# U.S. Competitiveness and the Profession of Engineering

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AS GLOBALIZATION ADVANCES, it has become commonplace (possibly even fashionable) to voice concern over the steady erosion of U.S. prominence in science and engineering. The concern is particularly centered in the physical, computer, and engineering sciences. It is less so in the life and pharmaceutical sciences. A veritable stream of editorials, media features, and governmental reports have repeatedly reflected alarm over the inexorable decline in U.S. technical capabilities—one that has been apparent for much of a decade. The concern is genuine. It was dramatically reinforced by a spike in unemployment of computer scientists and engineers in the 2003 period, reflected by data in the fall 2005 issue of *The Bridge*. While scientists and engineers have historically faired better in the labor market than college graduates as a whole, the peak has been interpreted as a 20-year high, trebling the traditional level of about 2% to the neighborhood of 6%. Major contributing factors were bursting of the dot-com bubble and *outsourcing* (and *offshoring*) compelled by foreign competition.

The extensive public discourse has so far had little telling effect and minimal actionable response from governmental leadership. But fortunately, in part through the prestige of the National Research Council and its October 2005 committee report "Rising Above the Gathering Storm," the latent crisis is being more widely apprehended, and initial proposals are being put forward to blunt the threat. Early steps include explicit recognition of the erosion of scientific leadership in the President's State of the Union message in January 2006, significant bipartisan collaboration in the Senate at about the same time in one bill "Protect America's Competitive Edge" and another "National Innovation Act," and the White House embracing some recommendations of the NRC report in its proposed budget for 2007. It would seem that quantitative analyses of long-term impacts on the U.S. economy, on national security, and on quality of life, education, and competitiveness would crystallize the urgency and stimulate vigorous action. But as yet it is not clear how these proposals may come together. The legislative process advances slowly, and actionable proposals must get through numerous House and Senate committees before a resulting consensus emerges from Congress later in the year. Much of the science and engineering community is following this critical process anxiously. This is an interval during which credible public advocacy can have significant influence. At least two groups are actively socializing the issue in the congressional venue—one championed by technical interests of industry and another by a collection of professional and educational societies. The matter cries for serious organization, leadership, unity, and focus to generate unrelenting pressure that follows the process to successful conclusion. For the immediate time, however, unfavorable employment factors are likely to persist. The spring 2006 issue of THE BENT mentions that offshoring is expected to grow at about 30-40% per year in the 2003-06 frame and that 52% of engineering jobs are estimated to be amenable to offshoring in the long term.


NUMBER OF NOBEL PRIZE WINNERS BY SELECTED COUNTRIES

*(counts estimated from Wikipedia, the free encyclopedia.)*

| Before 1940-42 | | After 1940-42 | |
|---|---|---|---|
| Germany | 18 | U.S. | 144 |
| France | 18 | U.K. | 48 |
| U.K. | 18 | Germany | 33 |
| U.S. | 10 | France | 20 |
| Switzerland | 10 | Russia | 18 |
| Netherlands | 9 | Switzerland | 14 |
| Russia | 3 | Japan | 12 |
| China | 0 | Netherlands | 9 |
| Japan | 0 | China | 5 |

Medal image: ®© The Nobel Foundation

This climate may be disruptive to the engineering profession and can severely dampen enthusiasm among young students seeking to make career commitments in the discipline. On the opposite side, however, rapidly-developing foreign countries (especially in Asia) are mounting extensive efforts to attract their U.S.-trained nationals back to their home environments.[1] Also, as a recent favorable circumstance, notable rekindling in the U.S. economy presages a potential increase in demand for science and engineering expertise.

After World War II, the U.S. enjoyed what might be termed a *free ride* in marketing to the rest of the world. To meet the military threat of this time, an enormous manufacturing capability was marshaled by a dedicated citizenry. Budget allocations for research and development grew from a pre-war level of about 0.5% of the gross domestic product to 3.0%.[2]

This war-time sextupling of investment in science and engineering produced new and unique technologies (such as radar refinements, VHF communications, underwater sound ranging, encrypted speech transmission, controlled nuclear reaction, heavy aircraft, and others). The common political threat, and the high visibility of the technological responses, engendered extensive public awareness and appreciation for scientific leadership.

