Spring 2005

The BRIDGE

LINKING ENGINEERING AND SOCIETY

NATIONAL ACADEMY OF ENGINEERING
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Promoting the technological welfare of the nation by marshalling the knowledge and insights of eminent members of the engineering profession.

The
BRIDGE

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Errata
In the photo accompanying the article "Remarks by Eli Ruckenstein, 2004 Founders Award Recipient" on page 51 of the winter issue of *The Bridge* (vol. 34, no. 4), Howard Brenner was incorrectly identified as Eli Ruckenstein. Mr. Brenner accepted the award for Dr. Ruckenstein.

Dr. Frances H. Arnold was identified in the winter issue as working at the IBM Thomas J. Watson Research Center. Dr. Arnold is the Dick and Barbara Dickinson Professor of Chemical Engineering and Biochemistry at the California Institute of Technology.

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The BRIDGE
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LINKING ENGINEERING AND SOCIETY

Editor's Note

Features

NAE News and Notes

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Editor's Note

Toni Marechaux is director of the Board on Manufacturing and Engineering Design of the National Research Council.

Celebrating Manufacturing Technology

The future of the manufacturing sector in the United States is much in the news these days. Major stories in almost every news outlet are focused on trade, American jobs, and the loss of the U.S. manufacturing and industrial base. More specific discussions are focused on the offshoring, or outsourcing, of white-collar, back-office, and technology jobs and the role of manufacturing in national and homeland defense. And in the background, proposals have been made for foreign guest worker programs analogous to H-1B and L-1 visas for highly educated professionals. All of these issues were touched on by speakers at an NAE symposium on October 4, 2004.

The session was moderated by Pamela A. Drew, chair of the National Research Council Board on Manufacturing and Engineering Design (BMED), which has conducted studies on specific topics in manufacturing; interactions between design, engineering, and manufacturing; and the significance of manufacturing for the nation. The symposium, "A Century of Innovation in Manufacturing," held at the NAE Annual Meeting, was intended to initiate a discussion on the significance of the manufacturing sector to our nation's stature in the world and our future prosperity. The symposium gave experts in many fields an opportunity to reflect on our journey so far and opened a discussion about where we should go from here.

The four distinguished speakers from the symposium who contributed papers for this issue have very different perspectives on manufacturing. In the last 100 years, a great many changes have been made in the way we design and manufacture the things we use in our daily lives. The authors discuss the current state of manufacturing, the role of manufacturing in our national and economic security, and future technologies that may change everything about how we make things and how and where we live.

One way to approach the intersection of national and homeland security and the economic health of the United States is in the context of the defense industrial base. Kenneth Flamm, the Dean Rusk Professor of International Affairs at the Lyndon B. Johnson School at the University of Texas at Austin, traces the complex history of post-Cold War policies that have shaped the military-industrial complex. He also describes the major contributions of the electronics manufacturing industry, particularly the development of computers, and the U.S. semiconductor industry.

Lawrence Rhoades combines his knowledge of economics, mechanical engineering, and business administration as head of Ex One Corporation (formerly Extrude Hone), a small company leading the way to manufacturing in the next century. Larry describes the transition from discreet-parts manufacturing to nontraditional manufacturing processes for machining, finishing, forming, and measurement. He then suggests how these new manufacturing processes will affect commerce, transportation, and our quality of life.

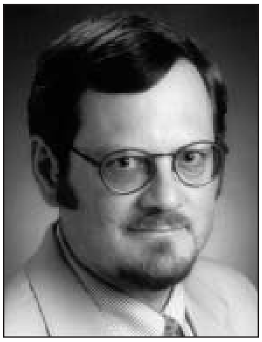
The paper by Sidney Perkowitz of Emory University takes us into the next century with a discussion of "digital people" in manufacturing and in our daily lives. Sid describes how technology is inexorably driving us toward new levels of product manufacturing and new kinds of manufactured products. Drawing on nanotechnology, molecular biology, artificial intelligence, and materials science, scientists are learning to create beings that can move, think, and look like people. They are using increasingly sophisticated machines to carry out a range of brave new manufacturing processes.

Alfonso Velosa, associate director of Gartner Incorporated, provides an analysis of the semiconductor industry in the global technology marketplace. He highlights the importance of product markets, device and process technologies, strategic planning, supply chain management, and research to manufacturing and engineering design. Al highlights the ups and downs of the semiconductor industry and describes emerging business models that are enabling U.S. companies to succeed in the global marketplace.

