Moreover, industry respondents perceive a growing tension between proprietary intellectual property and an open research environment—which they believe represents a serious threat to the health of the U.S. research base.

University, government laboratory and industry respondents alike agree that partnering is essential. Access to real world problems actually improves and sharpens the quest for new knowledge at universities. Most, if not all, industry technological advances can be linked to improvements in fundamental understanding. But, the shrinking time scales over which fundamental knowledge is converted into technology, products and services necessitate a more intimate connection between knowledge generation and technology development. The issue is not whether the linkage between universities, labs and companies should be strengthened, but how to manage the interface more carefully to preserve the core strengths of each.

Human Capital

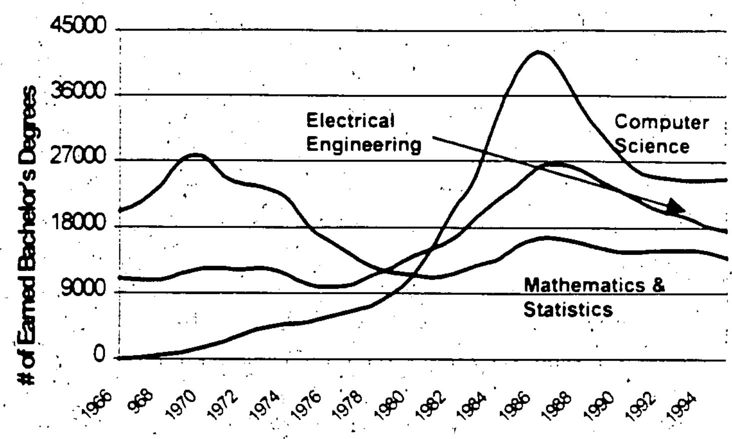
There is clear consensus that people are the critical link to competitiveness—and that the United States is falling short. At the K-12 level, the readiness of the majority of high school graduates either to enter the workforce or pursue advanced education is seriously questioned. U.S. students do not stack up well in math and science against the rest of the world, according to recent international studies. University enrollments in the disciplines relevant to IT are down, even as demand for skilled workers is reaching an all-time high (Charts 25 and 26). This is both a problem for and a challenge to the industry. Shortages of qualified scientists and engineers clearly have the potential to affect long-term competitiveness. Indeed, imbalances between supply and demand of talent at home only increase the centrifugal forces that drive companies offshore. As immigration restrictions have tightened, more companies charge that U.S. policies are actively creating the incentives for them to set up research facilities abroad. University and company executives agree that, at the very least, immigration policies should not force foreign students graduating from U.S. institutions to leave this country on completion of their degrees.

At the same time, information technologies themselves are an integral part of the solution. Software learning tools and networked learning opportunities offer the potential to revolutionize the learning environment and create the locally-trained workforce for the IT industry as well as the other manufacturing and services sectors that embed information technologies.

What is clear is that demand for IT professionals will only increase in step with the demand for info-machines. The U.S. needs a multi-pronged approach that includes interim reliance on global sources of talent, longer-term efforts to improve education and training for Americans and more investment in frontier research. Although the effort to augment the domestic talent base is essential, sector respondents also note that advances in areas like software productivity must be made because local labor markets will never be able to keep up with the exponential growth in demand for software. They stressed the need for a serious and concerted investment in

Chart 25:

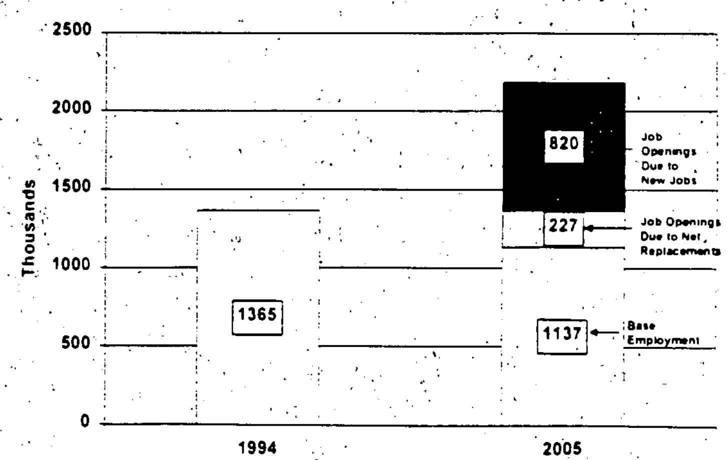
The Numbers of Bachelor's Degrees in IT Disciplines Are Dropping



Source: National Science Foundation. WebCASPAR Database.

Chart 26:

Department of Commerce Projects that Demand for IT Workers Will Grow Faster Than Supply



Source: Department of Commerce. *America's New Deficit: The Shortage of Information Technology Workers*. 1997. Figure 1.

automating the software process, not just in terms of original code, but to verify and validate tens of millions of lines of code applied integrated into complex systems.

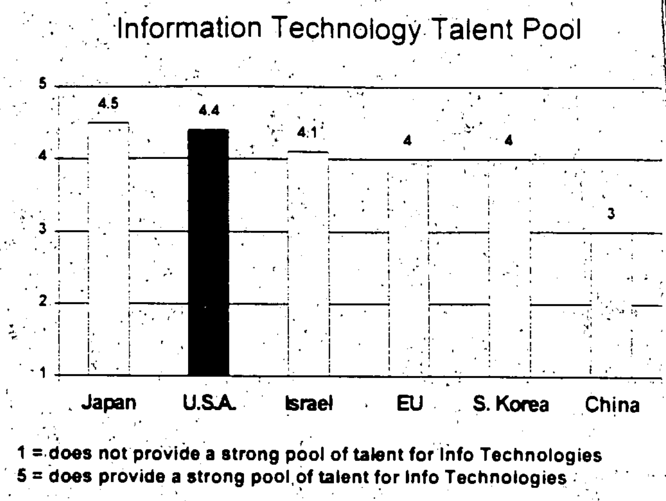
WHAT FACTORS ARE DRIVING GLOBAL R&D

The driving force behind R&D globalization in IT, according to participants, is the availability of highly skilled, productive people (Chart 27). The importance of people was at least an order of magnitude greater than any other factor, according to the sector respondents. In every instance, firms responded that they established their foreign R&D facility locations to tap a local pool of qualified workers. In an industry in which innovation is the key to competition, the capacity of a nation or region to supply a technically sophisticated and innovative workforce is its most important attribute.

Another key factor was local demand—both the presence of a local market for the products being developed and the need to tailor existing products to the needs or tastes of a specific market. For example, research leadership in speech recognition technology is thought to be in the Far East since the keyboard is poorly suited as an input mechanism for Chinese characters. For some companies, however, the transfer of research is quite simply the price of market access.

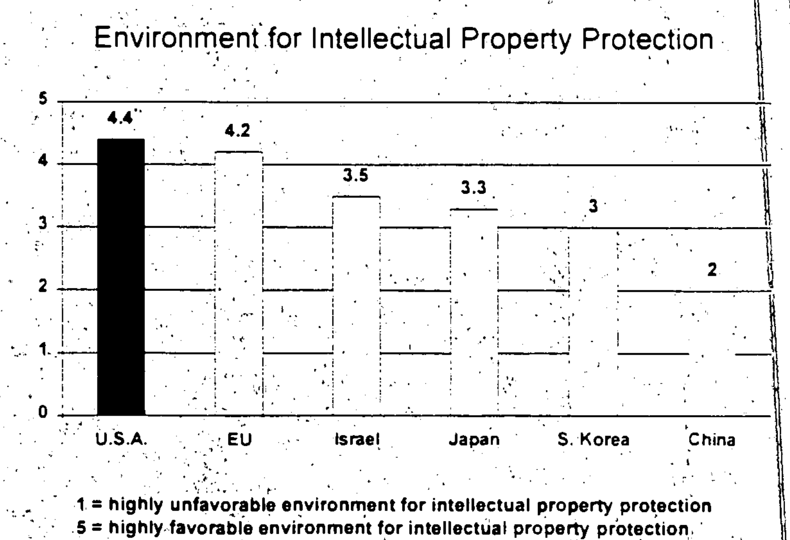
Intellectual property was an important negative factor in the globalization of research (Chart 28). The ability to capture the benefits of innovation provides the primary impetus for investment in R&D; strong national IP protection creates an investment-friendly environment. Most respondents agreed that the United States has one of the best IP protection systems—and that the lack of such systems in certain developing countries was an impediment to investing there.

Chart 27



Source: Council on Competitiveness Survey, 1997.

Chart 28



Source: Council on Competitiveness Survey, 1997.

Local incentives and local content requirements have also influenced R&D investments. Numerous countries are offering firms large subsidies for plant and equipment or training—as well as providing considerable tax breaks as part of incentive packages.

How Our Competitors Stack Up

Japan

The Japanese are prime competitors in a number of information technology sectors. Respondents praised the ability of Japan to make incremental product improvements and to wring costs out of the manufacturing process. The lack of venture capital and a risk taking, entrepreneurial culture—coupled with a penchant for government-directed economic initiatives—were viewed as impediments to the innovation environment.

India

India is developing as a prime location for offshore R&D activities in the IT sector. Its growth has been fueled by an excellent technical university system, especially in electrical and other engineering disciplines, along with much lower labor costs for programmers and other skilled workers. Recently, the government has invested in upgrading the telecommunications infrastructure that is a critical piece of the platform for IT. One industry leader picked India as the country most likely to develop a creative and innovative IT R&D workforce.

Israel

A majority of the firms interviewed had an R&D presence in Israel. Major factors working in Israel's favor are an entrepreneurial and creative culture and a good supply of highly skilled graduates from Technion University. Study participants also cite government incentives as playing a role in their decisions to locate R&D there.

Ireland

Ireland has staked its development efforts on attracting foreign direct investment in manufacturing and technology industries. Large government incentives, combined with a well-educated workforce, make Ireland a desirable location. Ireland probably best exemplifies the co-location of manufacturing and R&D, having used incentives to attract manufacturing and now seeing R&D activities coming in as well.

China

Locating in China is a key element of corporate strategies in gaining a toehold in the rapidly growing Chinese markets. The Chinese example demonstrates strongly the importance of human capital as a driver of investment. Although Shanghai is the business capital of China, Beijing appears to be the location of choice for nearly all of the firms interviewed because it produces tens of thousands of highly skilled engineering graduates each year. Intellectual property rights issues continue to be a major concern in China. Respondents believed that these issues would retard the growth of foreign operations in that country.

Korea

Korea provides an example of the scale of public investment that is being mounted by up-and-coming nations. The Korean government has invested vast sums of money in building local capacity in information technology industries. It has made great strides in the manufacture of information technology goods and is producing many highly trained technology graduates. An economy-wide slump to the troubles of some of Korea's largest firms has raised concerns about the ability of centrally planned strategies to yield indigenous innovation complexes. In the world of one industry respondent: "You can buy technology, but you can't buy innovation."

KEY ISSUES AND RECOMMENDATIONS

Despite its tremendous leadership in IT. the balance sheet of U.S. strengths and vulnerabilities is creating concern for the future.

Balance Sheet

STRENGTHS	LONG-TERM VULNERABILITIES
• Dynamic software and services sector	• U.S. IT trade deficit
• Entrepreneurial culture/unique venture capital market	• Pace of technology churn/rapid leadership shifts
• Strong consumer demand	• Emergence of new innovators—create competitor products and attract talent/research overseas
• World's best research universities/global talent magnet	• Better incentives for industry offshore (R&E tax and investment credits. one-stop regulatory shopping)
• Silicon Valley	• Co-location of R&D with offshore manufacturing/lower labor costs overseas
	• Declines in funding for breakthrough research in the United States
	• Declines in BAs in IT disciplines at U.S. universities

What Should We Be Doing?

Maintain Access to the Best Workforce:

1. K-12 Pipeline:
   - Increase funding for availability/use of IT in classrooms at all levels
   - Ensure that teacher education and credentialing include IT training
   - Provide funding to train teachers on the use and integration of IT in the classroom
   - Create a federally-funded. regionally-based partnership program among universities and high schools to promote IT education and encourage future degree recipients
2. Increased Incentives for S&E Degrees:
   - Set aside .5% of agency budgets to fund research fellowships in the science and engineering disciplines relevant to their missions
3. Access to Global Talent Pool:
   - Provide foreign graduates from U.S. institutions with a grace period to work in the United States

Strengthen Our World Class University Research System:

1. Leadership and state-of-the-art infrastructure:
   - Ensure that cutbacks at the Departments of Defense and Energy do not result in a de facto reallocation of resources among research disciplines
2. Priority Investments
   - Target federal investments towards building block technologies, such as software productivity, in which issues of affordability and appropriability deter company investment

Ensure that Intellectual Property Issues Do Not Compromise Open University Research Environments:

1. University-Industry Relationships:
   - Create university-led policy initiatives to develop guidelines on the management of proprietary relationships and exclusivity of information.

Provide a Regulatory Environment Responsive to Changing Market Conditions:

1. Competition Policy:
   - Ensure that regulations dealing with competition, in particular the interpretation of "potential competitor" accurately reflect an understanding both of technology trends and global competition
2. Accounting Rules:
   - Alter accepted accounting rules and practices that are not in line with the pace of change in the IT industry (i.e. acceleration of IT write-offs)
3. Contract Policy:
   - Ensure government contracts for hardware and software services reflect IT industry standards and trends

IT Sector Study

Co-Chairs:

Maurice Holmes
Xerox Corporation

Paul Horn
IBM Corporation

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Co-Chair and Sector Advisor Biographies

Maurice F. Holmes is the chief engineer and vice president of corporate engineering for the Xerox Corporation. Prior to these positions, he served as president of the Office Document Systems Division. Mr. Holmes joined Xerox in 1972 as a product development engineer and has held senior management assignments in research, technology, product development and general management. Mr. Holmes holds a B.S. in physics and an M.S. degree in mechanical and aerospace science from the University of Rochester.

Paul M. Horn was named senior vice president for research at IBM in 1996. He joined IBM in 1979 as a solid state physicist and has served as vice president and lab director of IBM's Almaden Research Center. Prior to joining IBM, he was a professor of physics at the James Franck Institute, University of Chicago. He is a graduate of Clarkson College and holds a doctorate from the University of Rochester.

Don Smith is executive director of the Center for Economic Development at the H. John Heinz III School of Public Policy and Management at Carnegie Mellon University. Before joining CMU, he worked with RAND's Critical Technology Institute, specializing in new technology financing and the development of regional clusters. He holds a B.A. in economics from Harvard and a Ph.D. from the Heinz School.

DRAFT

Going Global: ADVANCED MATERIALS

Industry Co-Chairs: Victoria Haynes
William Coyne
Sector Advisors: Debra van Opstal
Jay Henis

Materials sciences and engineering enable progress in virtually every sector of the economy and every walk of life. From semiconductors to long-life batteries, hip transplants to lighter weight cars, fiber optics to manufacturing tools, materials provide the basic building blocks of innovation. The industry's critical importance to the economic competitiveness of many sectors cannot be overstated.

For the next 10 years or more, the United States is expected to lead in many segments of the industry. Over the long term, however, slower net growth in investment in the United States and greater manufacturing parity around the world could squeeze the resources available for investment in frontier technologies.

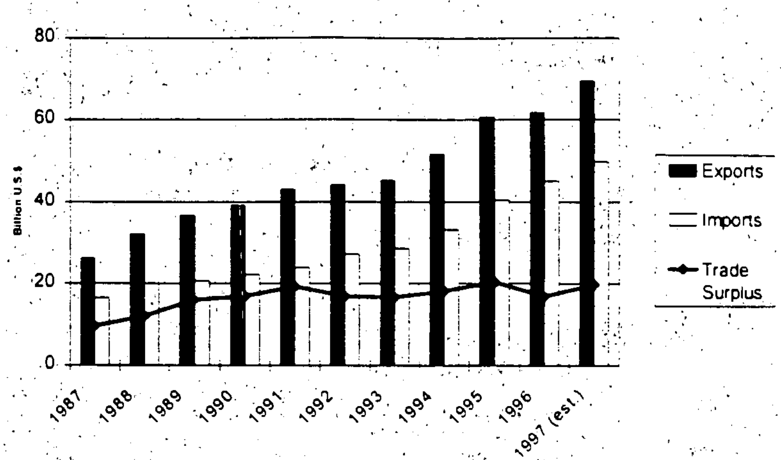
Participants in the sector study believe that the greatest challenge confronting the industry is not the loss of market leadership due to external competition, but an inability to reach its potential for innovation because of shortcomings in the US innovation environment.

Where We Stand

The strength of the advanced materials industry stems from 50 years of leadership in the chemical industry—one of the few industrial sectors in this country that consistently runs a trade surplus. The United States has been the undeniable leader in identifying new materials, characterizing their properties, developing new uses and applications for these materials, and in some instances, creating whole new industries based on their properties. In the important metrics, the U.S. industry looks strong:

Chart 1

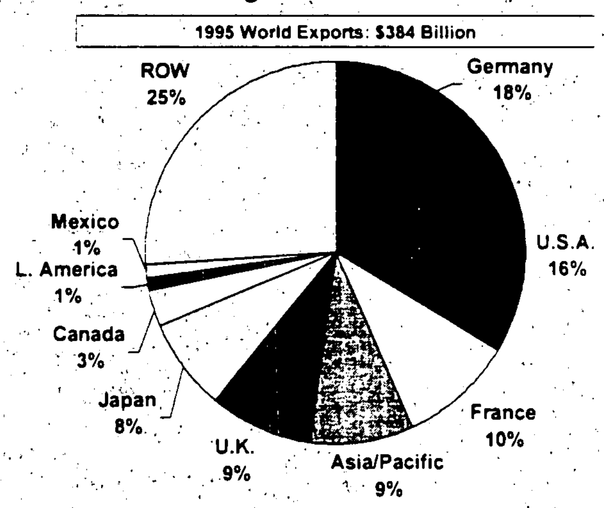
The U.S. Chemical Industry Maintains a Healthy Trade Surplus



Source: Chemical Manufacturers Association. *The U.S. Chemical Industry Performance in 1997 and Outlook.*

Chart 2

The United States Is the Second Largest Chemicals Exporter



Source: Chemical Manufacturers Association. *The U.S. Chemical Industry Performance in 1997 and Outlook*. P. 6.