The high valuation of technology and reverence for R&D persisted into the second half of the 20th century. During this period, industry (flush with success) monotonely increased its investments as the federal government contributions began to *plateau*, the latter have been nearly level for the last 10 years. In recent time, while industrial investment in R&D still shows some growth, its rate has slowed, and the emphasis is more on *D* than on *R*. The reason has been increasing competition from abroad and pressure of impatient stockholders for greater profitability. This has left the academic sector as the main performer of basic research. And, because the federal government is the principal source of funds for academic research (about 60%), the federal leveling plus the shifting of priorities to more applied work (to support mid-east issues and homeland defense activities) have significantly diminished academic basic work. This diminution in creation of knowledge, both by industry and by academia, has opened a major vulnerability in U.S. competitiveness.

**End of the Free Ride**

The second half of the 20th century saw confluence of three technical advances that, together, have markedly changed the post-war world:

(a) new understanding of sampled-data theory—that permitted the representation of intelligence in digital form,

(b) development of binary computation—building to some extent on non-linear pulse-circuit techniques devised for radar, and

(c) invention of the transistor (Fig. 1)—that heralded the field of solid-state micro-electronics, scalable to enormous complexities.

As a direct consequence: digital communications evolved, bringing signal quality totally independent of transmission distance; digital computation emerged, enabling enormous accuracy and speed in solution of complex calculations—along with intelligent software for information management; and, explosive development of electronic integrated circuits put low-cost, high-speed devices into the hands of engineers and scientists.

Coalescing of the techniques for packet communication, distributed computing, and digital storage, along with those for digital signal processing, has now produced high-speed data networking that has become ubiquitous in the developed world—the public unregulated version that we know as the Internet. Software capabilities of great variety enhance the utility of this world-wide connectivity. These networking capabilities have created the *flat world* and have enabled aggregation of communication-based activities at geographical locations anywhere in the world where a knowledgeable work force can do the best job for the lowest cost. This indeed amplifies our vulnerability.[3]

Communication-based outsourcing is not the only attraction. Great amounts of American manufacturing (especially textiles) have long been offshored to capitalize on literate low-cost work forces. This has been assisted by advances in transportation, particularly by large jet aircraft, where any point on the globe is no more than 20 hours flying time—making geography of little consequence. This capability is already extended to agriculture (in mid-January I enjoy fresh blueberries from Chile). Other major U.S. manufacturing areas—such as autos and aircraft—are becoming more visible targets for this process. An obvious moderating mechanism is a partnership. However, a more fatalistic view is that outsourcing provides an advantage for a while, but eventually the 'knowledge work' follows the production activity, and the *outsource-ee* becomes a competitor of the *outsource-er*. Although this *equalizing process* need not be zero-sum, it often acts to reduce the circumstances of one society while building the other.[4]

In any event, some displacement and dislocation in the domestic work force will occur over extended periods while an expected equalization materializes. And afterwards, there remains the question of how to maintain front-rank position in the contest with competitive peers, all of whom are vying for the same position.

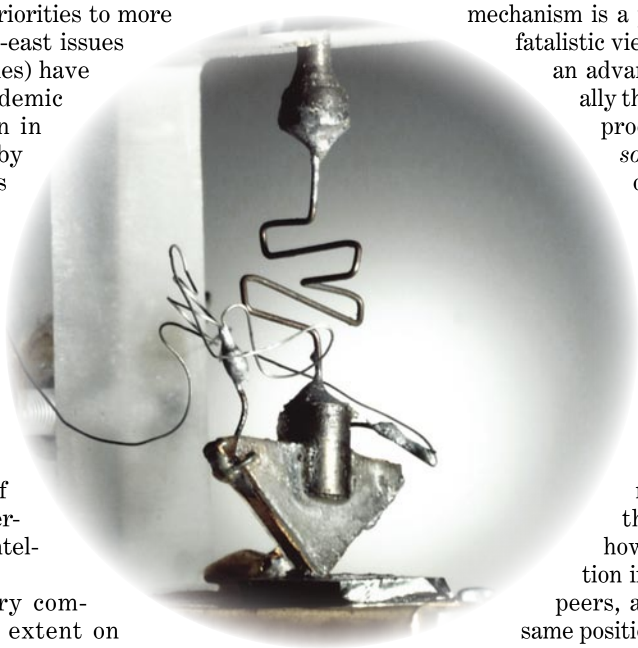


FIG. 1—The first transistor, 1949.