The information presented in the papers at the symposium and the questions from the audience made for an interesting and provocative discussion of the history, status, and direction of manufacturing technology. Clearly, the manufacturing sector faces many challenges in the emerging global economy. During the course of the symposium, different words were used to describe the next generation of manufacturing—flexible, distributed, green, and intelligent, to name a few—but everyone agreed that the future of manufacturing will depend on the same innovative spirit that inspired Henry Ford to build the first assembly line back in 1903.

The author traces the evolution of defense industrial and technology policies since the end of the Cold War.

Post-Cold War Policy and the U.S. Defense Industrial Base



Kenneth Flamm is a professor and the Dean Rusk Chair in International Affairs in the Lyndon B. Johnson School of Public Affairs at the University of Texas at Austin. He was Principal Deputy Assistant Secretary of Defense for Dual Use Technology Policy and International Programs from 1993 to 1995.

Kenneth Flamm

Technology development in the United States has historically been closely related to defense industrial policies. At times, new defense-related technologies led to the development of products that fueled growth in a broad spectrum of commercial industries. At other times, the U.S. military establishment has focused its resources on specialized technologies with little if any applicability to other markets. This essay traces the evolution of defense industrial and technology policies from the end of the Cold War to the post-9/11 world.

The rise of modern high-technology industries (e.g., semiconductors, computers, key elements of modern communications systems, aircraft and space technology, and biotechnology) was stimulated by post-World War II government investment in (1) research and development (R&D) to strengthen national defense and (2) the education of skilled scientists, engineers, and technical staff to work in these new industries. However, in these industries sales of dazzling new commercial products soon eclipsed sales of high-technology products to military customers. During the Cold War, roughly two-thirds of U.S. R&D was funded by the federal government, primarily for defense. Today, that percentage has been reversed, with two-thirds of U.S. R&D funded by private industry.

The Defense Industrial Base

Only a handful of U.S. industries are now dominated by defense spending (so-called defense industries), and most of them produce "defense-unique" products (e.g., ammunition and ordnance, tanks and armored vehicles, ships, aerospace vehicles and technologies, search and navigation electronics, and some kinds of optical instruments) for which the military is the primary customer. The largest defense sector is military-related electronics, which accounts for almost 50 percent more in sales than aircraft. The relationship between the defense establishment and these industries is symbiotic—the military depends on them for its technical advantage, which is at the heart of U.S. security doctrine, and the industries depend on the U.S. armed forces as their primary customer.

Despite the military origins of computers and microelectronics, these industries are not on the list of defense industries. Even though the military is still an important funder of specific, leading-edge technologies in these fields (e.g., supercomputers and microelectromechanical systems [MEMS] devices), commercial demand for these products has far outstripped the requirements of the military.

> *U.S. defense suppliers turned to exports to take up the slack in the domestic military market.*

The aircraft industry is an exception. For almost a century, demand shifted back and forth between military and commercial customers. The aerospace industry, which never "graduated" from its symbiotic relationship with the military, is still highly leveraged with military technology investments. Recently, however, as commercial space launch has become more important in telecommunications, the trend has shifted toward more commercial sales.

Shipbuilding, besieged by inexpensive foreign competitors, has become increasingly dependent on selling high-priced, specialized systems to the military. Today, the U.S. shipbuilding industry is virtually a captive supplier to the U.S. Navy.

The end of the Cold War had surprisingly little effect on defense industries, partly because U.S. defense suppliers turned to exports to take up the slack in the domestic military market. As a result, the dollar volume of sales over time remained relatively stable. The only large declines were in sales of ammunition and tanks and space vehicle equipment (the latter is probably attributable to the vertical integration that accompanied consolidation).

The Post-Cold War Conundrum

The relative stability of U.S. defense industrial output contradicted the prevailing forecasts as the Cold War wound down. U.S. defense spending was expected to fall sharply, with procurement budgets forecast to fall by as much as 70 percent. In the 1980s and 1990s, adjusting the defense industrial structure to predicted post-Cold War budgets was a central theme, based on clear, deceptively simple logic. The U.S. defense procurement system, which had evolved from a structure dating back to World War II, operated largely in a cost-plus-markup contracting framework. Contractors were encouraged to invest in substantial fixed facilities and capabilities and then recoup their overhead costs through charges added to U.S. Department of Defense (DOD) contracts. If procurement budgets shrank, as expected, and the number of contractors remained stable, a company would have to set aside an increasing portion of its contracts to recouping its unchanged overhead costs. Thus, funds available for new systems would inevitably diminish sharply.