- The trade balance of U.S. chemical firms remains in healthy surplus. For some years, the chemical industry has accounted for over $1 dollar of every $10 of U.S. goods exports[1] and accumulated $182 billion in trade surpluses for the 10-year period ending in 1997. The United States is the second largest single country exporter of chemicals (Charts 1 and 2, previous page).[2]

- The balance of intellectual property trade is also strong, reflecting the high intellectual content of products and processes developed in the United States.[3] Exports of intellectual property from U.S. parents to their affiliates reached $3.2 billion in 1995, generating a trade surplus of nearly $1.2 billion.

- U.S. inventors hold 46 percent of all advanced materials patents filed in the United States, about the same share held in 1982. Japan comes in second with 31 percent, followed by the European Union with 15 percent of U.S. filed patents (Chart 3).[4]

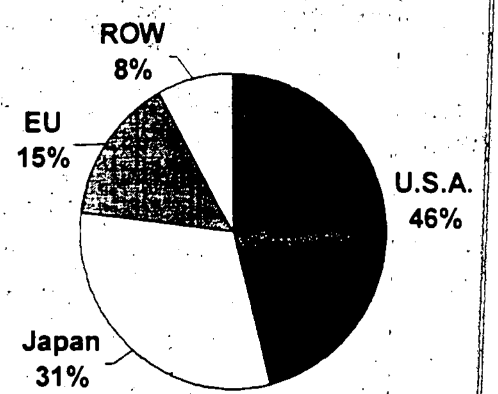
- The United States accounts for 28 percent of all international scholarly articles in chemistry (Chart 4).[5]

Why Innovation Matters

In concert with strong U.S. performance, the industry is globalizing rapidly (Chart 5, next page). New market opportunities overseas and a maturing technological base are dramatically changing the focus and

Chart 3

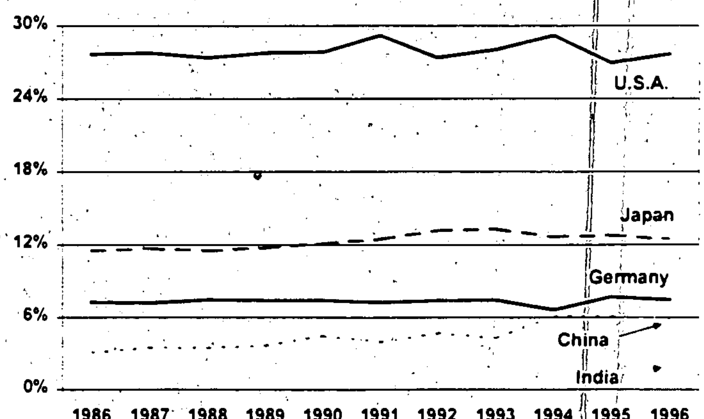
U.S. Inventors Hold the Largest Share of Advanced Materials Patents



Source: CHI Research, Inc.

Chart 4

The U.S.A. Has Consistently Led the World in Scholarly Articles in Chemistry



Source: American Chemical Society. http://pubs.acs.org/hotartcl/cenear/970901/origin.html.

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[1] Lenz, Dr. Allen J. and Dr. John Lafrance. *Meeting the Challenge: U.S. Industry Faces the 21st Century—The Chemical Industry*. U.S. Department of Commerce, Office of Technology Policy. January 1996. P. 30.

[2] Chemical Manufacturers Association. *The U.S. Chemical Industry Performance in 1997 and Outlook*.

[3] American Chemical Society. *Chemtech*. "The U.S. Competitive Advantage in Intellectual Property Trade." September 1997.

[4] Albert, Michael B., Ph.D. *Technological Competitiveness Analysis for Five Technologies in 15 Countries*. CHI Research, Inc. Haddon Heights, NJ. 29 October 1997. Table 1, p. 30.

[5] "Facts & Figures." *Chemical & Engineering News*. September 1997. http://pubs.acs.org/hotartcl/cenear/970901/master.html.

structure of the industry—with profound implications for its future investments in innovation.

Participants in the sector study described three trends impacting the capacity for innovation in the industry: the global diffusion of R&D; fewer dollars and more focused R&D; and a shift toward higher value products.

Global Diffusion of R&D

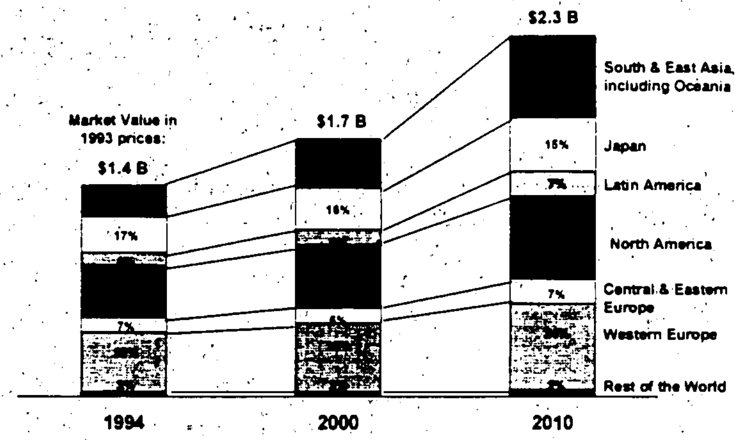
Both the volume chemical companies and specialty chemical companies are increasing R&D efforts where they manufacture—and the marginal dollar of investment in plant and equipment is going overseas—now and for the foreseeable future.

European chemical producers were in the forefront of the R&D globalization movement, with the United States as a net beneficiary (Chart 6). The Department of Commerce estimated foreign investment represented more than 45 percent of the total industry investment in chemicals in 1993 Chart 7, next page).[6]

But U.S. chemical companies are moving R&D operations overseas as well, increasing their overseas investments from $444 million in 1985 to $1.6 billion in 1995 (Chart 8, next page).[7] While these investments are concentrated for the most part in technical service and local customization, they involve discovery research as well in more technologically sophisticated environments.

Chart 5

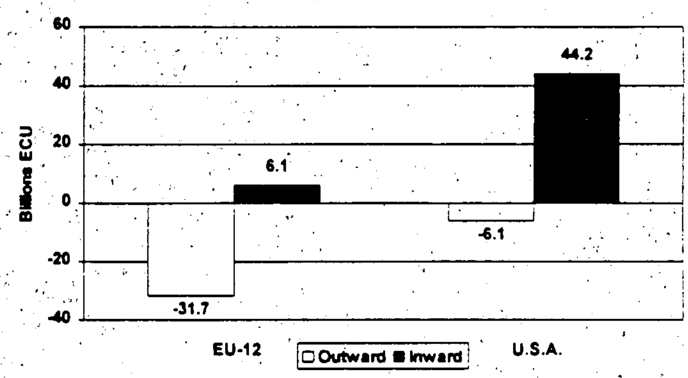
The Fastest Growing Demand Will Be Overseas--and Investment Follows New Markets



Source: CEFIC. http://www.cefic.be/eco/ecobul/Eb9511b.htm.

Chart 6

Europe Was in the Forefront of Shifting R&D Investments in the 1980s and 1990s



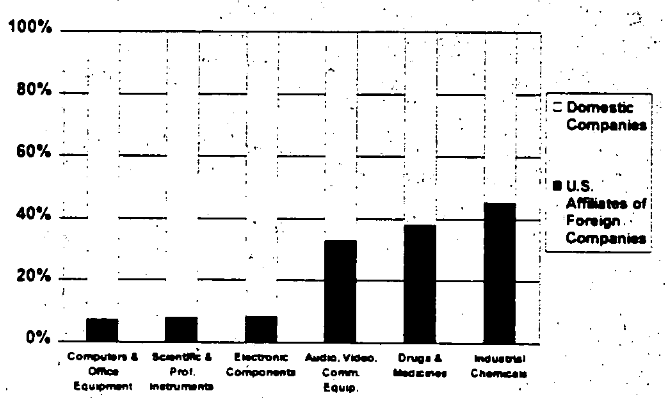
Source: CEFIC.

[6] Dalton, Donald H. and Manuel G. Serapio, Jr. *Globalizing Industrial Research and Development*. U.S. Department of Commerce, Office of Technology Policy, Asia-Pacific Technology Program. October 1995. Table 2, p. 15.
[7] *Survey of Industrial Research and Development: 1995*. National Science Foundation/SRS. Table 5, p. 34.

The U.S. Chemical Industry Is Globalizing Rapidly – with Profound Implications for Investment in Innovation.

Chart 7

Foreign-Affiliated Companies Accounted for $2.3 Billion--Almost Half--of All Chemical Industry R&D in the U.S.A.

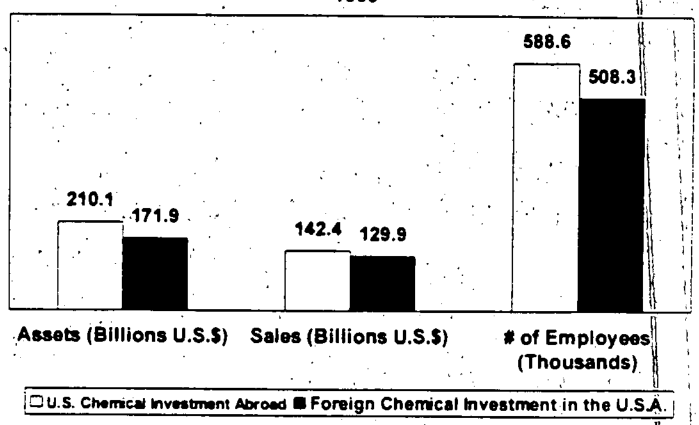


Source: Dalton, Donald H. and Manuel G. Serapio, Jr. *Globalizing Industrial Research and Development*. U.S. Department of Commerce. October 1995.

Chart 8

But, U.S. Companies Spend More Overseas Than Is Invested Here by Foreign Companies...

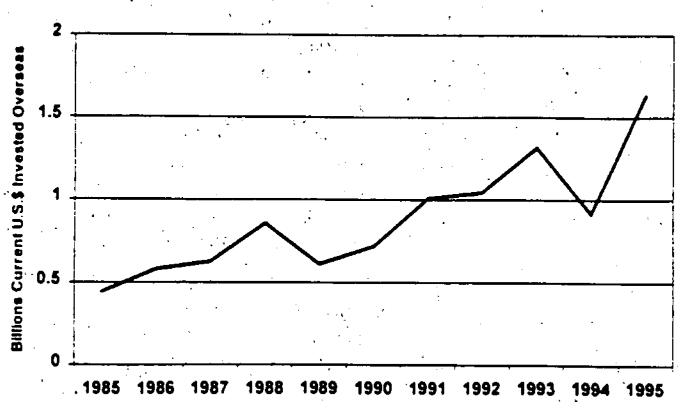
1993



Source: Chemical Manufacturers Association. *The U.S. Chemical Industry Performance in 1997 and Outlook*. November 1997. P. 17.

Chart 9

...And U.S. Chemical R&D Investment Is Flowing to New Markets.



Source: National Science Foundation. *Research and Development in Industry: 1995*.

Another driver of R&D globalization, beyond co-location with manufacturing, is the need to service new markets and customers better. More and more of their customers are shifting responsibility for R&D down to their suppliers. Materials companies, like other suppliers, are often required to help their customers do applications research. A decade ago, the manufacturing might have gone overseas while the R&D remained in the United States. Today, the ability to offer full-service operations near major customers—both foreign companies and foreign affiliates of U.S. companies—is increasingly part of the competition for new business.

Arora and Gambardella also note that the rise of specialized engineering firms has contributed to globalization by diffusing chemical process technology internationally. By supplying technology and know-how for a wide variety of chemical processes, the specialized engineering firms have facilitated the entry of more and more sophisticated competitors into the global chemical market.[8]

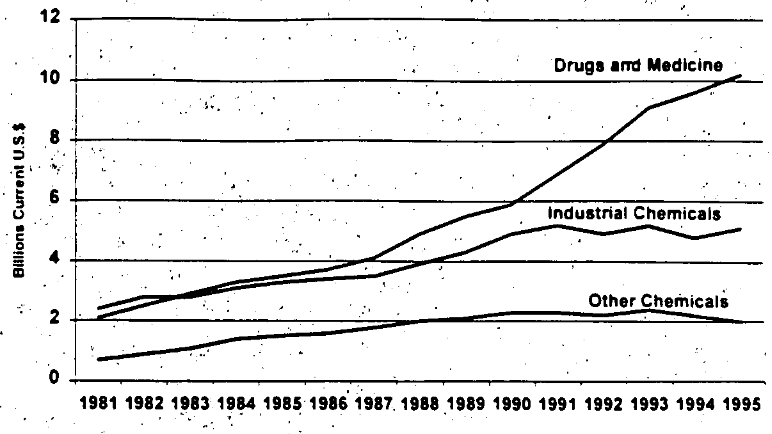
Fewer Dollars and More Focused R&D

Intensifying global competition in commodity chemicals, driven both by the growth of worldwide operations of established manufacturers and the rise of national chemical industries around the world, has changed the amount and direction of R&D investments. Lower profit margins have meant less money for R&D overall—and most of the volume producers have seen their R&D budgets stagnate in the nineties (Chart 10).

Company research dollars are more clearly focused on the bottom line. Twenty years

Chart 10

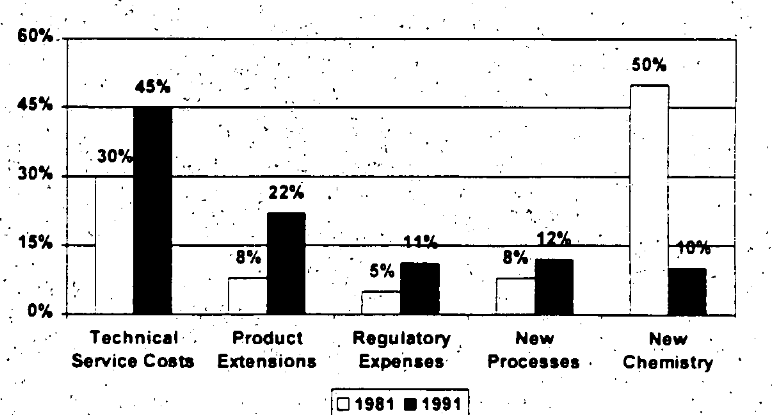
Company R&D Spending in Chemicals in the United States Has Stagnated in the 1990s



Source: National Science Foundation. *Research and Developmnent in Industry: 1993* and *1995* (early release tables).

Chart 11

And the Chemical Industry Has Shifted its R&D Focus Away from New Chemistry



Source: Weiner, S.C., M.G. Woodruff and A.K. Johnson. *Developin a Chemical Industry Strategy: State-of-the Industry Profile*. Prepared for the U.S. Department of Energy by the Pacific Northwest Laboratory. October 1994. P. 42.

[8] Arora, Ashish and Alfonso Gambardella. "The Chemical Industry—First Version: 10 November 1997." *Papers Presented at a Conference on America's Industrial Resurgence: Sources and Prospects*. Board on Science, Technology, and Economic Policy. National Research Council. Washington, D.C. December 1997. P. 18.

ago, the R&D departments of major chemical companies devoted a significant portion of their activities to basic or curiosity-driven research in chemistry and related fields. Today, the returns from manipulating molecules are too uncertain to support what one company representative described as "innovation by wandering around."

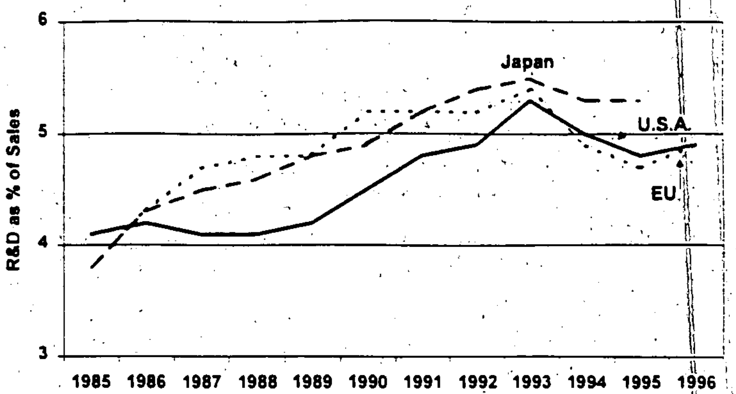
As a result, enormous shifts are occurring in the allocation of the R&D investment. Leaner R&D organizations still carry out research, often focused on incremental product or process improvement, but funding for new chemistry as a whole has sharply declined. Some companies continue to invest in breakthrough technology, but a substantial portion of that research is dedicated to improving their position in existing markets (Chart 11, previous page).

By contrast, the research funding of Japanese companies has been rising steadily—from less than 4 percent of sales in 1985 to well over 5 percent in 1995. Today, its industry is more research intensive than either the Europe or the United States (Chart 12).[9]

Unlike some other sectors, the chemical industry has almost solely funded its R&D activities. On average, the government funds about one-fourth of the R&D performed by U.S. manufacturing companies—but less than 2 percent of the U.S. chemical industry's research is funded by the government.[10] Hence, declines in industry R&D funding take on greater significance for the future of innovation in the industry.

Chart 12

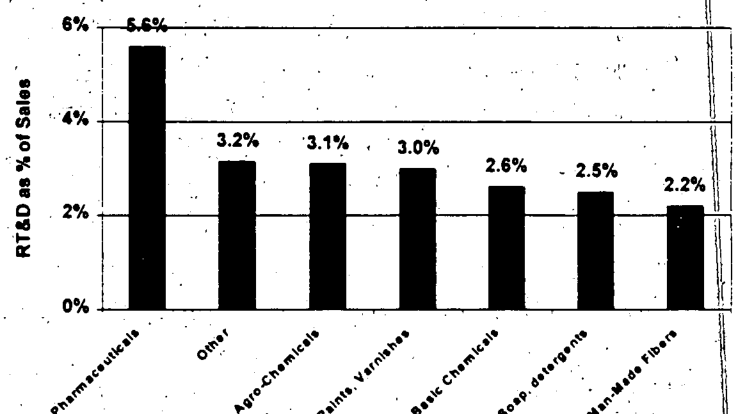
Japan's R&D Investment in Chemicals Outpaces both the United States and the EU



Source: CEFIC.