PHOTO: BELL LABS

**The U.S. Posture**

Recognizing that most societies see science and engineering as key to technological development and hence to the enhancement of quality of life and international competitiveness and that a great part of the world's population (now growing toward seven billion, with nearly half in Asia) is making enormous investments toward reaching parity with U.S. capabilities, what posture should the U.S. adopt? Knowledge creation and discovery must continue as the foundation. Basic research—both unfettered inquiry-driven and directed mission-oriented—remains a mainstay in the production of new ideas. But more than knowledge creation, we must attend to creation of the *creators*—that is, the educational processes that cultivate research capacity, technical leadership, and astute management. Because most of the basic research in the country is performed in academia and because education is central to producing the creators, heightened responsibility for our society's well-being falls heavily upon the research universities. In meeting this academic responsibility three ingredients seem vital:

(i) expanded federal funding for university research,

(ii) revision of curricula to emphasize research experience, idea generation, team collaboration, and the stimulation of technical leadership, management talent, and communication skills, and

(iii) vigorous participation and engagement of industry in federally cost-shared academic research.

Gaining (i), expanded funding, requires concerted *missionary* work on the part of academic researchers—that is, actively contributing to public understanding of the societal benefits of science and engineering. This understanding must reach a level where public demands for concrete action flood our congressional leaders. Academics jealously guard their time and typically prefer to remain above pedestrian public activities. But this involvement is an *overhead* on a successful research program, and faculty must awaken to this realization and to the necessary commitment—in their own interest, if not in that of the country. By way of example, talks at civic luncheons are sometimes a chore, but in one I found the chairman of an important appropriations committee. The time was well spent!

Additionally, most research universities enjoy close rapport with their respective congressional delegations. But much of this access is spent in seeking favored funding for parochial, self-serving projects. A broader view is needed to advocate for the total academic enterprise. In some instances an effective model has been the joining of academic specialists across several states to win commitments from multiple delegations. Such congressional cabals, especially if they are bipartisan, can result in significant movement and action.

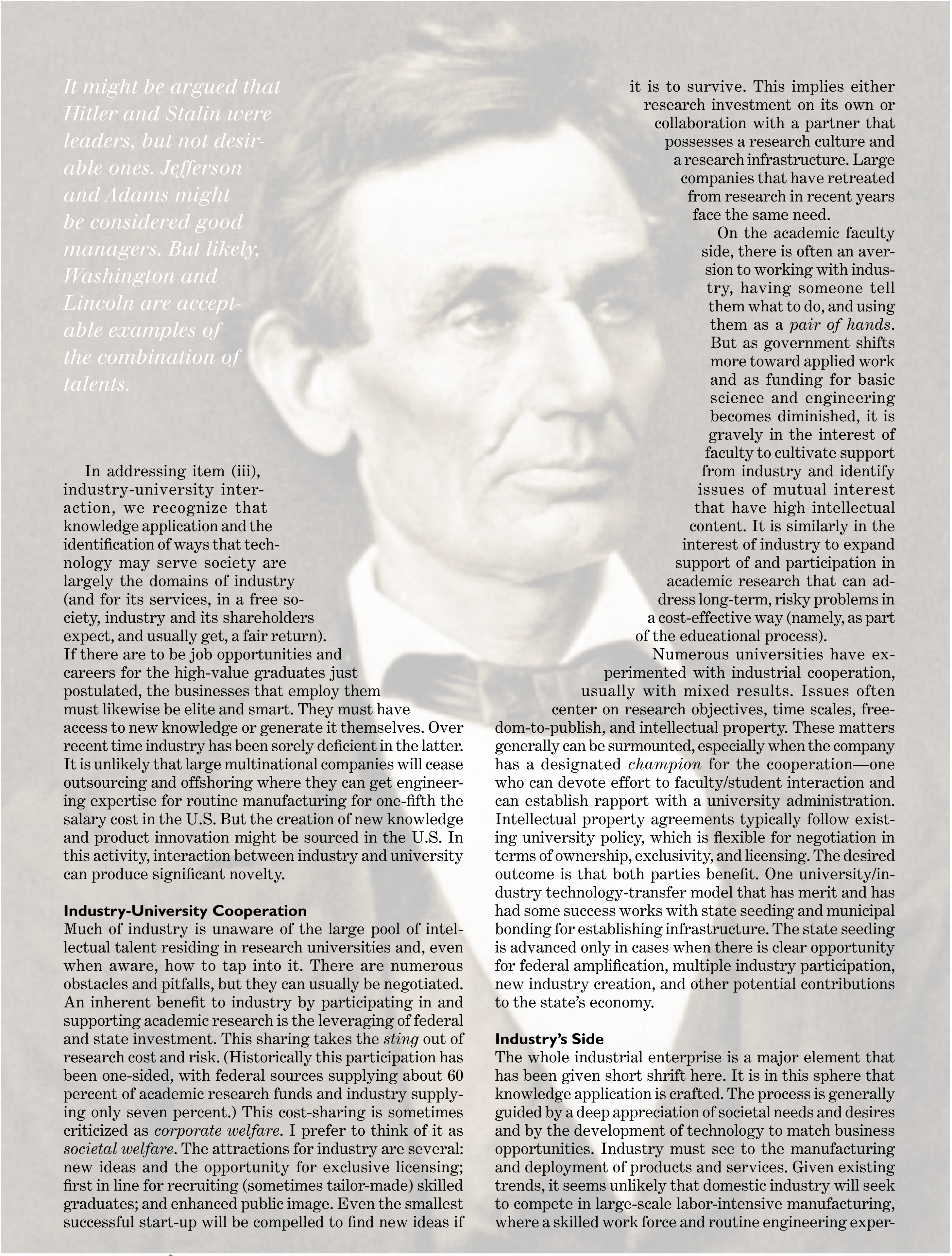
*"The past president of China is an engineer; a former president and a former premier of Taiwan are respectively scientist and engineer; and in South Korea, the minister of information and telecommunications is a Ph.D. electrical engineer from Stanford, and the minister of science is a Ph.D. electrical engineer from SUNY.*