This argument for restructuring defense industries was made by William Perry, who became deputy secretary of defense when the Clinton administration took office in 1992 and was appointed secretary of defense shortly thereafter. As secretary of defense, Perry put forward a three-part strategy. First, shrinking funds would be stretched by instituting more economically efficient purchasing processes. Reform of the acquisition process had been urged by a succession of bipartisan commissions, and there seemed to be a political consensus supporting it. Perry proposed that the acquisition of defense systems be retooled to be more like the competitive, price-conscious practices used in commercial industry. Greater competition, it was argued, would also stimulate innovation among defense suppliers.

Second, efforts would be made to procure systems and technologies from outside DOD's traditional circle of suppliers, that is, from firms selling mainly to commercial customers. In semiconductors and computers, for example, commercial industry was investing vastly larger sums in new technology development than DOD, and commercial markets had greater technological momentum. Thus, DOD could both save money and encourage the rapid incorporation of new technologies into its systems by tapping into burgeoning innovation in the commercial arena.

The logic behind this "dual-use" strategy seemed unimpeachable. The military would turn to commercial suppliers for leading-edge technologies in fields where commercial markets were driving technological change and, at the same time, stimulate the transfer of DOD-funded technologies with commercial potential to firms willing to adapt them to commercial markets. It was argued that this would ultimately lower the cost of new technologies to DOD because of economies of scale and greater investment from private sources.

The dual-use strategy was not popular, however, with traditional defense suppliers who feared they would be facing new competitors in a time of falling budgets. Resistance also arose from the uniformed services, the ultimate customers, who anticipated additional strains on their budgets with little promise of receiving qualitatively better hardware in the near future. The benefits, they believed, might only be realized in the medium to long term.

The third element of the Perry prescription involved reducing the defense industry's fixed overhead costs. For government-operated or government-owned facilities, a new base realignment and closure (BRAC) process (begun in 1991 under the previous administration) would be charged with eliminating unneeded facilities. The situation for private industry, however, was more complex. In July 1993, Secretary Perry urged the top defense companies to merge and consolidate to reduce overhead as procurement declined. At a Pentagon dinner (dubbed the "Last Supper"), Perry pledged to support efforts by the defense industry to undertake its own consolidation. In marked contrast to earlier policies, he said DOD would adopt measures to facilitate consolidation by assuming a more active role in government approval of mergers and acquisitions among its suppliers and implementing cost-reduction incentives for mergers and acquisitions (e.g., projected cost savings from mergers would be shared by DOD and its suppliers).

The International Dimension

At the same time, equally difficult issues were becoming apparent globally. Post-Cold War downsizing was also under way overseas. Major U.S. allies, who also had substantially smaller procurement budgets, faced difficult choices, sometimes between sustaining a single, very high-overhead, very high-cost supplier and losing the capability of producing a particular type of defense system entirely. Thus, to keep key systems from becoming unaffordable, there were substantial economic pressures to export defense systems, perhaps even to less-than-savory customers.

The logic behind the "dual-use" strategy seemed unimpeachable.

To reduce pressures for exporting technologies with potential proliferation implications, DOD proposed offering more technology cooperation with close allies. The idea was to offer an explicit quid pro quo on proliferation. Access to U.S. defense technology investments would be exchanged for prior agreements restricting exports of systems that used the technology. The most trusted allies (dubbed the "Inner Circle") would be offered the greatest access in exchange for the greatest restraint; agreements with less intimate friends might be negotiated later for less access, and, perhaps, less restraint. Ultimately, it was hoped, this policy would lead to some institutional structure that would reduce economic pressures for the proliferation of advanced military technologies.

The flip side of this initiative was DOD opposition to increasing U.S. subsidies or increasing exports by American arms makers. Detailed internal studies showed that, except in a few specific cases, export subsidies were likely to have a small impact on overall U.S. market share. Broad subsidies and promotions might increase U.S. share globally by, perhaps, 10 percentage points; but they might also trigger countermeasures by strapped foreign competitors that would increase the risks of proliferation. DOD argued that it would be better to promote U.S. exports through cooperative arrangements with allies linked to restraints on their exports.

Finally, DOD opposed increasing waivers for R&D recoupment charges, which essentially freed U.S. arms exporters from having to levy a charge to repay DOD for a portion of its R&D investment in exported military systems. R&D recoupment charges on exports had been a significant factor in reducing the cost to DOD of developing some new systems, thereby stretching U.S. procurement funds. Waivers of these charges significantly lowered the price of exported systems, but raised the ultimate total cost to DOD of developing systems.

The international initiatives had mixed results. DOD succeeded in reviving moribund international programs with U.S. allies, and, despite current political tensions, increased cooperation with allies in NATO and with Japan continues to this day. However, DOD either lost interagency battles or bowed to political realities on most other issues. As a result of heavy industry lobbying, a policy directive made the untargeted promotion of military exports (using diplomatic, political, and economic leverage) on economic grounds the default government position. Congress passed a "self-financing" export promotion scheme (with defense industry support) that had little if any real effect and did not evolve into the costly subsidy its proponents had hoped for.