Chart 13

In the EU, Chemical Companies Are Shifting R&D into Higher Value Segments



Source: CEFIC.

[9] Arora, Ashish and Alfonso Gambardella. "The Chemical Industry—First Version: 10 November 1997." *Papers Presented at a Conference on America's Industrial Resurgence: Sources and Prospects*. Board on Science, Technology, and Economic Policy, National Research Council, Washington, D.C. December 1997. P. 18.

[10] Lenz, Dr. Allen J. and Dr. John Lafrance. *Meeting the Challenge: U.S. Industry Faces the 21st Century: The Chemical Industry*. U.S. Department of Commerce, Office of Technology Policy, Washington, D.C. p. 21. January 1996.

Shift toward Higher Value Products

In both the United States and the EU, firms are moving into higher margin, more specialized segments of the industry: advanced materials, agricultural products, electronic materials, biotechnologies and pharmaceuticals (Chart 13, previous page). For these areas, R&D—focused on research breakthroughs, not incremental improvements in product or process—plays a huge role in positioning materials companies for global leadership. Innovation flows from the multidisciplinary interface of sciences—chemistry, physics, biology, information and engineering—and the integration of materials technologies in electronics, computing, optics, aeronautics, and automotives.

The industry itself is restructuring into new technologies and markets beyond the scope of traditional chemistry and chemical engineering. Indeed, the production of chemicals has become less an end in itself than an enabling step that allows applications in other industries.

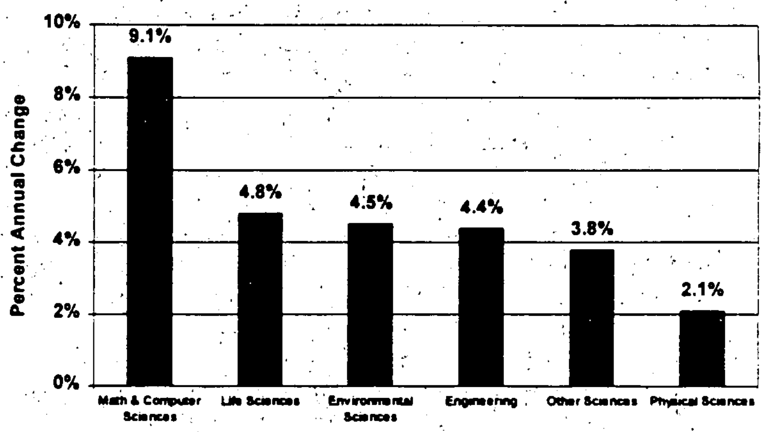
The United States enjoys a comparative advantage in attracting investment in these frontier areas because of its more complex university research infrastructure—one that overseas competitors cannot easily replicate. Although there are centers of excellence in materials science in Europe and Japan and emerging in China, Israel and Russia, no country matches the United States in the sheer depth and breadth of expertise.

There are no signs that breakthrough research will be globally dispersed. Precisely because innovation occurs at the interfaces between scientific disciplines and technology platforms, *proximity matters*. U.S. firms may trawl globally for new ideas and talent, but their investments in frontier research and discovery remain clustered in the United States within companies and in

Frontier R&D Will Play a Huge Role as Companies Restructure towards Higher Value, Lower Volume Products...

Chart 14

But the Federal Investment in Physical Sciences and Engineering Lags Other Disciplines



Source: American Chemical Society. *Chemical & Engineering News*. September 1, 1997.
http://pubs.acs.org/hotartcl/cenear/970901/lifescience.html.

partnerships with research universities and government laboratories.

The problem is that the dollars available for investment in breakthrough research have been shrinking. Federal and university sources of funding for the physical sciences are growing only slowly relative to other disciplines (Chart 14, previous page). The defense sector, historically an important source of new materials, has decreased in size and contribution to the materials sciences[11] Large companies face a number of constraints in funding breakthrough research. The time required to realize a financial return is long and risk-filled. There are few assurances that the company will fully capture the returns on its investment.

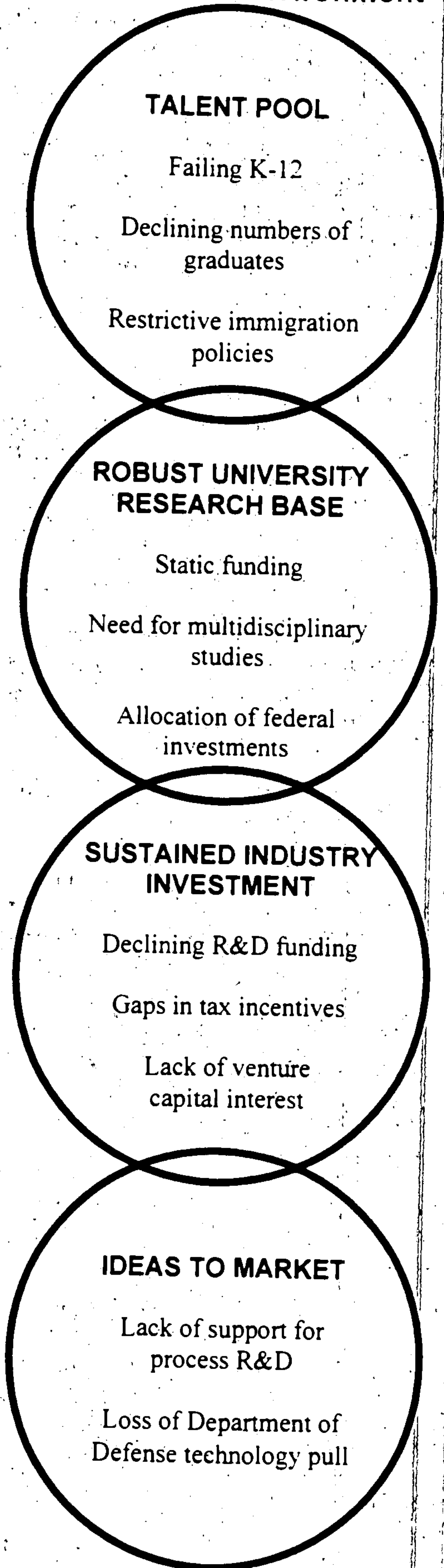
Sustained innovation in these areas will require new types of R&D and funding arrangements. The ability to leverage resources through partnerships, to encourage vertical linkages among small and big firms and between materials companies and their suppliers, and to fund multidisciplinary programs that integrate materials research with process engineering will all be critical support components for innovation in the high-end chemicals industry.

Emerging Vulnerabilities in the Innovation Infrastructure

The historical leadership of U.S. companies did not happen by accident. Sector study participants identified four elements of national infrastructure that contributed to the strong position of U.S. firms: the quality of the talent pool; a robust research infrastructure; sustained industry investment in R&D; and an environment that supports commercialization of new applications. As we look to the future, however, there are some problems in each of these areas that need to be addressed by universities, companies and the government (Chart 15, previous page).

[11] National Science Foundation. *Report of NSF Panel on Areas of Opportunity: Division of Materials Research*. January 12, 1995.

Emerging Vulnerabilities in the U.S. Innovation Environment

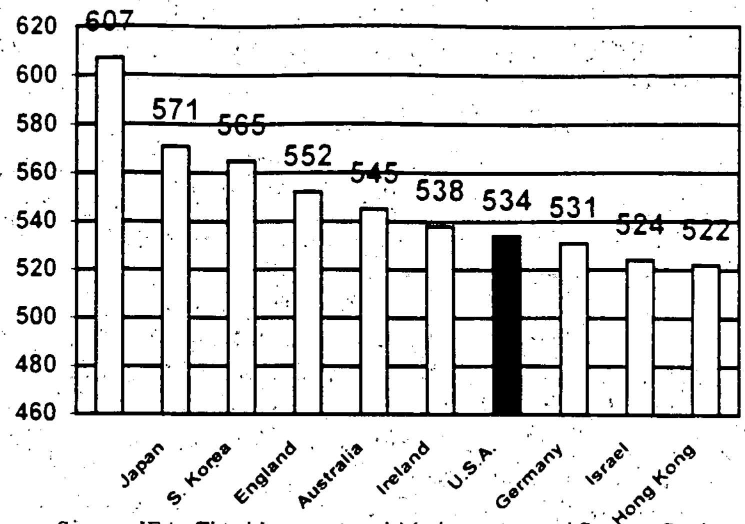


Talent Pool
Respondents to the sector surveys agreed that human talent was their chief priority and major concern. As one company noted, investment will flow wherever it finds the best people. Historically, both the investment and the people have come to the United States—one indication of the strength of the university system and the leadership in cutting-edge research. Increasingly, however, participants perceive that the talent pool that supports the chemical industry in the United States is at a crossroads.

Failing K-12 systems: Most are troubled by a flawed K-12 system, particularly in math and science, that forecloses a scientific or engineering career for U.S. citizens at the earliest stages of the educational process. The recent TIMSS study comparing the academic achievements of 7th, 8th and 12th grade students in science and mathematics across the world ranked the performance of U.S. students behind Singapore, Japan, South Korea, England, Australia and Ireland—a clear warning signal (Chart 16).

Availability of scientists and engineers: The graduate student science population has been static or declining for the past 10 years (Chart 17). In the physical sciences, the numbers of graduate students dropped by 2.6 percent between 1994 and 1995 and remained almost flat over the 10 years period between 1985-1995.[12] In metallurgy and materials and chemical engineering, the number of graduate students dropped by 5.8 percent and 2.6 percent respectively between 1994 and 1995.[13] While the number of students enrolled in chemical engineering programs had essentially no growth over the decade to 1995, the number of graduate students in metallurgical and materials engineering

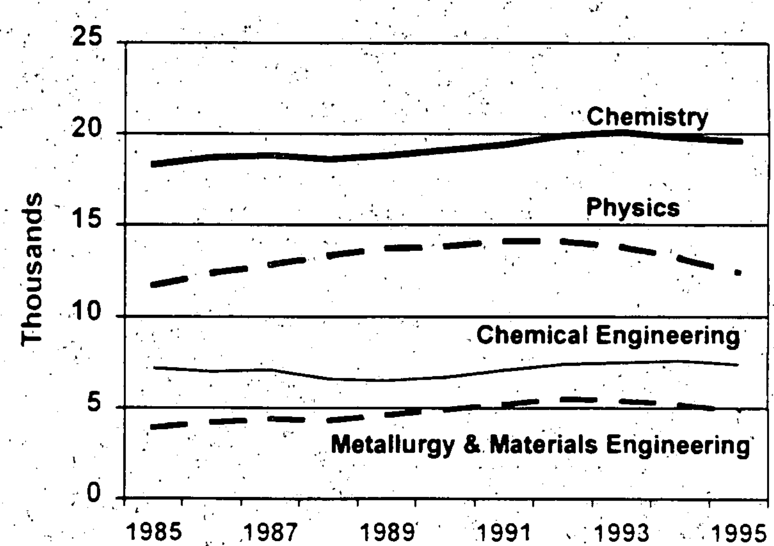
U.S. Eighth Graders Fall Behind Many Others in Science Achievement



Source: IEA. *Third International Mathematics and Science Study (TIMSS)*. 1994-1995.

Chart 17

The Numbers of U.S. Graduate Students in the Physical Sciences Are Static or Declining



Source: American Chemical Society. *Chemical & Engineering News*. September 1, 1997, http://pubs.acs.org/hotartcl/cenear/970901/graduate.html.

[12] *Chemical & Engineering News*. American Chemical Society. 1 September 1997. http://pubs.acs.org/hotartcl/cenear/970901/graduate.html
[13] Ibid.

posted a slight 2.8 percent rate of growth over the decade.[14]

Robust University Research Base

One of the core strengths of the United States is its leading-edge university research base. Over the past 50 years, the United States has led the world in the depth and breadth of contributions by its universities. These institutions are a vital link in the continued leadership of the United States, particularly in chemicals and advanced materials. An analysis of industry patents shows a relatively high linkage between basic science and industry innovation in the advanced materials sector (Chart 18).

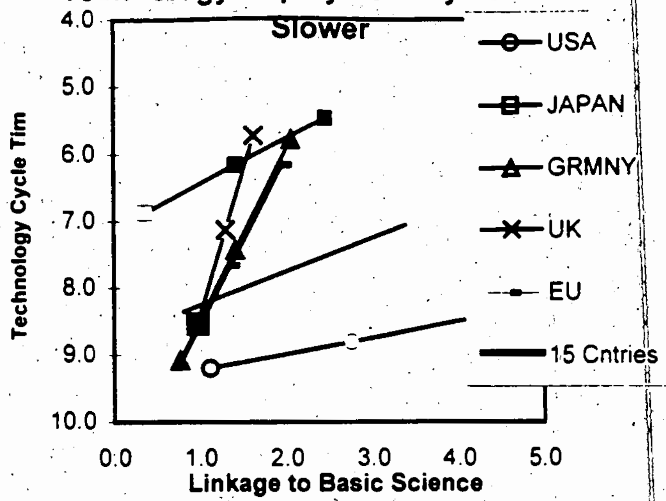
Sector participants had concerns about: 1) the declining levels of funding for frontier research at universities; 2) the need for more multidisciplinary programs that reflect the state-of-the-art in industry; and 3) the barriers to university-industry partnerships which impede quick diffusion of research results.

Declining Funding Base: The end of the Cold War has hit the funding base for chemistry and chemical engineering disproportionately hard. Because the federal government's support for research is mission-driven, the post-Cold war budgets have seen a net shift of resources away from physics, chemistry, mathematics, and engineering into the life sciences (Chart 19).

The universities are in the front lines of funding stresses. Although funding for academic research has rebounded recently, the physical sciences are not faring as well as other fields. The percent increase in research funding for the physical sciences between 1990 and 1997 was lower than in any other disciplines—by a considerable margin (see Chart 14).

[14] *Chemical & Engineering News*. American Chemical Society. 1 September 1997.
http://pubs.acs.org/hotartcl/cenear/970901/graduate.html

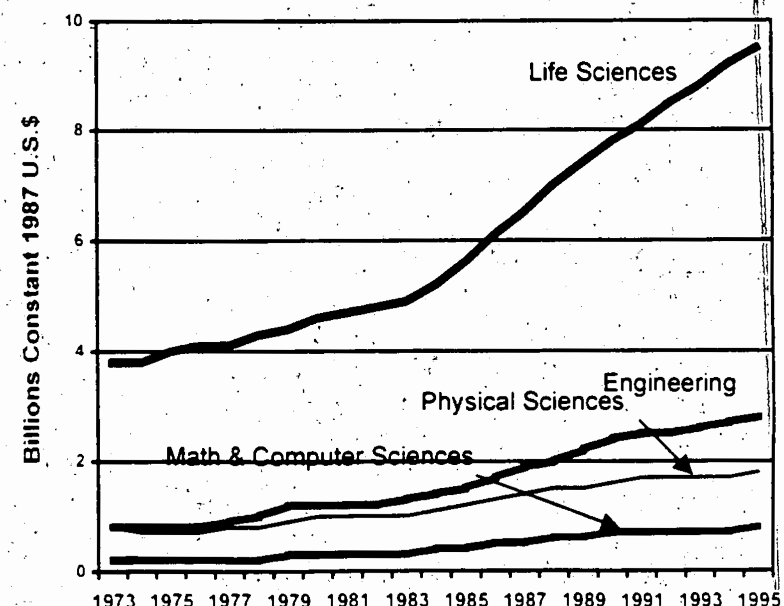
U.S. Industry Relies on Basic Science More than Competitors--but Technology Deployment Cycles Are Slower



Source: Albert, Michael B., Ph.D. *Technological Competitiveness Analysis for Five Technologies in 15 Countries*. CHI Research, Inc. Haddon Heights, NJ. 29 October 1997. Figure 11, p. 29.

Chart 19

R&D Funding in Materials-Related Fields Is Inadequate



Source: National Science Foundation. WebCASPAR database: http://caspar.nsf.gov.

Multidisciplinary Programs of Study: Industry respondents stressed the need for graduates who could communicate across disciplines—individuals who had breadth as well as depth. They noted that university training has become narrowly specialized and stove-piped. Ph.D. candidates take fewer courses than they did 15 or 20 years ago and tend to immerse themselves deeply into a particular area of research almost immediately. Many departments have minimal course distribution requirements and offer no minor fields of study requirements.[15]

Universities have unwittingly exacerbated the problem by failing to foster linkages among different departments and disciplines. Industry has also exacerbated the problem by failing to create sufficient numbers of internships and co-operative programs that would expose students to the teaming and cross-disciplinary efforts that characterize industrial labs.

There are signs of serious efforts to address the issue. The National Science Foundation has recently launched the IGERT Program (Integrative Graduate Education and Research Training) to enable the development of multidisciplinary programs. Projects support by IGERT are based on a multidisciplinary research theme and organized around a diverse group of investigators. A number of university respondents have also indicated that their institutions are seeding cross-disciplinary programs at the undergraduate as well as the graduate level. The sector interviews did not highlight any similar programs in industry, but companies could also re-orient their university funding programs along these lines to reinforce the incentives for multidisciplinary work.

New Technological Priorities Drive the Industry

NEEDS	CHALLENGES
Chemical Synthesis	New Catalysts Multifunctional Materials
Materials Technology	Prediction of Materials Properties Synthesis Technology Additive Technology Precise Manipulation of Molecules Enhanced Performance
Process Engineering	New Design Principles, Tools, Systems And Infrastructures Manufacturing Flexibility

Source: Based on *Technology Vision 2020—The U.S. Chemical Industry* American Chemical Society; American Institute of Chemical Engineers; Chemical Manufacturers Association; council for Chemical Research; Synthetic Organic Chemical Manufacturers Association. 1996.

[15] van Opstal, Debra. *Global Innovation National Competitiveness.* Center for Strategic & International Studies. Washington, D.C. 1996. P. 21.

Barriers to University-Industry Collaboration: University-industry partnerships are critical to sustaining the capacity for innovation in the United States. Because companies have narrowed their research focus to "enterprise-enabling" research and shorter-term product research, they rely more than ever on universities to generate the science to fuel breakthrough research and discovery.