In other countries, petitioning governmental leaders and decision-makers on behalf of science seems easier, because of their technical backgrounds and their ingrained devotion to technological development. The past president of China is an engineer; a former president and a former premier of Taiwan are, respectively, scientist and engineer; and in South Korea, the minister of information and telecommunications is a Ph.D. electrical engineer from Stanford, and the minister of science is a Ph.D. electrical engineer from SUNY. In the U.S. it is unusual to find this level of technical expertise in top ranks of government, although relevant specialists are usually found in the agencies that disburse research funds. This, in itself, points up the grave responsibility for staffing these positions with the most knowledgeable individuals available. The program managers wield great power and essentially control the objectives of research in the nation—because academic researchers *follow the money!*[5]

Grant allocations must be made thoughtfully, with vision, and on a merit basis. The award process must be efficient and transparent. But more than anything, there must be adequate funds to award! Funds are now so pinched that it is common to encounter a *"what's the use?"* attitude toward the substantial labor needed to identify a significant research problem, form a team, and prepare a proposal for a contest in which only one of a dozen or more may be selected. In earlier times, funding was not so constrained and often returned remarkable advances (a prime example might be the search technology behind the fast-developing company Google, initiated as part of an NSF-funded project on digital libraries at Stanford University).

In addressing (ii), revision of curricula, one meets the traditional academic inertia. Too often, faculty members are set in their ways and mostly enjoy teaching their individual specialties. But to produce graduates who will maintain our competitive edge into the future, new educational emphasis should be devoted to research exposure, knowledge creation, imaginative application, team collaboration, ethical behavior, and the development of communication, managerial, and leadership skills. Some engineering faculty complain that we already have too much to teach and that business schools should address the *people factors*. But experience suggests that talents for leadership and management might perhaps best be stimulated early—literally, in the hands-on research activity. A leader inspires or initiates concerted group effort toward a common goal. The mechanisms might be varied—fear, force, charisma, or confidence in knowledge of the task. A manager organizes and administers application of resources (including human capital) to an assigned objective. The underlying talents are not the same, but, when the combination is instilled in a single individual, the student product is admirable. (It might be argued that Hitler and Stalin were leaders, but not desirable ones. Jefferson and Adams might be considered good managers. But likely, Washington and Lincoln are acceptable examples of the combination of talents.) So, as others have noted, the emphasis may not be on producing more science and engineering graduates, but on producing versatile graduates of higher value, having unique skills and a penchant for sustaining their excellence through career-long self-education. Such graduates might be less attracted to the necessary (but sometimes pedestrian) role of manufacturer/implementer, but more to pioneering in innovation, ideas, and knowledge creation and in determining how new knowledge can be applied.

It is interesting that the 2006 international conference Davos, held in Switzerland in January, identified *innovation* as a key theme. And, it would seem unusual if a careful review and coordination of curricula could not wring out more opportunities to adapt to the changing world—so as to produce a well-prepared graduate. In accomplishing this, the role of the instructor is likely to change—from the *Herr Professor* image, with selected students worshipping at the feet, to one where the professor is more mentor and coach and, in some instances, colleague. Some egos may be bruised in the process, but success would enhance both student and instructor.