Even as the need to leverage research has grown, industry survey participants contend that the process of technology transfer has become legalistic and burdensome. One company's preference was not to partner with "first-tier" research universities that, in its view, were inflexible. Pricing is an issue as well. Industry representatives believe that universities overestimate the value of intellectual property and underestimate the additional investment required to turn a research discovery into a product. There appears to be a widening cultural gap between universities and companies over intellectual property that needs to be addressed.

Sustained Industry Investment

As the industry moves into new areas of research and technology, the need for risk capital is likely to grow beyond its availability. There are both market and policy constraints on risk capital availability.

Venture capital interest in this area is limited, a particular problem for the small start-ups and fast moving entrepreneurial companies which devote most of their efforts to breakthrough products and technologies. Of the estimated $8 billion that was available in the private venture capital market in 1977, less than 2 percent went to materials start-ups. Disincentives for VC investment are structural. The long cycle times and relatively high failure rates, the lack of assurance about the protectability of the technology and the inability to set a market price (given that materials companies are part of a value-chain) pose fundamental barriers to increased VC interest.

At the same time, sustained federal funding for critical programs, such as the Small Business Innovative Research (SBIR) grants, is uncertain and unpredictable. Such programs are the lifeblood of materials startups. Materials-related research accounted for one-sixth of all SBIR grants in 1993 (Chart 20).[16] According to a Harvard Business School study, high-tech startups bolstered by federal R&D grow 40-75 percent faster than those without government support.[17]

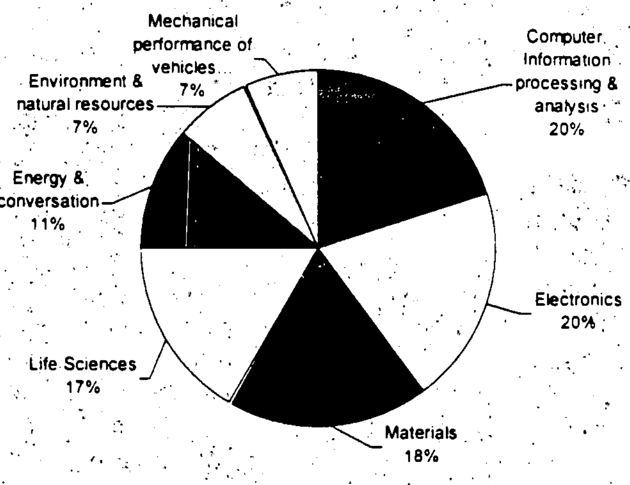
Federal tax incentives for R&D also fall short of stimulating more risk capital availability. Although chemical companies have the highest levels of R&D per employee of any industry, the relative decline in their R&D spending reduces or eliminates eligibility for the R&E tax credit. The credit was intended to encourage companies to invest more in R&D in the United States, but it requires an annual increase in expenses over a base rate—regardless of the level of the base.

Short of restructuring the credit, federal policy could incent high-risk investments in innovation in 2 ways:

Tax Incentives for Research Consortia: Materials research is a natural area for partnership, given that the costs and risks are high, and the appropriability of the investment is uncertain. Although the nation supports partnerships as an important policy goal, the tax code ironically disadvantages companies which participate in collaborative research efforts by lowering their eligibility for tax credits. According to a recent study by Arthur Anderson, the tax credit companies receive from contributions to

Chart 20

Small Business Innovation Awards, by Technology Areas: 1983-1993



Source: National Science Foundation. *Science & E[illegible] Indicators—1996*. Figure 4-10.

[16] National Science Board. *Science & Engineering Indicators—1996*. Washington, D.C. 1996. Figure 4-10.
[17]

R&D consortia may actually be lower than if the company had performed the R&D in house. The study concludes that a flat R&D tax credit for member contributions to an R&E consortia would increase national incentives for partnership and collaborative research.[18]

Tax credits for R&D acquired as equity investment: Some of the most promising breakthrough research is being performed in small companies. The trend in the industry is to support this work—sometimes through direct funding of external R&D, which is a qualified expenditure under the terms of the credit. Increasingly, however, companies are offsetting the level of risk and cost of the R&D expenditure by taking an equity investment in the small company or start-up. Although these R&D investments are often aimed at developing very innovative and high-risk technologies, they do not qualify as R&D expenditures for the purposes of the tax credit.

Ideas to Market

The ability to discover new materials is no guarantee of leadership unless they can be affordably commercialized. This tends to be a chicken and egg problem for materials innovation. It is difficult to invest in new materials development until a commercial application is assured while commercial applications do not generally emerge until the material is developed.

This inherent contradiction is creating a drag on investment in and development of new materials. Sector participants identified three principal needs.

Catalyzing Vertical Partnerships: Linkages between materials suppliers and end-users can bridge the gap between innovation and application. Companies in this sector believe that the federal

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government, particularly through programs like the Advanced Technology Program, can be instrumental in catalyzing vertical integration. The net effect of such partnerships is to lower the risk for the materials suppliers and speed applications to market by their customers. For one company, an ATP grant served as an external review mechanism that validated its ongoing research into high temperature superconductivity—a program that was about to be cut based on its lack of return. Materials companies' positive view towards the ATP program have less to do with funding levels than its ability to create the right environment for investment in innovation.

More Interface Between Science and Engineering: In materials, the lines between basic research, development, application and engineering increasingly overlap, but the science and engineering departments often do not. Concurrency and teaming among scientists and engineers is critical to solving complex problems effectively, but chemistry and chemical engineering remain worlds apart on university campuses. This not only diminishes the research effort and slows the diffusion of ideas into the market but fails to prepare students for the challenges they will face in industry research departments.

More Emphasis on Process Research: The seminal report of the National Academy of Sciences on materials science and engineering concluded that:

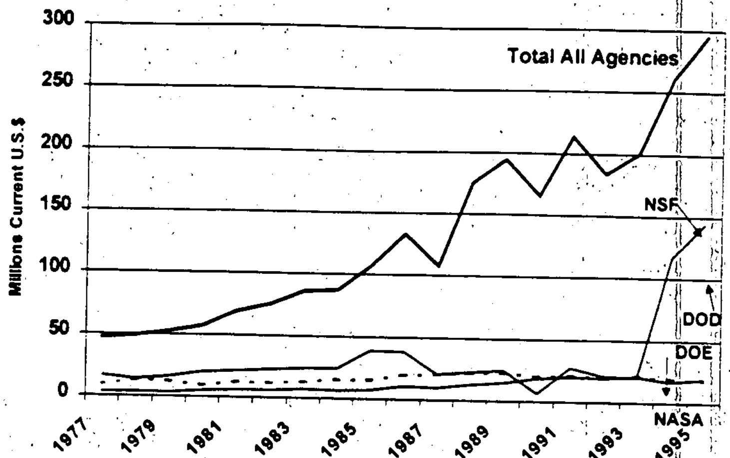
"Synthesis and processing together form a critically important element of materials science and engineering that has too often been neglected by universities, industries and government. Because of weaknesses in materials synthesis, there is growing concern that the United States is losing its dominance in basic materials research... The essential difficulty seems to be that, with increasing frequency, industries abroad are bringing the results of R&D or of innovative design to production and then to the marketplace in considerably less time than is the current practice in this country. In too many instances, the new products produced elsewhere are more innovative in design and more reliable in function and are produced at a lower cost than in the United States."[19]

The reduction in defense procurement—which provided funding for process research as an integral part of applications development—has brought this issue to a head. Without the stimulus of procurement, the low dollar support (a few hundred million for the whole country) and the fits-and-starts-funding patterns for materials engineering have exposed weaknesses in the U.S. system (Chart 21). Although materials engineering is often treated as the poor stepchild of discovery research, the technical problems associated with advanced processes and the development of new catalysts are no less scientifically challenging.

The NSF is attempting to address this issue with the creation in 1996 of 13 more materials engineering research centers, bringing the total number to 24. Indeed, increases in NSF funding single-handedly improved the funding outlook for the field. But, this is largely reflective of the fact that overall funding for materials engineering is relatively low. NSF cannot carry the full burden of a system-wide problem.

Chart 21

Federal Obligations to Universities & Colleges for Research in Metallurgy & Materials Engineering



Source: National Science Foundation.

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What Should We Be Doing

Benchmark the Industry: The lack of data on the advanced materials sector—research funding and performance, enrollments, international comparisons—is handicapping the industry's ability to assure national support. The companies and their associations should take the lead in aggregating information on a sector whose importance to the economy can only increase.

Assure Government Support for Frontier Science and Engineering: The definition of frontier research is that the path ahead is dark or unknown, precisely the areas in which industry is unlikely to go. As industry research has become more strategically focused and tied to the bottom line, government support in frontier research areas of science and engineering has become critical to sustaining innovation. In addition, there is a need for more dedicated investment in diagnostic and control instrumentation which is becoming ever more sophisticated and expensive.

Stimulate Concurrency and Teaming Between Scientists and Engineers: Current university programs, even multidisciplinary ones, tend to emphasize fundamental theory, analysis and discovery rather than materials design, processing and manufacturing. Total federal support for materials engineering, in the hundreds of millions for the entire nation, is already far from optimum levels. But, the separation between the science and engineering departments further undercuts the ability to deploy new materials knowledge quickly and economically.

Strengthen Tax Incentives for Collaborative Research and Investment in Small Company Research Programs: Sector participants indicated that, although their accounting departments take advantage of the R&D tax credit, it does not influence their up-front decisions on how much to invest in R&D. Barring a restructure of the credit, they offered two ways that reform of the tax credit could stimulate additional R&D investment in support of national goals. Collaborative research efforts would be encouraged if the credit for consortia was a least as large overall to the credit received for in-house research. Investment in small company innovative research could be stimulated if coverage of the credit were extended to R&D taken as equity investments.

Sustain Support for SBIR: The Small Business Innovative Research program is a significant driver of materials-related innovation in this country. But, its funding—tied to agency research budgets—has become inconsistent and uncertain. The program is critically important, particularly for materials start-ups, and needs a sustained source of support.

Increase the Availability of Industry Internships and Peer Interactions: Industry has a responsibility to help familiarize students with industry research methods and organizations. Companies need to play a more pro-active role in supporting university internship and co-op programs that provide students and faculty with direct exposure to research needs and opportunities in the private sector.

Catalyze Industry Partnerships: Government-supported partnerships, like the ATP, play a critical role in materials innovation beyond the money that the government cost shares with the private sector. For some companies, the partnerships stimulated vertical linkages with manufacturers for applications research—leveraging both cost and risk. For others companies, the peer-reviewed proposals validated the quality of in-house research in longer-term project areas, like high temperature superconductivity. The programs have far more reaching, yet often subtle, impacts than their relatively small levels of funding would imply.

Act Now to Revive K-12 Education: A wide range of solutions to America's failing K-12 system have been proposed—from setting higher standards for students and teachers, to encouraging stronger leadership by school administrators, to introducing competition in school systems. The viable solutions are on the table; the time to act is now.

Advanced Materials Sector Study

Co-Chairs:

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3M

Victoria Haynes
The BFGoodrich Company

Members:

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Allied Signal

Donald Paul
Chevron Corporation

Robert Pangborn
Dow Chemical

James W. Meyer
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Spiros Dimolitsas
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Arati Prabhakar
Raychem Corporation

Robert Eagan
Sandia National Laboratories

Henry Weinberg
Symyx Corporation

Mary Good
Venture Capital Investors, LLC

Co-Chair and Sector Advisor Biographies

Dr. William E. Coyne was appointed **3M**'s senior vice president for R&D in January 1996. Prior to that, he served as vice president for R&D, president and general manager for 3M Canada Inc., and group vice president for the medical products, health care, and the health care products and service groups. He received his B.S. in pharmacy and his M.S. in pharmaceutical chemistry from the University of Toronto and earned his Ph.D. in organic chemistry form the University of Virginia.

Dr. Victoria F. Haynes is vice president of R&D and chief technical officer of **The BFGoodrich Company**. Responsible for the direct management of central R&D resources, she advises the company on the management of technical resources. Prior to joining BFGoodrich, Dr. Haynes spent 15 years with Monsanto. Before that, she was a post-doctoral associate at Purdue University after receiving her Ph.D. in physical organic chemistry from Boston University, following a master's degree in college chemistry teaching. She earned an bachelor's degree in chemistry from UC Berkeley.

Jay M.S. Henis holds a Ph.D. in physical chemistry from Syracuse University. He was a senior scientist and director of Corporate New Technology Development for the Monsanto Company until his retirement in 1991. He currently serves as president and CEO of Orex Pharmaceuticals (a company dedicated to the oral delivery of proteins and other low bioavailability therapeutics) and president of Henis Technologies, Inc. (a consulting firm specializing in technology development covering a wide range of materials and separation science, technology evaluation and business development).

Going Global: Automotive Industry

Industry Co-Chairs: Kenneth Baker
John McTague
Sector Advisor: Ron Pandolfi

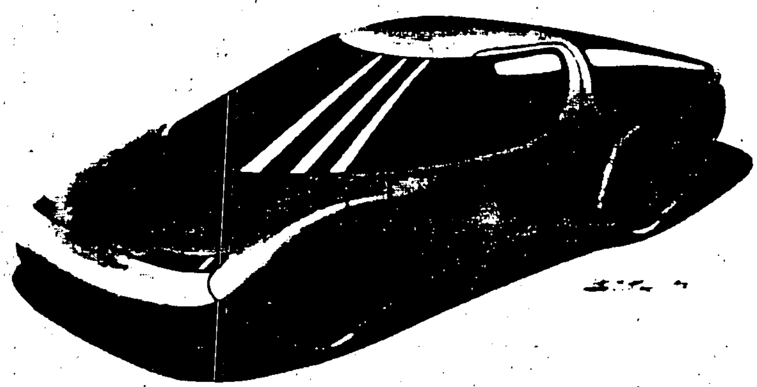
Why Innovation Matters

The automotive industry is in the midst of a major technological transformation that promises to alter substantially the cars we drive and the way we drive them. There is a revolution underway in electronic and automated controls, fuel-efficient or alternative fuel vehicles and lightweight materials—and it is occurring at a more rapid rate than envisioned even a few years ago (Figure 1).

Newly engineered materials will provide lighter vehicle structures with improved corrosion resistance. New electric motor designs, batteries and power semiconductors are enabling electric vehicles. Jumping up a step in complexity, these same technologies will support hybrid vehicle concepts that couple electric propulsion with a heat engine for longer distances. Over the horizon, but gaining speed, are fuel cell devices able to transform fuel and air directly into electricity without the efficiency limitations imposed by heat-engine cycles. The revolution in microelectronics and information technology will enable drivers to avail themselves of new communications systems and services, including navigation, entertainment and vehicle diagnostics. Further out is the option to remove the driver from the loop entirely via automated highway systems.

The automotive industry is in the midst of major technological transformations...

Figure 1



Source: Rocky Mountain Institute.

Leadership in advanced automotive technologies will determine whose companies dominate the car markets of the 21st century.

The pace and timing of innovation in this industry is critical. Global competition in the automotive industry will be based on developing cars suited to less traditional markets, where the transportation infrastructures are often not well developed, per capita income is lower, and the price of fuel is higher. New technologies and alternative designs are necessary simply to make driving possible for millions of people in emerging economies. But, leadership in advanced automotive technologies will determine which car companies dominate the global markets of the 21st century.

Globalization of the Automotive Industry

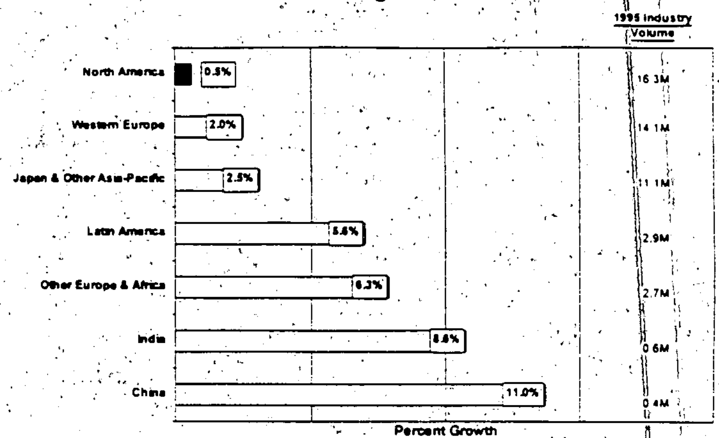
The end of the Cold War catalyzed new forces that have fundamentally changed the balance between national and global drivers for the industry. From its earliest days, nations have looked to the automotive industry as a mainstay of employment and a showcase for national capabilities. Nations nurtured their auto manufacturers, and native corporation rallied behind their national flags. A nation's welfare was integrally connected with the welfare of its major automotive manufacturers.

Today, acquisitions and mergers have blurred the traditional national identities in the automotive industry. The traditional large-scale vertical integration within a single country is giving way to a more flexible horizontal diffusion of operations that span geographic and national borders. Two forces are shaping globalization in the industry: the

And the fastest growing markets are overseas.

Chart 1

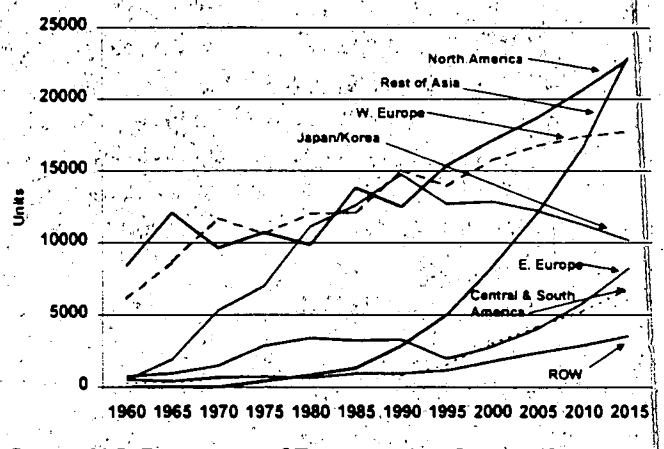
Annual auto market growth, 1995-2005



Source: 1995 Ford Annual Report.

Chart 2

World Vehicle Production Is Going Global.
(World vehicle production, 1960-2015)



Source: U.S. Department of Transportation. Bureau of Transportation Statistics. www.bts.gov/btsprod/nts/tb11x30.html growth of demand offshore and the emergence of new national competitors.

Growth in Global Demand: For the first time in a hundred years, there is virtually no net projected growth in the industry's traditional markets in North America, Western Europe and Japan. Most of the growth in demand will be in the emerging economies of Asia, Eastern Europe/Russia and Latin America (Chart 1, previous page). U.S. automotive manufacturers are building new capacity where demand is the greatest—and sending R&D operations overseas with production (Chart 2, previous page).

Although the United States remains the dominant location for research investment by U.S. manufacturers and suppliers, as well as for foreign companies, R&D investments at the margin are flowing overseas. The United States and Germany hold about 90 percent of the industry's nearly $18 billion R&D investment, but sector executives indicate that investments in other countries—notably China, Japan, the U.K., France, Sweden and Israel—are expected to rise (Charts 3 and 4). A growing proportion of their research abroad extends beyond that needed to meet local regulations. Indeed, new product and fundamental research is an increasing part of the research mix overseas (Chart 5).

Growth of New Competitors and Capacity: Many nations are making serious efforts to build up domestic automotive capability, far beyond estimated local demand, or attract foreign automotive

R&D is going global.

Chart 3

Although Most R&D Investments by U.S. Companies Are in the United States and Germany...

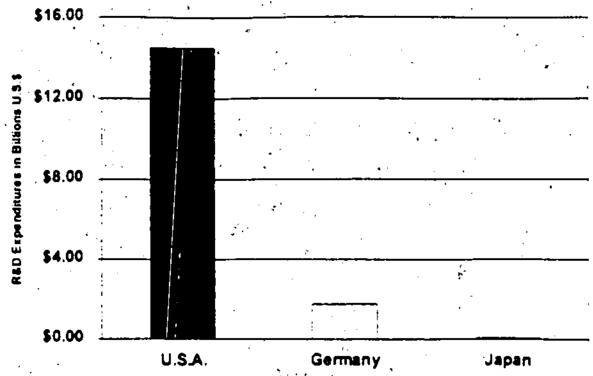


Chart 4

...R&D in Emerging Countries Is Rising...

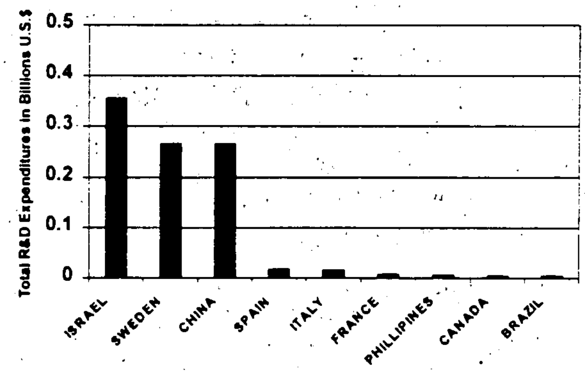
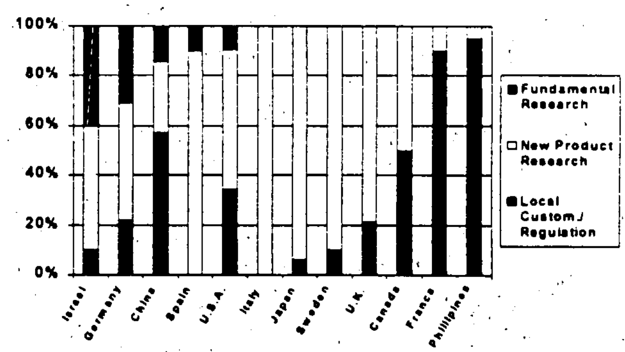


Chart 5

And More Fundamental and New Product Research Is Going Overseas



Source: Council on Competitiveness Sector Surveys. 1997.

investments—and with good economic reasons. The industry is a major driver off economic growth, employing millions of people often at higher than average wage rates. It is an enormous wellspring of technology, bringing up the overall national level of component and manufacturing technology. Having a robust automotive industry remains one of the key indicators of first-nation status. Few large nations have been able to sustain a robust economy without one.

The net effect on the global industry, however, is substantial overcapacity, which has created a high-stakes competition for market share (Chart 6). Globalization of capacity forces companies to compete for business in each aspect of the automotive industry, independent of the national flag of the corporation. This is particularly true for supplier companies, but also increasingly true for auto manufacturers.

Where We Stand

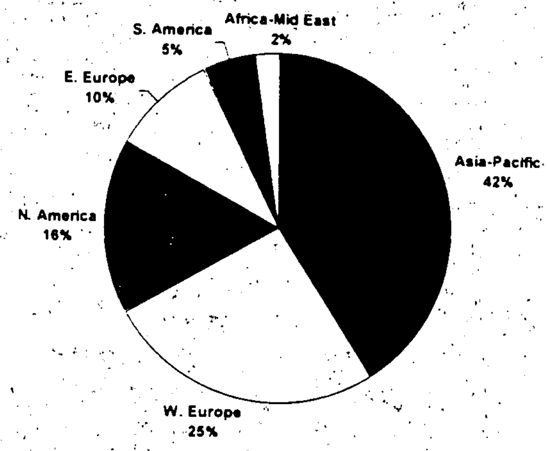
The U.S. auto industry views technology as the key to global competitive success. The companies are among the highest R&D investors in any U.S. industry (Chart 7). For the United States, advanced technology and innovative research remain the key, and perhaps the only, means of growing its global share of the automotive industry.

Our margin of technological leadership is bolstered not only by the R&D that U.S. companies perform in the United States, but also by significant R&D investments in the U.S. by all major global competitors. As the industry goes

Global overcapacity is intensifying competition

Chart 6

Global Excess Capacity
Regional Distribution; Average 1997-2002



Source: Coopers and Lybrand. *Auto Facts*.

U.S. automotive companies are among the highest R&D investors.

Chart 7

Top 10 U.S. Industrial R&D Spenders in 1995
(billions of dollars)

General Motors	***$8.388***
Ford	***$6.509***
IBM	$5.227
AT&T	$3.718
Lucent Technologies	$2.697
Hewlett-Packard	$2.302
Motorola	$2.197
Johnson & Johnson	$1.634
Pfizer	$1.442
Chrysler	***$1.400***

Source: Ford Motor Company.

global. the ability to attract high value research activities and high tech plants into the United States will be critical, regardless of the flag of the corporation.

But, U.S. leadership in automotive technology is not guaranteed for the long-term. Sector executives expressed four principal concerns.

- National and industrial myopia embodied in a tendency to concentrate on product and process innovations for the familiar, but saturated, traditional markets
- Risks to the U.S. engineering talent pool
- Growth in science and technology competencies overseas
- National policies that create de facto advantages for off-shore competitors

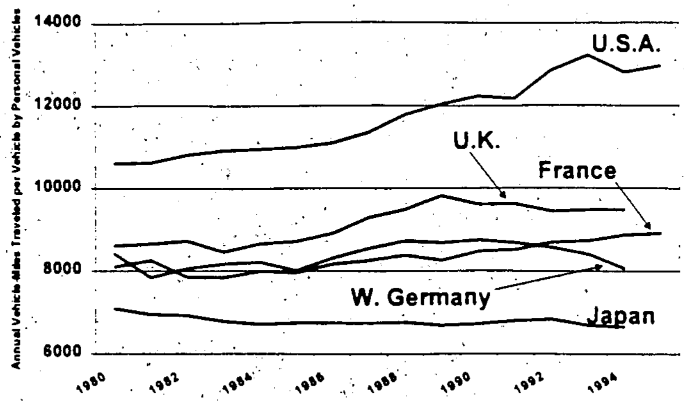
National and Industry Myopia: The October 1997 Toyota Motor Show provided a wake-up call to the international auto industry that the revolution in automotive technologies may be coming faster than anticipated. In response to the unveiling of several fuel-efficient, low-emission cars by Japanese manufacturers, U.S. automakers have stepped up the timetable for the introduction of their own advanced technology models. But, the lack of demand for such vehicles in their home—and largest—market remains a key innovation hurdle.

The U.S. auto market is fundamentally different from the other markets around the world. Americans rely on their personal cars

But the U.S. market is increasingly unique.

Chart 8

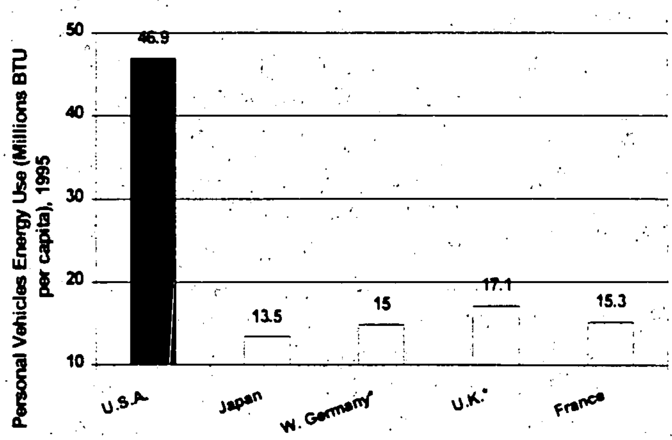
Americans Travel Much Greater Distances...



Source: Lawrence Berkeley Laboratory. International Energy Studies. Energy Analysis Program. 1995.

Chart 9

And Use Much More Energy...



Source: Lawrence Berkeley Laboratory. International Energy Studies. Energy Analysis Program. 1995.

more than anyone else does. The vast majority, 91 percent, relies on cars as their principal mode of transportation, and most American families own two cars. Our tastes run towards heavier vehicles. The fastest selling cars in the United States today are lightweight trucks. Given the longer distances traveled in heavier cars, we consume more energy per vehicle than Japan, West Germany and the U.K. combined (Chart 9, previous page).

Prices at the pump are also lower in the U.S than almost anywhere else (Chart 10). These differences in gas prices have less to do with the base price of oil than the fact that foreign governments impose much higher taxes on fuel (Chart 11). The problem is that when a gallon of gas costs less than a comparable gallon of milk or water, customer demand for innovation for fuel-efficient or alternative fuel vehicles is not particularly strong.

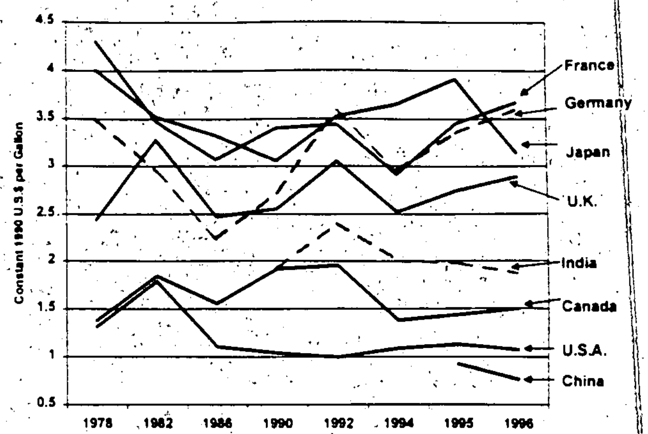
Ultimately, the uniqueness of the American market is unsustainable. Global climate change concerns related to atmospheric carbon dioxide are growing, although more research is needed to establish both the linkage and the impact. Moreover, increased motor vehicle production will drive up prices for raw materials, including oil, in the U.S. market, likely forcing a shift in consumer preferences towards more fuel efficient vehicles.

The bifurcation of the U.S. market from the rest of the world, however, creates current innovation dilemmas. To stay in the game globally, U.S.-based manufacturers must innovate.

Chart 10

But pay less at the pump

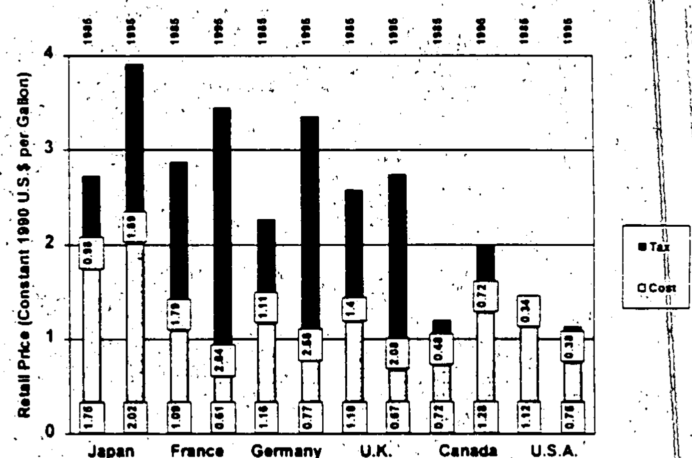
(Price of gasoline per gallon)



Source: Lawrence Berkeley Laboratory. International Energy Studies. Energy Analysis Program. 1995.

Chart 11

Differences in Gasoline Prices Are Tax-Based.



Source: Lawrence Berkeley Laboratory. International Energy Studies. Energy Analysis Program. 1995.

But, the market pull for advanced technology vehicles is coming primarily from overseas, which in turn reinforces pressures on U.S. and foreign manufacturers to shift investment globally. Such as shift could damage the U.S. infrastructure for innovation in the automotive industry.

Without a national strategy and agenda to leverage industry resources for breakthrough research and engineering in the U.S., to stimulate consumer demand for fuel-efficient and alternative fuel cars, and to provide the infrastructure to fuel them, it is not clear that the key technologies transforming the industry will be developed and deployed here. The danger is that this could be a revolution that occurs overseas, perhaps even led by U.S. companies operating abroad.

Risks to the U.S. Engineering Talent Pool: Lagging support for university research and declining numbers of engineers do little to offset these centrifugal investment pressures.

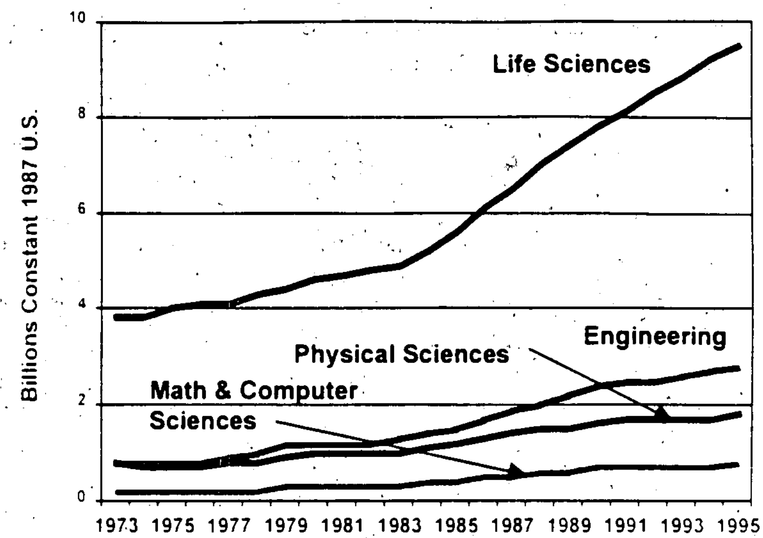
Automotive research spans a wide range of basic and applied disciplines. The basic disciplines of physics, chemistry, mathematics, and engineering remain fundamental to the auto industry; a host of new technologies in materials, energy, and electronics are setting the pace for development.

But, funding for the physical sciences and engineering in U.S. universities has been static or declining over the past decade (Chart 12). With the end of the Cold War,

Risks to the research base and talent pool.

Chart 12

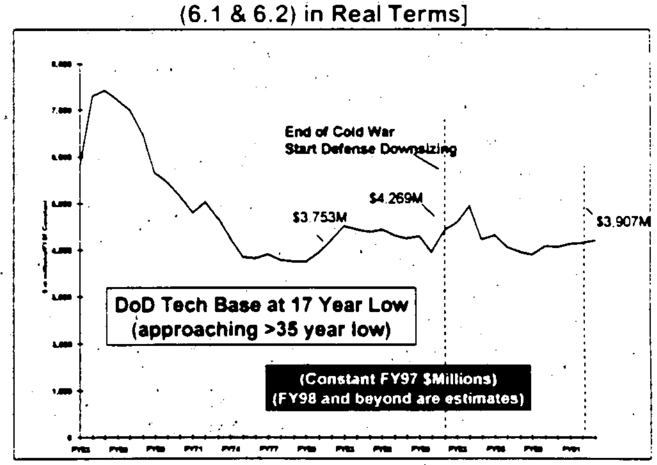
Support for University Research in Engineering and Physical Sciences Is Lagging



Source: National Science Foundation. WebCASPAR database; http://caspar.nsf.gov.

Chart 13

DoD Research Support Is Reaching a 35-Year Low
[Department of Defense (DoD) Technology Base (6.1 & 6.2) in Real Terms]



DoD funding, a bulwark of support for these fields, has also declined substantially. Indeed, recent estimates indicate that the overall DoD budget for basic and applied research is reaching a 35-year low (Chart 13, previous page).

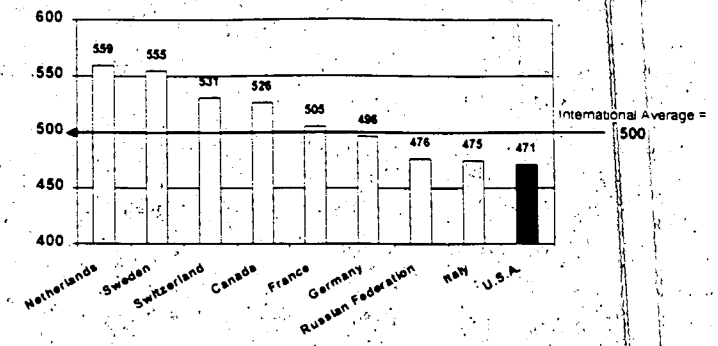
Sector participants were also concerned about the quality of education and technical training at all levels in the United States. Global competitiveness to attract auto industry investment will hinge on access to a well-trained workforce. Over time, the industry will be drawn to regions providing the best educational and training infrastructure.

Recent studies indicate that the United States lags other nations in the quality of its science and mathematics education at the K-12 level (Chart 14). Apprenticeship and vocational training opportunities remain much higher overseas. This constitutes a major competitiveness issue for the U.S. auto industry. If product quality is to meet global standards, assembly workers must master a wide range of technologies including advanced electronics, computers, robots, sensors and lasers.