*It might be argued that Hitler and Stalin were leaders, but not desirable ones. Jefferson and Adams might be considered good managers. But likely, Washington and Lincoln are acceptable examples of the combination of talents.*

In addressing item (iii), industry-university interaction, we recognize that knowledge application and the identification of ways that technology may serve society are largely the domains of industry (and for its services, in a free society, industry and its shareholders expect, and usually get, a fair return). If there are to be job opportunities and careers for the high-value graduates just postulated, the businesses that employ them must likewise be elite and smart. They must have access to new knowledge or generate it themselves. Over recent time industry has been sorely deficient in the latter. It is unlikely that large multinational companies will cease outsourcing and offshoring where they can get engineering expertise for routine manufacturing for one-fifth the salary cost in the U.S. But the creation of new knowledge and product innovation might be sourced in the U.S. In this activity, interaction between industry and university can produce significant novelty.

**Industry-University Cooperation**

Much of industry is unaware of the large pool of intellectual talent residing in research universities and, even when aware, how to tap into it. There are numerous obstacles and pitfalls, but they can usually be negotiated. An inherent benefit to industry by participating in and supporting academic research is the leveraging of federal and state investment. This sharing takes the *sting* out of research cost and risk. (Historically this participation has been one-sided, with federal sources supplying about 60 percent of academic research funds and industry supplying only seven percent.) This cost-sharing is sometimes criticized as *corporate welfare*. I prefer to think of it as *societal welfare*. The attractions for industry are several: new ideas and the opportunity for exclusive licensing; first in line for recruiting (sometimes tailor-made) skilled graduates; and enhanced public image. Even the smallest successful start-up will be compelled to find new ideas if it is to survive. This implies either research investment on its own or collaboration with a partner that possesses a research culture and a research infrastructure. Large companies that have retreated from research in recent years face the same need.

On the academic faculty side, there is often an aversion to working with industry, having someone tell them what to do, and using them as a *pair of hands*. But as government shifts more toward applied work and as funding for basic science and engineering becomes diminished, it is gravely in the interest of faculty to cultivate support from industry and identify issues of mutual interest that have high intellectual content. It is similarly in the interest of industry to expand support of and participation in academic research that can address long-term, risky problems in a cost-effective way (namely, as part of the educational process).

Numerous universities have experimented with industrial cooperation, usually with mixed results. Issues often center on research objectives, time scales, freedom-to-publish, and intellectual property. These matters generally can be surmounted, especially when the company has a designated *champion* for the cooperation—one who can devote effort to faculty/student interaction and can establish rapport with a university administration. Intellectual property agreements typically follow existing university policy, which is flexible for negotiation in terms of ownership, exclusivity, and licensing. The desired outcome is that both parties benefit. One university/industry technology-transfer model that has merit and has had some success works with state seeding and municipal bonding for establishing infrastructure. The state seeding is advanced only in cases when there is clear opportunity for federal amplification, multiple industry participation, new industry creation, and other potential contributions to the state's economy.

**Industry's Side**

The whole industrial enterprise is a major element that has been given short shrift here. It is in this sphere that knowledge application is crafted. The process is generally guided by a deep appreciation of societal needs and desires and by the development of technology to match business opportunities. Industry must see to the manufacturing and deployment of products and services. Given existing trends, it seems unlikely that domestic industry will seek to compete in large-scale labor-intensive manufacturing, where a skilled work force and routine engineering expertise can be found in more cost-effective locations. Again, the attractive place to compete is in unique high-value activities of knowledge creation, work force education, and in identifying technology to match societal needs. While labor-intensive mass manufacturing is de-emphasized in this view, the creation of new technologies for manufacturing is not, nor is the engineering management of contracted work. Implied throughout, too, is industry's responsibility for deployment, maintenance, and salvage, much of which is local. A predilection for this mode may already be established, as we witness new products such as Razr, iPod, and Xbox, and new services based on search engines, voice-over-Internet, and broadband fiber to the home.

Offshore manufacturing poses real concerns in national defense. And, this matter reflects in a different way the growing importance of partnerships—partnerships among nations, as well as among multinational companies.