The United States also increasingly lags many other regions in the number of undergraduate engineering degrees. While U.S. engineering degrees gradually declined to about 61,000 in 1993 after reaching a peak in the mid-eighties, European graduates nearly doubled to an annual total of nearly

Chart 14

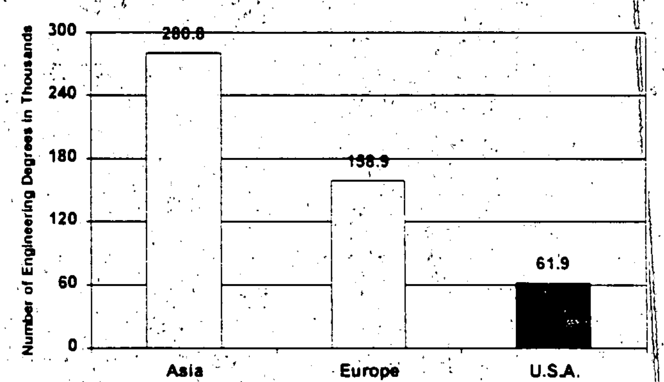
U.S. Mathematics & Science Literacy in 12th Grade Is Significantly Lower Than the International Average



Source: IEA. *Third International Mathematics and Science Study, 1995-96.*

Chart 15

Asia Outpaces Europe and the United States Combined in Engineering Degrees



Source: National Science Foundation. *Data Brief.* Science Resources Studies Division. Vol. 1996, No. 12. November 27, 1996.

159,000 (Chart 15, previous page).[1] But, Europe and the United States would have to combine their total engineering degree numbers to match the growing numbers of degree recipients in Asia—around 281,000. Moreover, roughly 50 percent of students enrolled in doctoral engineering programs at U.S. universities are foreign nationals (Chart 16)—and a growing percentage of foreign students are returning home after completion of their studies (Chart 17).

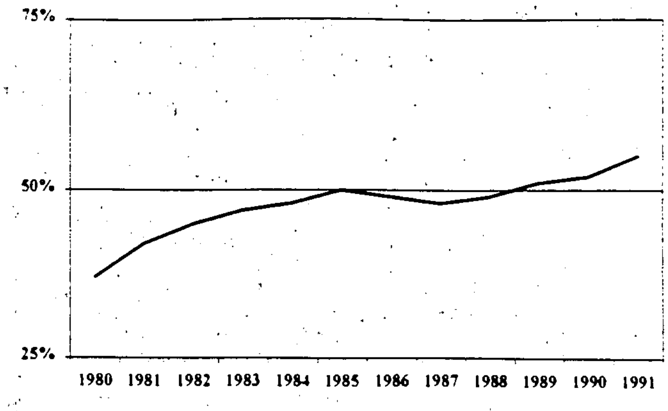
Science and Technology Competency Abroad: Until recently, only the developed nations had the educational infrastructures capable of producing the high quality scientists and engineers needed for the automotive industry. Today, developing nations—notably China and India—have substantial pools of engineering talent. These engineers interact collaboratively on a global basis thanks to advances in computers and telecommunications. As a result, they are able to provide high quality S&T services to automotive companies and at a significant discount compared with the developed nations.

Developing nations—from China to Brazil—are pooling talented scientists and engineers into centers of excellence to compete for automotive research in niche areas. Their technical centers have demonstrated an ability to partner effectively with industry and to leverage national research programs.

[1] National Science Foundation. *Data Brief.* Science Resources Studies Division. Vol. 1996, No. 12, November 27, 1996.

Chart 16

Foreign Nationals Make Up a Majority of Engineering Doctoral Students in the United States



Source: National Science Foundation. WebCASPAR. Http://caspar.nsf.gov

Chart 17

But an Increasing Number Are Returning Home

(Foreign Engineering Doctoral Recipients from U.S. Universities With Firm Plans to Stay in the U.S.A.)

	1980	1992
S. Korea	58.5%	14.9%
Taiwan	55.8%	22.5%
Europe	53.4%	33.7%
Other Asia	51.4%	31.2%
China	38.1%	36.2%
Japan	18.5%	12%
Brazil	27.3%*	12.9%

Source National Science Foundation *Science & Engineering Indicators–1996* App Pp 68-71 Table 2-34
* = 1990

Brazil's Sao Paulo region has achieved high marks in new engine design, drawing on Brazil's leadership in combustion physics and advanced materials. Bangalore, India has built a first-class scientific workforce of software engineers and related research scientists that the auto industry cannot ignore. With top education, the best equipment, and a quality infrastructure, scientists in Bangalore work for a fraction of the wages demanded in developing countries. Israel, which has the world's highest percentage of scientists and engineers including a multitude of former Soviet émigrés, excels at ensuring technology transfer from its domestic military and civilian work to investor companies.

National Policy Differences: Governments in North America, Europe and Japan have embraced the global economy. They have allowed and encouraged transnational automotive manufacturers to deploy technologies in emerging markets. This has permitted individual auto companies and their suppliers to site research in one nation, components and assembly in a second for distribution in yet another country, continually re-adjusting their operations to take advantage of opportunities throughout the world.

To keep or attract the highest value investments, many countries offer a variety of incentives that include substantial tax credits, training credits, low-cost loans and deductibility for some types of developmental expenses. In many cases, these incentives exceed what is available in the U.S.

Chart 18

Many Nations Offer a Plethora of R&D Incentives

France:	--50% credit for incremental R&D expenditures --R&D buildings qualify for 50% supplementary 1st year depreciation --Grants available to assist foreign investors in locating R&D centers
Germany:	--Software development costs now deductible --Loans and/or major grants for R&D or new technology may be obtained from Federal Ministry of Research and Technology
Japan:	--Tax credit available for up to 20% of incremental R&D expenditures—including those for new product development, product improvement, and invention or design of new techniques
S. Korea:	--Technology and manpower development credit of up to 50% --Research and experimental facilities credit of 5% (or special depreciation of 50% of the acquisition cost of facilities) --Technical license royalties tax-exempt for 5 yrs --5-year tax holiday may be obtained for foreign investors bringing in high technology
Malaysia:	--Double tax deductions allowed for certain expenses connected with approved scientific research projects
Singapore:	--Double tax deduction for R&D expenses in certain cases --Capital investment allowance of 50% in certain cases --Initial 25% investment allowance and 3% annual allowance for R&D buildings --Grants of 20%-30% of the costs of certain R&D activities with potential technological benefit to the country
U.K.:	--Capital grants, below-market interest loans, loan guarantees, and/or tax incentives may be granted for various R&D programs, upon government approval

Source: AAMA.

Governments, particularly in emerging economies, also employ another technique to augment their science and technology base: implicit or explicit requirements linking technology transfer to market access. (Chart 19).

Transfer of the latest technology is quite simply the price of entry into these formerly closed markets. Other common demands include the establishment of collaborative R&D centers and funding of research at local universities and national research facilities. Local content regulations often drive the technology transfer process.

Without government intervention to enforce international trade agreements, technology is flowing abroad from U.S. industrial and national laboratories as well as from U.S. universities.

Sustaining National Leadership

Control of the intellectual property and processes surrounding advanced automotive technologies will drive competition in the industry well into the next century. The unrelenting pace of technological change and global diffusion of manufacturing, in conjunction with unprecedented pressures on profits (a combination of overcapacity and global competition), is creating a very fluid situation.

Clearly, among the key elements of national leadership are research superiority and a robust talent pool. While essential conditions, these are far from sufficient. In the absence of

Chart 19

Emerging Economies Use Import Polices and Non-tariff Barriers to Pull in Technology Investments

	Import Policies	Investment Barriers
Brazil	Local content required to qualify for lower duties.	Foreign investment limited in strategic sectors (incl. Transport). Incentivess for auto co's linked to export perfromance.
China	Prohibitively high tariffs, unpredictable application, lack of transparency, corruption, import licencese and quotas, import substitution policies	Tech transfer requirements.
India	Restrictions on consumer goods imports. High tariffs.	Automatic approval for equity investments of 51% in 35 industries
Israel	Most trade barriers eliminated.	Positive environment for foreign investment.
S. Korea	Multiple barriers: quotas, very high tariffs, unpublished internal restrictions/guidelines.	Although on 1/1/97 97% of sectors "open," effective access limited by law, regulations, and inexplicit administration guidance.
Malaysia	Duties average less than 10%, but tariffs run much higher where there is local production.	Local and foreign investors receive fiscal incentives subject to performance reqs, local content and tech transfer.
Singapore	98% of goods enter country duty free—but tariffs remain on autos and gas.	High degree of foreign investment.

market demand, technology breakthroughs in fuel-efficient and alternative fuel vehicles may simply fall on barren ground or go elsewhere for development and deployment. Either way, the ability of the U.S. to sustain innovative leadership and attract high-value investments from industry will be eroded.

Economic Incentives are Critical: In the price-sensitive motor vehicle market, it's always uncertain whether and what consumers will pay for new technology. Given the unique market conditions in the U.S., however, production of advanced technologies, like hybrid vehicles, will require more than industrial and government R&D funding. Movement from laboratory and pilot-scale facilities to markets in the U.S. will have to involve economic incentives, including fleet purchases by state and federal governments and personal tax credits.

In every country in which alternative fuel vehicles have made significant headway, for example, the national government has played a critical role by establishing incentive pricing, through taxes or subsidies, for the purchase of new alternative fuel vehicles, conversion of conventional vehicles or for the refueling infrastructure.

In Canada, New Zealand, the Netherlands, Italy and Brazil, the effective price of alternative fuels is considerably less than gasoline. Unlike these countries, the U.S. fuel tax structure penalizes all the alternative fuels other than

What We Should Be Doing

Economic Incentives for Fuel-Efficient and Alternative Fuel Vehicles

- The State and Federal Governments Should Meet Acquisition Targets Set Out under the Energy Policy Act of 1992.

Chart 20

Federal Agencies Are Falling Short in AFV Acquisition

	Required AFV Acq.	Actual AFV Acq.
1996	6666	5488
1997	5600	2600
1998	8000	3500 (est.)

compressed natural gas, ethanol and electricity.[2]

In Japan, the government has created a tax deduction for purchase of alternative fuel vehicles at the national level, a reduction in the car purchase tax at the local level and provides low-interest loans for purchase of low-emission vehicles.

Unlike other countries, the U.S. government has focused almost exclusively on government-industry research partnerships (e.g. the Partnership for a New Generation Vehicle) and procurement mandates. Although the Energy Policy Act of 1992 (EPACT) set targets for acquisition of alternative fuel vehicles for its own light duty vehicle fleets, for state-purchased fleets and for cars purchased by energy providers, many agency purchases have fallen short of the targets.

Government purchases of vehicles for public fleets may help launch the market for fuel-efficient and alternative fuel vehicles, but only customer demand can sustain it. Although energy efficiency and pollution controls are important national goals, economic incentives for the larger population have played a relatively small role in the U.S. In the absence of market signals, such as increases in the price of gasoline, or regulatory requirements, such as higher emission standards, state and federal governments may need to

[2] Department of Energy, Energy Efficiency and Renewable Energy, Office of Transportation Technologies. *Replacement Fuel and Alternative Fuel Vehicle: Technical and Policy Analysis*. July 1997.

What We Should Be Doing

State and Federal Governments Need to Create Economic Incentives to Stimulate Customer Demand

- Consumer tax credits for the purchase of fuel-efficient and alternative fuel vehicles
- Low interest loans for fuel-efficient vehicles
- Fuel taxes that incent alternative fuels over gasoline
- Preferential parking and access to express lanes for alternative fuel vehicles

offer purchase incentives—both direct in the form of tax credits and indirect such as preferential parking and access to express lanes—to create enough volume to drive down production costs.

Public-Private Partnerships are Critical: Although the Big Three R&D budgets as a whole are increasing, funds available for breakthrough research are not. Public-private partnerships, like the Partnership for a New Generation Vehicle (PNGV), are needed to leverage resources and increase the national potential for innovation. Given that the pace of technology change has been faster than anticipated, the scope and focus of PNGV should be expanded in three ways. First, the partnership should be refocused on research needs for the vehicles of the future, well beyond the original 2004 framework. A number of the technologies selected early on for the PNGV are now too close to commercialization to be ripe for collaboration. Second, automotive suppliers, who are an increasingly integral part of the research web in the automotive industry, should be invited to participate in the consortia. Third, the United States needs to rethink the issue of participation by foreign firms in public-private partnerships in the U.S. As the industry mergers blur the nationality of firms, the key criteria for participation should not be country of incorporation, but the value added to the U.S. economy.

Partnerships with universities and national labs are critical: Sector executives agreed that research partnerships involving the

What We Should Be Doing

Refocus the Partnership for a New Generation Vehicle

- Expand the scope of research beyond the 204 time frame
- Invite automotive suppliers to participate in the consortia
- Include companies based on value-added to the U.S. economy and technology base rather than country of incorporation

auto industry (OEMs and suppliers), national laboratories and universities are crucial to maintaining U.S. technological leadership.

Universities create not only the future talent feedstock for the industry, but the advances in frontier science and technology that are underpin advances in breakthrough technologies. The national labs have unmatched supercomputer capabilities that can be utilized for industrial applications. Auto manufacturers currently are among industry leaders in supercomputer usage, but even their largest computers lag national lab capacity.

Partnering offers win-win solutions. Universities benefit both from the feedback on cutting-edge research issues and the opportunity to provide graduates with first-hand experience in problems relevant to the industry. The national labs benefit from the practical insights and time discipline that partnerships provide.

The ability to solidify these technological networks among the key sectors of the U.S. economy will become critical in sustaining and attracting investment in advanced automotive technologies. Sector respondents identified a few areas for improvement.

1) *Eliminate Red Tape*: Partnerships in the past have been slow to develop because of the complexity of the laboratory system and government regulations. Although significant progress has been made in simplifying the agreements and applying those conditions to

What We Should Be Doing

Promote Auto Industry Partnerships with Universities and National Laboratories

- Simplify the process and eliminate unnecessary overhead charges in partnerships with national laboratories
- Increase interdisciplinary university programs
- Create industry-sponsored apprenticeship programs

multiple laboratories, the act of establishing a new cooperative research and development agreement (CRADA) still gives many companies a punishing lesson in bureaucracy and extra overhead charges. Although no money changes hands (U.S. scientists are supported by government funds while company money supports company scientists), the negotiations over intellectual property rights and other issues can drag on for years. Moreover, the DOE assesses a 30 percent overhead rate on CRADAs over and above the laboratory overhead rates.

2) *Increase Interdisciplinary University Programs*: Sector respondents observed that advanced technologies in the transformed auto industry require far more multidisciplinary training than is available today at American universities. They urged that graduates heading for industry employment become more comfortable working in interdisciplinary environments or "project teams." Graduates must be familiar with the new "interdisciplinary disciplines," such as mechatronics that integrate electrical, electronic and mechanical device characteristics.

3) *Apprenticeship Programs:* Sector participants suggested that both the industry and the research universities need to focus on educational requirements that cannot be met solely in the university environment. More

cooperative and apprenticeship programs are essential to provide students with experience in the transition from an analytic to an innovative phase of development.

Automotive Industry Sector Study

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DRAFT

Going Global: Express Package Transportation and Logistics
The Role of Research, Development and Organizational Innovation

Sector Advisor: Bruce R. Guile

> *Last year American companies spent $670 billion—a gaping 10.5% of GDP—to wrap, bundle, load, unload, sort, reload, and transport goods. So clogged is the gross national pipeline with unnecessary steps that the grocery industry alone believes it can wash $30 billion, or nearly 10% of its annual operating costs, out of the system. A typical box of breakfast cereal spends a stunning 104 days getting from factory to supermarket, haltingly progressing through a concatenation of wholesalers, distributors, brokers, diverters, and consolidators, each of which has a warehouse.*
>
> Ronald Henkoff
> "Delivering the Goods"
> *Fortune*, November 28, 1994

Integrated Logistics and Express Package Transportation

Price and service competition among U.S. manufacturing and service companies are driving firms to adopt business practices that minimize inventory costs and reduce cycle times throughout the value-adding chain of events in the production, distribution and delivery of goods and services. These economic pressures and opportunities are driving rapid changes in the physical flow of goods—transportation, trans-shipment, and warehousing of materials, components and finished goods—in the U.S. economy and, to a certain extent, globally.

As a result, there is a growing demand for relatively rapid (2-3 days domestic; 10-14 days international), time-definite package transport that is supported by enough information technology (package tracking and access to the information) so that the transportation system can be treated by manufacturers, distributors and retailers like a nearby warehouse and by customers like a local retail store; i.e. you know exactly where something is and when you can get it.

Two technologically dynamic, though not particularly R&D-intensive, industries enable the current changes in the physical flow of materials, components and finished goods: electronic commerce and express package transportation. The marriage of these two industries in application is variously described as supply chain management, logistics or value chain management.

Supply- or value-chain management can be difficult to understand as it cuts across historically separate business functions. Full-scale value-chain management will integrate (on the back of an enterprise-scale database) a Web-based retail "store," production, materials and resource planning, and procurement. Management scholars and practitioners know it as a combination of aspects of Materials Resource Planning II, Just-In-Time and Total Quality

Management.[1] U.S. manufacturers, service companies and consumers appear to be driving demand for logistics[2] services, but it is global phenomenon, if for no other reason than many production processes involve international transport of materials, components, and finished goods.

Logistics is a systems integration and management activity that can improve customer service and company image while reducing cycle time (increasing asset utilization) and reducing inventory and transportation costs. And there are plenty of opportunities to take costs out of most supply chains. Distribution—the function that logistics providers most commonly handle—is generally defined to address inventory processing, storage and warehousing, transportation network analysis, transportation and delivery, and sometimes order processing and customer service.[3] The expense associated with these functions in a company varies greatly. One long-running, survey-based, U.S. data set yields an average distribution cost equal to 7.94 percent of company sales revenue with costs higher in some industries (e.g., processed foods) and in smaller companies (under $200,000,000 in sales), and lower for products with high value to weight and volume ratios.[4] In other economies, the average costs of distribution are usually higher, 8.8 percent in Japan and 14 percent in South Korea by one recent estimate.[5]

Traditionally the economics of transportation have dominated decision making about how products are aggregated for shipment. The physical characteristics of the goods being moved affect the economics of transportation but not the physics: only a small portion of non-bulk shipments (less than 5 percent) cannot be broken into packages[6] of 150 pounds or less. What is

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1 See, for example, Davis, Tom. "Effective Supply Chain Management," *Sloan Management Review*, Summer 1993; Saccomano, Ann. "Demand-chain management turns traditional supply chain inside out," *Traffic World*, March 13, 1995; Bowersox, Donald J. "The Strategic Benefits of Logistics Alliances," *Harvard Business Review*, July-August 1990; and Muller, E. J. "Pipeline to Profits," *Distribution*, September 1990.

2 It is important to note that logistics typically applies to more than just business applications and does not apply exclusively to packages. Military logistics (humans, equipment, weaponry, and food to and from where it is needed when it is needed) is a related and important field. Also, many of the technical tools and techniques of logistics are as valid for managing supertankers full of oil as they are for moving boxes of baby powder through a retailer's distribution chain. The Council of Logistics Management -- the dominant association for logistic professionals -- defines logistics without regard to speed or weight: "the process of planning, implementing and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods and related information from point-of-origin to point-of-consumption for the purpose of conforming to customer requirements."

3 Author after *MGI Cargo Analyst*, "R is for Logistics," January/February 1995, p. 11.

4 Davis, Herbert W. And Drumm, William H., "Physical Distribution Cost and Service, 1995," *Annual Conference Proceedings*, Council of Logistics Management, San Diego, CA, October 8-11, 1995, pp. 219-228.

5 Industry Logistics Association (of South Korea), quoted in "Korea Needs to Streamline the Supply Chain," *Korea Herald*, October 5, 1997.

6 Package shipping can include a number of overlapping markets, including customers/individuals shipping packages, letters or flats, catalog or Internet sales shipping, company-to-company or site to site within a company by an independent carrier, and company to company or site to site within a company by private fleet or dedicated contract fleet.

particularly interesting about package transportation and logistics is how the changing economics of production—the total value chain managed by a manufacturing or service firm—changes the calculus of distribution, drives the disaggregation of shipments, and makes winners and losers out of manufacturing and service operations.

The competitive pressure that is driving value chain management and time definite delivery—both for manufacturing and service companies and for the carriers that serve them—is illustrated by rates of growth in time-definite originated shipments. Comparing four quarters beginning in October 1993 to four quarters beginning in October 1994, the annual rate of growth in time-definite shipments handled by integrated carriers was 13.5 percent or between 2 and 3 times the rate of GDP growth in that period.[7]

The Provider Industries

To understand what is happening it is important to understand that effective value-chain management is an organizational innovation that is a complex soup of management expertise, information technology and transportation assets. Further, the demand for logistics services—like the demand for accounting services or legal counsel—is satisfied both by in-house providers (the logistics division of a company) and vendors. Therefore, the industry that provides this service isn't one industry but several.

- Integrated express carriers (management, information technology and transportation assets) provide logistics services to companies, as well as traditional business-oriented package shipping, package express services and individual consumer services. Globally, these companies are joined by multinational freight forwarders and "hybrid" express carriers that offer express service within a country but use freight forwarding to reach overseas locations. These companies compete—sometimes directly sometimes not at all—with national postal services.[8]

- Trucking and air cargo companies—traditional transportation assets for industry—move huge volumes of goods. Increasingly these companies are forced to provide, both independently and with dedicated fleets closely managed by the customer, rapid and time-definite delivery.

- Third party logistics providers—sometimes using their own transportation assets and sometimes using other's assets—provide supply-chain management solutions by providing the necessary scheduling, control and information technology. Typically, third party logistics suppliers have a history either as a freight forwarder (no assets) or as a transportation carrier

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7 *MGI Cargo Analyst*, "Where (800-Pound) Gorillas Come From," Third Quarter 1995, p. 23.

8 Competition between U.S. integrated express carriers and the U.S. Postal Service is a contentious issue. Integrated express carriers argue that they compete directly with the Postal Service, which has an unfair advantage because it holds a government-granted monopoly (letter mail) and subsidizes its package (parcel) business with revenues from the monopoly business. See *Statement of Kent C. "Oz" Nelson, chairman of United Parcel Service before the House Subcommittee on Government Reform and Oversight*, September 26, 1996.

with some transportation assets—tractors, trailers, trucks, planes, and/or warehouse or trans-shipment facilities.

- Information technology companies, especially network and software companies, play a large and growing role in the industry. The limiting factor in a company's ability to extract value from time definite transportation are the MRP, DRP and other information systems that companies run and the daunting (mostly organizational, not technical) task of making them work together well enough to be of value.[9] A further issue is the relationship of opportunities in logistics to the growing use of the Internet for commerce. Dedicated communication networks for controlling a supply-chain are developing in tandem with growing uses of the Internet for the same functions. Some very credible participants (Microsoft, for example[10]) in the information business view the Internet as an information/ communications tool that can allow smaller companies to handle the information aspects of value chain management and logistics. In some companies, the use of sophisticated approaches to value chain management involve working through the use of the Internet for retail selling, customer service, and dealer and vendor information exchange.

Technology and Organizational Innovation in the Industries

A very broad set of technological advances are relevant to these diverse companies in the package transportation and logistics industries: a) computers, communications networks, database software, electronic/optical sensors; b) electromechanical devices for materials handling in facilities and vehicles; c) vehicle/fleet related specialized equipment; and d) decision support or system design and analysis tools (see Figure 1, next page). In the context of a broad base of relevant technologies, three generic business problems motivate technical work in the industry:

- Improve customer-perceived value of service offered, e.g. communications and computer technology that allows reliable tracking and time-definite delivery.

- Improve efficiency in production of logistics and transportation services, e.g. materials handling and tracking technology to drive transportation and handling cost down or increase volume of packages handled at same quality.

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[9] The organizational difficulty of marrying new information technologies to transportation services to reduce distribution costs and improve flexibility and productivity may mean that new implementations are easiest. Companies that grow up in an environment where these tools exist for experimentation, development and use may be more likely to adopt these approaches. This may partially explains why some of the most successful implementation of these approaches occur in relatively new and rapidly growing organizations (Dell, Wal-Mart). Personal communications with Daniel DiMaggio, senior vice president and COO, UPS Worldwide Logistics and Ray Greer, senior vice president, Logistics and Technology, Ryder Systems, Inc.

[10] Microsoft has developed and launched something it calls the Value Chain Initiative. Microsoft's operating system software provides--under this initiative-- a platform for integration of different software packages that perform logistics- or value chain- related functions. As of March 31, 1998 the best description was available at http://microsoft.com/industry/trans/

Figure 1
The Technology Base for Express Package Transportation and Logistics

Facilities, Equipment and Rolling or Flying Stock
- Hub or cross-docking facility design, maintenance and operation
- Materials handling—hub, warehouse (cache areas), in-fleet
    + Equipment
    + Coding, tracking, sensors
    + Software, databases, communications (LAN, WAN, GPS)
- Fleet Design, Maintenance and Operation—aircraft and vehicles
    + Specialized design
    + Fuel efficiency
    + Operating procedures/decision support for maint. and operating control
- Packaging/Containers
- Distributed communications, database coordination/interactivity

Supporting and Providing Logistics and Value Chain Management
- Distributed package collection systems ("retail" package collection)
- Customer site shipping systems ("wholesale" sites)
- Provision of outsourced distribution and vcm for customers
- Global (multinational; multi-site; package transport; sorting and tracking) system design, maintenance and operation

Strategic Business Analysis and Decision making
- Data mining
- Operations research; modeling and simulation in support of network design or operation

- Enable creation of new markets, e.g. technology that allows a company to offer new services (supply chain management, integrated logistics) or to operate in new geographic regions (integrating a cross-docking facility in Louisiana or a hub in Asia into a transportation system).

The technological underpinnings of electronic commerce and express package transportation—and of their marriage in application to business problems—are diverse. In general, however, the core technologies are primarily information technologies (sensors, databases and networks) that can provide value-chain visibility and enable control of the value chain. Critical supporting technologies include operations research, materials handling and a broad range of transportation technologies.

The industries that provide these services, as mentioned above, are not traditional R&D-intensive industries. The technical work (research, development and demonstration) performed by companies in these industries is constrained by several factors:

- Only a few transportation service companies command enough of the market to justify traditional product or process R&D activities across a broad range of technologies. This is not unrelated to assets. Companies such as UPS, FedEx and DHL can justify R&D investment in sensors, vehicle design and materials handling equipment, for example, because they can apply such technologies in a large number of assets. Software companies, as suppliers to both transportation services companies and to users of logistics services, have a broad base that justifies R&D investment.

- The importance of systems integration—for integrated carriers like FedEx and UPS, for third party logistics suppliers such as Ryder Integrated Logistics, and for manufacturers such as Hewlett-Packard—means that companies often focus on assembling and deploying compatible technologies, rather than performing traditional R&D. Industry leaders shop globally for technologies such as computers, software, communications networks and materials handling equipment, and they rely on vendors to do R&D.

- In the delivery of package transportation and logistics services there are few "controlling" technologies. In contrast, for example, to pharmaceutical research where a patentable product confers long-lasting advantage, there are few unique technical solutions to those problems confronting companies. Consequently, even the most technically advanced companies in the industry do little research. The dominant technical work is engineering research or system development that is directly motivated by specific business problems. Companies are engaged primarily in the development of specialized new function/performance equipment or software and all that pertains to their system design, testing and deployment.

The global technical base for this industry is, therefore, best understood in two parts. The first part is made up of a wide variety of "hard" technologies in which there are classic product R&D challenges. What advances in sensor or bar-coding technology would reduce cost and increase efficiency in moving packages? What is the necessary bandwidth for global communications systems handling millions of packages a day and what compression algorithms work best for the type of data being handled? What technological constraints limit the viability and value of alternative fuel vehicles in package delivery truck fleets?

The second part is expensive and technically risky investment in systems integration—such as electronic links between flower growers and flower buyers nationwide. This is a type of technical innovation that is perhaps best characterized as demonstration rather than R&D. A company "demonstrates" the viability of a technology-enabled organizational innovation to the market.[11] In this type of technical activity there is rarely a separate R&D organization and companies rarely have R&D budgets. Generally, the focus is on tailored applications—specialized systems developed jointly by providers and users. It is as risky and technically demanding as traditional product R&D (remember Federal Express ZAPMail?).

In summary, companies that deliver value-chain management or logistics perform, in general, very little research or development; the primary technical value-added is in integrated system design and deployment, including system software development. Further, in the design and deployment of systems, U.S. companies buy software in the United States but shop globally for electronic and materials handling components, some of which are technically or economically superior to those available from U.S. companies.

Applications and Implications

- **Example 1**: Founded in 1984, Calyx & Corolla has revolutionized the flower retailing and wholesaling industry by providing direct delivery service from growers to buyers. Flowers are perishables and the value of cut flowers to a consumer is inversely related to the time since the flower was cut. In partnership with Federal Express, Calyx & Corolla put shipping hardware and software at grower's nurseries and—working with a software consultant—built an order taking and shipment tracking system to make ordering flowers for next day delivery direct from the grower as easy and inexpensive as ordering flowers from a local retail florist.

- **Example 2**: Ryder System, the largest third party logistics company in the United States, handles and manages all inbound and outbound logistics for the Saturn automobile manufacturing operation in Spring Hill, Tennessee. Materials and components arrive at a specific loading dock of the factory in 15-minute windows, shortly before they are to be used. Replacement and repair parts for Saturns are shipped directly from the factory to dealers "on demand" rather than snaking their way through the typical regional distribution system for automobile parts. Ryder hauls the finished automobiles to dealers under the same contract with Saturn that covers the inbound materials and component logistics—and the contract terms are such that Ryder has a continuous incentive to squeeze time and cost out of the very complex logistics operation that surrounds automobile assembly.

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11 An interesting example of this is DHL's Dublin City Centre Mobile Office, a city center-based bus providing the facilities of a DHL office. This "innovation" was in part responsible for DHL being awarded a Price Waterhouse/Irish Times Innovation Award. From the award citation: "Home to the company's walking couriers, the Mobile Office replaces a dozen vans -- along with their associated parking problems -- and allows DHL to deliver shipments earlier in the morning and later in the evening, with the back-up of the hi-tech communications equipment on board."

- **Example 3**: Hewlett-Packard is moving toward having the majority of its value chain visible for its highest volume product—ink jet cartridges. HP outsources all transportation to common carriers and the majority of tactical warehouse operations to third party logistics companies. However, HP maintains strict control of the design, engineering and distribution programs for these outsourced warehouses. They are also working closely with selected carriers to maintain the visibility of the goods while in transit. The goal of the work in HP is visibility of the ink jet cartridge value chains from raw materials through end consumption regardless of the sales channel. From HP's perspective, this visibility allows a high degree of control over both the technical aspects of production (quality) and the business elements of distribution. This level of control, long exercised for large capital goods such as aircraft or machine tools, is a considerable competitive advantage for product that retails for less than $50.00 and is sold in volumes of hundreds of thousands per year.

These three examples are illustrative of a pervasive trend that integrates a specialized transportation service with management systems, transportation facilities, materials handling, and information technology to dramatically improve the productivity and flexibility of both manufacturing and service companies. In many ways, these are traditional goods transportation activities, albeit with some special characteristics—the goods travel relatively fast (from overnight to a few days) and in units with relatively small weights and volumes (few bulk shipments, train carloads, or truck loads). What is lost, however, in thinking of this as a traditional transportation industry is the way in which these transportation services, when integrated with enterprise software and supported by sophisticated tracking and materials handling technologies, are revolutionizing both service and manufacturing industries.

Not surprisingly, the logistics provider's industries' claims for cost savings and increased customer satisfaction are legion. And, indeed, relatively neutral professionals who have published analysis and case studies in a wide range of industry and professional journals have substantiated such claims.[12] Although it is difficult to generalize about the implications of logistics applications there seem to be three major elements:

- The total distribution costs of goods (and services such a flower retailing) can be reduced per unit of value delivered to a customer. In many cases this is a straightforward reduction in cost and cycle time (and, ultimately, price). In other cases, a buyer's willingness to pay for goods and services delivered to his or her door may be higher; costs may be greater but the "product" worth more to a buyer. This is often described as gains in customer satisfaction.

- The application of integrated logistics to a wide variety of industries is driving structural change in many industries, the primary consequence of which is to reduce or eliminate the traditional role of distributors or wholesalers.

- The growth of integrated logistics is linked intimately to the growth of electronic commerce in all forms—from telephone catalog sales to direct replenishment systems that electronically

[12] See, for example, any issue of *Business Logistics* published by the Council of Logistics Management and those publications listed in footnote 1.

link a widget factory to the manufacturing-initiating order at another factory that makes components for widgets.

Estimates of the ultimate impact of integrated logistics are certainly beyond the scope of this paper and, in all likelihood, beyond the ability of most forecasters. Only time will tell how fundamental and pervasive the changes will be.

The Various Markets

The 1996 U.S. market for "expedited cargo" is estimated to be 4.7 billion shipments that generate $65.3 billion per year in revenue for transportation carriers.[13] A few companies dominate this diverse market—UPS, Federal Express, RPS Inc. and the U.S. Postal Service. A very large number of trucking companies competes for small shares of this market by providing less-than-truckload (LTL) transportation services. There is an analogous—but much smaller group—of cargo air carriers and passenger airlines that handle cargo in this category. While a few companies are dominant in this $65 billion expedited cargo market, there are also both private and dedicated fleet operations that handle—for a single parent company—what would be called expedited cargo were it handled on a contractual basis with a transportation carrier.

The international express package market is somewhat different in that it is best characterized as a segment of the air cargo business. The striking things about the international air cargo market are: a) the small size of the international markets relative to the U.S. domestic market; and b) the degree to which the United States plays a dominant role in world air cargo as an origin or destination. In 1995, for example, U.S. domestic air cargo was 6,090,000 tonnes, U.S.-Europe was 1,182,000 tonnes, and U.S.-Pacific Rim was 1,762,000 tonnes. In contrast, Intra-Asia/Pacific Rim was 2,868,000 tonnes, Intra-Europe was 983,000 tonnes, and Europe-Pacific Rim was 1,139,000 tonnes.[14] In the international express package market, DHL and TNT join (and in many cases lead) UPS and FedEx as dominant carriers. For example, one recent estimate of the Intra-Asia market for express package services estimated that DHL holds about 36 percent of the market; TNT has 27 percent of the market; FedEx has 13 percent; UPS has 5 percent; and all other carriers split the remaining 19 percent.[15]

It is much harder to estimate markets for logistics services, both vendor provided and in-house services. In the United States, according to one estimate of the 1995 market, the largest U.S. third party logistics supplier was Ryder with $867 million in logistics revenues and the largest 20 logistics firms had combined revenues of over $5.1 billion.[16] The global market for

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13 Colography Group, from "UPS Walkout Delivers Few Crises -- So Far," *Wall Street Journal*, Tuesday, August 5, 1997, page B1. Expedited cargo is defined to include domestic air, domestic ground parcel, domestic less-than-truckload, and U.S. air exports.

14 *MGI Cargo Analyst*, "World Air Freight Forecast," Fourth Quarter 1995, p. 23.

15 MergeGlobal Inc., *The Wall Street Journal*, "Federal Express, UPS Battle for a Foothold in Asia," p. B1.

16 Armstrong, Richard D. "Who's Who in Logistics: Primary Characteristics of the Major Players," *Annual Conference Proceedings*, Council of Logistics Management, 1996.

logistics services is provided by a wide range of companies, including divisions or groups within very large industrial firms, such as Hitachi (Hitachi Transport Systems, Ltd.), that provide both in-house and third party services.

On a national basis there appear to be two key features of the United States that make it a leading location for logistics activity (provider companies and user companies) that is linked to value chain management. First, the United States is a large market with few internal political barriers to the flow of goods. Trucking deregulation, in particular, has made national logistics systems possible.

Second, the U.S. lead in the development and application of a broad set of technologies that can be described as network technologies—private networks, the Internet, and the software to use them for electronic messaging and commerce—is a another key feature. Although value chain management and logistics—in theory—do not depend on electronic networks, the implementation of these business practices in the modern U.S. economy are heavily infused with electronic commerce. The application of value chain management and logistics by U.S. companies rides on the back of heavy private and public investments in network technology and information technology for transportation systems. The core national R&D base for electronic commerce and express package transportation is in networks, and it is a very robust R&D base.