Innovation implies the application of new knowledge, which must come from some store. A pervasive worry is that we are largely living on knowledge created over the past decade, although this condition can be sustained for perhaps another five years before the store is depleted and the situation becomes critical. Performance then would cease to be competitive. One marker of this trend is the U.S. output of technical articles, which has essentially been flat since 1992 and has been exceeded by that of Western Europe since 1996. An insidious aspect is that criticality might be far enough into the future so as not to draw much attention. This is yet one more important reason to form partnerships to encourage public and congressional understanding.

Because industry must have new knowledge to stay competitive—indeed to survive—the hope is that basic research and innovation can be strengthened enough in the U.S. to stoke constantly the knowledge store and maintain global leadership. Given the risk-averseness of stockholders and the necessity of stable, sustained support for long-term research to succeed, government remains the key factor in nurturing leadership. Government can encourage research investment by industry, but governmental investment is most certainly central and necessary to academic research. This necessity is well understood by governments abroad, where basic, sustained, programmatic support is already being implemented and handsomely financed.

**Reprise**

The thesis here is that knowledge creation is preeminent to leadership. Knowledge creation derives from basic research. Over half of the U.S. basic research is performed in academia, largely with governmental funding. This support has languished over recent years, as industry has also reduced its investments. Leadership and technical capabilities are consequently eroding. Educational efforts to attract young students into science and engineering may be ineffectual, unless satisfying careers and stable contributory jobs can be demonstrated. These typically are based upon exploitation of new knowledge. While it is believed that industry R&D will grow under mounting pressure of global competition, it seems absolutely key that federal and state governments substantially expand support of U.S. academic research. This can occur if the various proposals mentioned earlier successfully coalesce and navigate the legislative process. Constant public support and advocacy are critical to assure a positive outcome.

An abiding concern is that the societal contributions of research in physical science and engineering have less public visibility because they are more difficult to relate to daily lives of individual citizens—despite the many technologies that affect people directly, such as MRI's, CAT scans, ultrasonic cardiography, laser surgery, biomaterials, and electronic prostheses (pacemakers, hearing aids, and artificial larynges).

A continuing question is how to enhance public awareness and gain congressional attention for the basic physical science that helps protect our future? Survey data suggest that public understanding of science arises primarily from television. This, in turn, suggests that public broadcast might give special emphasis to the societal benefits of scientific innovation. Additionally, congressional attention is clearly responsive to public opinion, which can be offered through personal letters, telephone calls, and visits. The coalitions, mentioned at the outset, share related objectives and are working to keep science and engineering initiatives before governmental officials. But, unifying and coordinating processes should be urged to enhance their effectiveness and focus. Individuals in each technical sector can contribute influence. In whatever way efforts are consolidated, the resulting coalition would find senior faculty of leading research universities and representatives of science-based industry willing collaborators. In concert, a non-partisan strategy and a plan of action can forcefully be laid before our leaders in Washington.

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1. During recent times more than half (55%) of the Ph.D. candidates in engineering in U.S. universities were from other countries. Up to 2001 more than half (56%) of the foreign graduates remained to work in the U.S. This statistic may be changing as developing countries prosper and enhance both their employment opportunities and their technical education. An MIT e-newsletter points out that of all bachelor's degees in China, 40% are in engineering. In the U.S. the number is 5%. As a perspective, we graduate more M.B.A.s than bachelor's in engineering.
2. During and after this era a number of immigrant scientists joined those of the U.S., further strengthening the growth in R&D spending and in research capability. It is relevant to note the Nobel prizes before and after WW II. (No prizes were awarded during 1940, '41, or '42.) Prior to this interval, European countries garnered the most prizes, while afterwards the U.S. was more successful.
3. The classic example of a communications-based activity is the massive outsourcing by American businesses of customer-care call centers to Asia (especially India, where an able, English-speaking work force can provide excellent service at low cost).
4. Just how convoluted this process may get is illustrated by one U.S. company financing a multibillion-dollar microelectronics plant abroad, with the government of the host country subsidizing the new business while receiving foreign-aid payments from the U.S. At the same time, the U.S. company is supporting excellent science and engineering scholarships for U.S. students and advocating production of more graduates to meet industrial shortages (which might be somewhat at odds with recent employment opportunities). A central issue for young students is whether, upon graduation, they can find satisfying jobs and gratifying, contributory careers in our society.
5. Over the last few years, *following the money* has somewhat distorted the balance in research, as basic science funding has diminished and emphasis has shifted to applied military problems and to well-supported health care.

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