R&D, Services and Competitiveness

National competitiveness is a function of the ability of a nation's assets (location, people and capital) to add value to products and services sold both domestically and in other countries. There is a well-documented conclusion that scientific and engineering research, development and demonstration activities—and the personnel, facilities and supporting educational programs that drive such work—play a key role in competitiveness. First, research and development jobs are often relatively high-wage activities, making a contribution to national welfare directly through the incomes generated for individuals. Second, research and development can create effective dominance for company (first-mover or fast-follower) with long-term benefits to the company and company's host country. Third, R&D can help create a locational advantage that is not specific to a particular company by creating R&D assets in the form of a density of skilled people and culture of technical entrepreneurs. Finally, R&D competence in industrial equipment or systems can create a competitive advantage and economic gains for user companies that are downstream from the companies performing R&D.

Most studies of national competitiveness, and industry studies in support of competitiveness arguments, have focused on manufacturing industries; it is widely accepted—implicitly—that that a nation's economic performance is directly connected to its natural resource endowments and manufacturing prowess. However, in 1994, manufacturing, mining and agriculture—three production activities often associated with national competitiveness—combined accounted for less than 24 percent of U.S. Gross Domestic Product (GDP). The services that collectively account for the remaining 75 percent of U.S. GDP also account for 79 percent of U.S. employment. As services have come to dominate the U.S. economy—and the economies of other industrialized nations—it is critical that our thinking (and policies) changes to reflect the changed nature of our economy.

The service sector includes such fundamental societal functions as:

- Finance, insurance and real estate (18.4 percent of 1994 GDP)
- Wholesale and retail trade (15.5 percent of 1994 GDP)
- Transportation, communications and utilities (8.7 percent of 1994 GDP)
- Traditional private services such as health care, private education, entertainment and repair services (19.4 percent of 1994 GDP)[17]

The dominant role of services in the U.S. economy is not a new phenomenon—the number of people employed in service businesses has exceeded the number of people employed in manufacturing and agriculture combined since about 1950, and service sector employment doubled between 1970 and 1995. However, misperceptions abound. Services are regarded as secondary industries that are technologically backward, not capital intensive and employ people only at low wages. In reality, the technological intensity of service industries is often high (transportation, telecommunications and health care services, for example); many service industry incomes are often well above average (doctors, lawyers, investment bankers and airline pilots, for example); and there is substantial capital investment by service companies (transportation firms, communications firms and national retail chains are excellent examples).

Logistics and Package Transportation: The Challenge for U.S. R&D Policy

Logistics and package transportation is a particularly interesting (if not necessarily representative) technically dynamic service industry with an intimate connection to a nation's competitiveness. There are two characteristics of the industry that muddy the water with regard to the relationships between technology and national competitiveness: a) both in the United States and abroad, package transportation is historically a regulated and/or subsidized industry; and b) the nature of the industry means that users reap substantial economic benefits from logistics regardless of who owns or controls the assets, i.e. U.S. producers and consumers can reap considerable economic benefits from effective logistics whether the services are provided by the U.S. Post Office, U.S. companies or foreign-owned companies.

With regard to regulations and subsidies, there is a long history of transportation regulation, at both the national and international level, that continues to play a role in the structure of the market and of competition. State and national government (U.S. and other nations') regulation and state-financed competition for carriers have dramatically shaped the industry to date. Regulations in air cargo transport and inter- and intrastate trucking have shaped the development of the U.S. express package industry. Essentially, the regulations (covering entry control, service areas, tariff filings, prices and commodity limitations) served to limit competition by: a) impeding new carriers from directly competing for routes or commodities; and b) regulating price competition.[18]

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17 *Survey of Current Business, August 1996.* Department of Commerce. p. 151, Table 11.

18 Ayotte, Mark J. 1994. "Congress Acts to Preempt Regulation of Intrastate Transportation of Property." Briggs and Morgan. www.briggs.com/preempt.htm

Deregulation of U.S. domestic air cargo transport in 1977 and interstate trucking in 1980 effectively transformed the competitive environment for the domestic express package industry. Deregulation led to increased competition among package carriers—the number of carriers authorized for nationwide general commodity services rose from zero in 1980 to 5400 in 1987.[19] As a result of this new competition, prices dropped for express package operations—by almost 25 percent six years after deregulation.[20] The more recent (1995 and 1996) deregulation of intrastate transportation is expected to increase competition in U.S. express package transportation.

Government regulation of, and involvement in, international competition in expedited cargo (both transnational and in-country) also has a long history and many forms—regulation of trade, government financed competitors (postal services), and laws restricting foreign ownership of vital infrastructure industries. There is a long history of nations demonstrating the belief that there is an inherent national interest in having a healthy (if not efficient), domestically controlled package transportation system. Worldwide government investments in postal services, and regulations making it difficult or impossible for companies based (and usually owned) in one country to carry goods into or compete for domestic business in another country, are clear evidence of this. These expressions of national interest in infrastructure die hard, even in an increasingly global economy.[21]

With regard to the economic importance of who owns logistics providers, there is no simple argument. National interests in controlling package transportation—whether motivated by national security or economic concerns—do not map well onto a global economy in which materials, components and finished goods move across national boundaries with the same frequency and purpose that goods move to and from a warehouse across the street from a factory. The implementation of sophisticated global logistics and package transportation systems enables globally dispersed and transnational patterns of production and consumption. They allow Asian manufacturers to serve U.S. customers and south-of-the-equator produce growers to serve north-of-the-equator restaurants. The growth and increasing capability of these systems allow rapid changes in the assets (location, people and capital) in use and—to a certain extent—unhinge traditional notions of national comparative advantage and competitiveness.

Further, it is not clear how a country captures high-value adding activities from a technically sophisticated and effective logistics and package transportation industry. In product industries a good is produced and consumed in one, two or several discrete places, and it is possible to understand "national" returns from production and consumption because economic activities have locations. Logistics and package transportation industries—like intercity

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[19] Smith, Frederick. 1988. "Air Cargo Transportation in the Next Economy." *Technology in Services*. eds. Bruce R. Guile and James Brian Quinn: 163.

[20] Moore, T.G. 1983. "Rail and Truck Reform -- The record so far." *Regulation* (November/December): 38.

[21] See, for example, "The Continent is Still a Tough Neighborhood for UPS," in *Business Week*, September 29, 1997.

passenger transportation, finance and telecommunications—are infrastructure-based where both production and consumption are network based.[22]

Two figures (see Figures 2 and 3, next two pages) illustrate how logistics and package transportation differs from some traditional manufacturing industries. Figure 2 was developed to illustrate the critical importance of, and controlling role played by, semiconductor manufacturing equipment. In the case of semiconductor manufacturing equipment, upstream "control" of technology has considerable downstream consequences. This picture of the industry is strategic in nature and relates to the ability of firms in the downstream electronics industries to compete. The national economic benefits that this figure calls attention to are jobs in electronics industries. This producer-focused approach to competitiveness analysis is quite common. Figure 3 illustrates the relationship of package transportation and logistics to the industry's technology base. There are no controlling technologies, and the primary economic benefits are assumed to accrue to the users of the service. This user-focused approach may lead to very different policies.

In an increasingly global economy, where the most efficient production process for goods and services demands that goods cross national boundaries quickly and without significant impediment, the value of domestic ownership or government control of the industry would be outweighed by the value of efficient participation in the global economy. A country that is effectively served internally and linked to global markets by a group of express carriers benefits enormously regardless of the national origin or ownership of the express carriers. What, then, needs to be done? What will strengthen both the United States' ability to compete as a location for logistics "activity," and what will help assure that U.S.-based companies reap the economic benefits of logistics innovation?

It is, perhaps, easiest to identify public investments that are not justified by the promise of integrated logistics. For example, private investment in hardware and software for network systems is substantial; additional public investment in multipurpose networks cannot be justified on the basis of its contribution to implementing effective logistics systems. Further, private investment in proprietary value-chain management software and networks, in transportation facilities and technology and in organizational innovations to exploit logistics-dependent opportunities is robust. Finally, the component technologies (sensors, enterprise-scale databases, materials handling equipment) for logistics systems are being developed and brought to market around the world. There is little justification for public investment in specific hardware technologies when no specific component technology seems to play a controlling role in the success of provider companies.

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[22] Health care and education (network-based production with long-term consumption) occupy some middle ground. There are, of course, traditional location-oriented economic development policies that can capture value for a particular region. The history of transportation is intimately connected to the geography of economic development. Historically, cities rose up around ports. More footloose transportation assets than rivers and deep water ports -- railways, roads, and airports, for example -- create economic activity where there was little and make existing economic activity more efficient. Package transportation and logistics is no different. There are regional clusters of competence and companies around traditional transhipment points (San Francisco, Amsterdam, Singapore) and newly created centers of activity where carriers locate hubs, cross-docking facilities, or other distribution assets. The State of Maryland, for example, has made an effort to attract distribution facilities serving the major metropolitan areas of the east coast. See *Washington Post*, Washington Business section "Retail's Secret System," p. 12, February 24, 1997.

Figure 2
Producer-Focused Analysis of the Economic Benefits of Technology

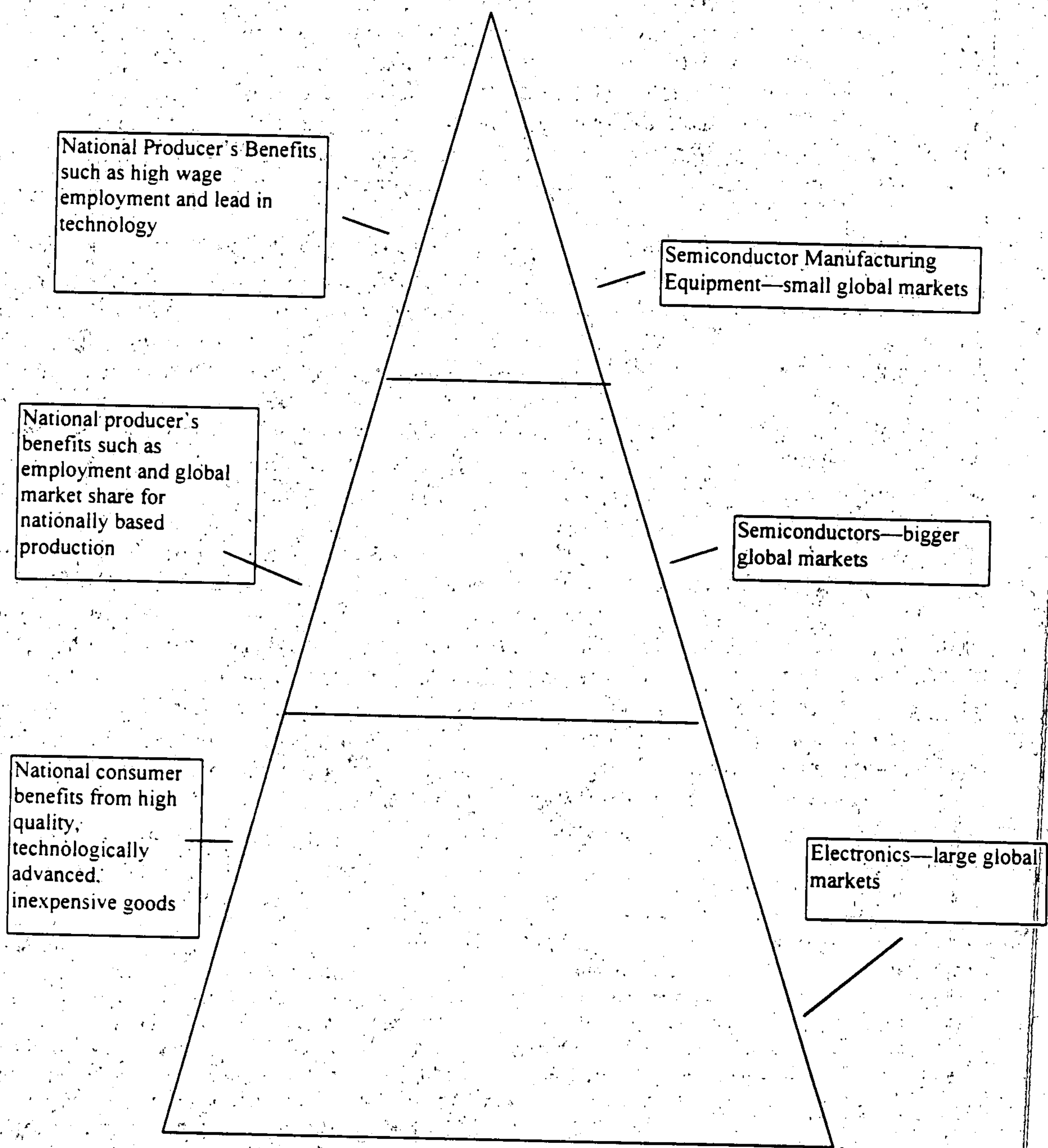
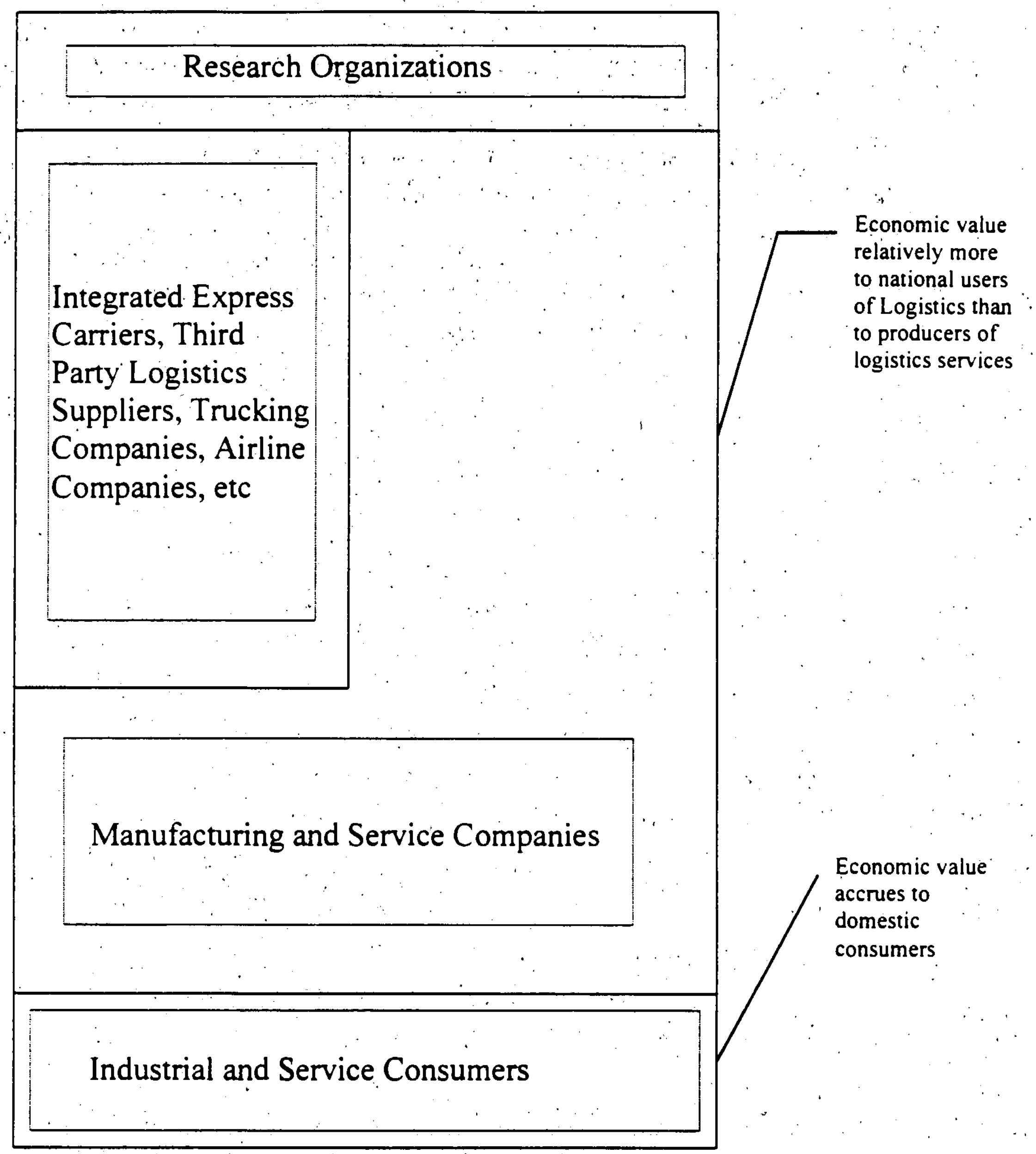


Figure 3
Technology in Logistics and Package Transportation



There are, also, a few classic technology policy issues that are of critical importance to the industry. Issues such as radio spectrum allocation, public investment in transportation R&D and assets, issues relating to the use of the Internet, and to electronic commerce, generally are critical technology issues for the industries that provide logistics services. Again, however, private interest and investment in these issues is already high, and it is hard to make an argument that there is a need for special logistics-oriented R&D programs or policy in these areas.

The primary need for public R&D investment in this broad area may in advanced technical education. The national demand for network-sophisticated computer science and engineering professionals greatly exceeds current supply. Logistics and package transportation providers will have to compete with almost every other industry for that scarce resource. However, federal funds (research center funds, individual investigator research funds, scholarships and teaching fellowships) could play a key role in strengthening the ability of U.S. universities to develop and deliver logistics-focused MS and Ph.D. level talent in Industrial Engineering, Operations Research or Networks/Computer Science. These individuals—whether they are employed by integrated express carriers, logistics providers, or by corporate in-house logistics groups—are probably the most effective means to assure that the economic benefits of logistics innovation accrue to U.S.-based companies and U.S. consumers.

Express Package Transportation and Logistics Sector Study

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Bruce Guile, currently managing director of the Washington Advisory Group, was formerly director of the Program Office of the National Academy of Engineering. Dr. Guile led projects on the commercialization of new technologies (published as *Profiting from Innovation*), capital markets, innovation management and corporate investment portfolios (published as *Time Horizons and Technology Investments*), and innovation and capital in start-ups and small high-tech businesses (*Risk and Innovation: The Role of Small, High-Tech Companies in the U.S. Economy).*

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