The Inner Circle idea was attacked from both ends of the policy spectrum. Nonproliferation activists opposed the idea of sharing U.S. technology, even with trusted allies. Proponents of arms exports did not like the idea of restraints on exports as an institutionalized feature of cooperative arrangements and worried about allied industrial competitors getting access to U.S. technology. Although the general policy was rejected, remnants of the idea survive today on a program-by-program basis. In the Joint Strike Fighter (JSF) Program, for example, allied industrial participation was invited, linked to a review of exports that included JSF technology. The controversies also survive, and the struggle continues.

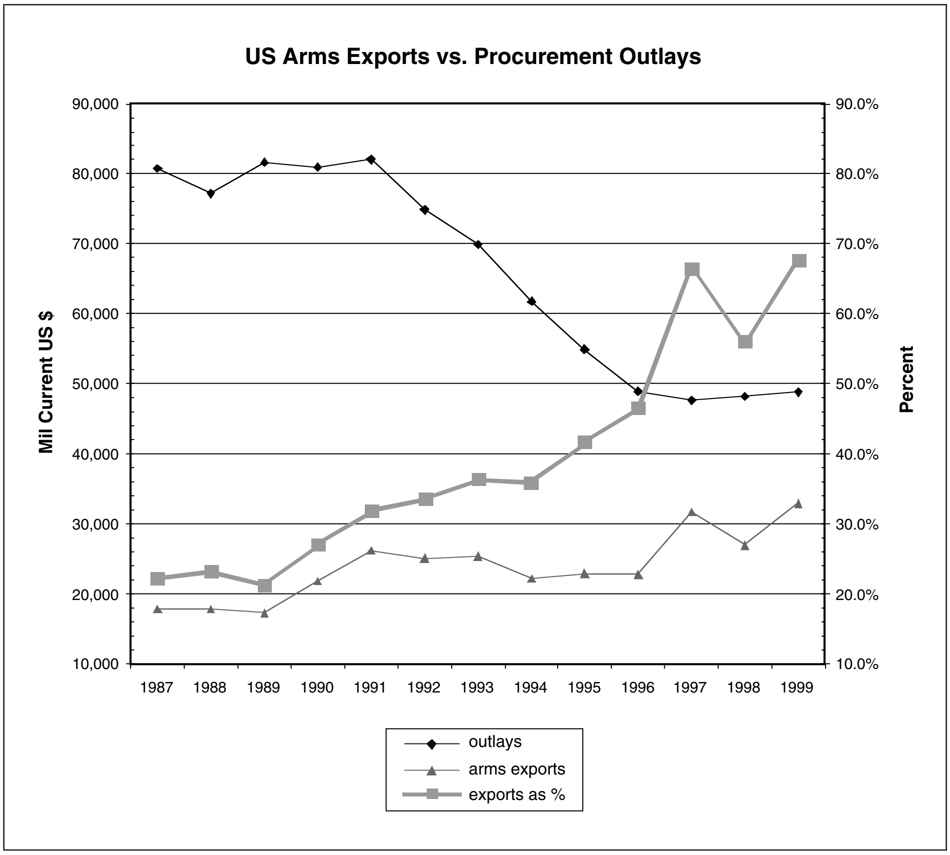


FIGURE 1 U.S. arms exports vs. procurement outlays. Source: adapted from U.S. Department of State, 2002.

The policy changes and the mathematics of global procurement budgets undoubtedly resulted in greatly expanded exports of military systems. U.S. arms exports increased from about 20 percent of domestic military procurement in the late 1980s to almost 70 percent of domestic procurement outlays in 1999 (see Figure 1). Concerns about the proliferation of militarily significant capabilities by increasingly strapped foreign competitors remain.

From Endgame to "N-Game"

Domestically, the policy initiatives of the 1990s also had mixed results. The verdict on acquisition reform is still out. In an inversion of previous policy, a new directive made unique military specifications for components and parts (as an alternative to commercial products) acceptable only if they could be explicitly justified and defended. By most accounts, this change has been successful.

Changes were made to the Federal Acquisition Regulations (FAR) to encourage commercial acquisition processes whenever possible. Campaigns were mounted to encourage acquisition executives and program managers to consider price in acquisition policy, and policy directives encouraged bottom-line price justifications for acquisitions, in lieu of the traditional cost-based approach with its extensive documentation requirements. "Cost as an independent variable" became a shorthand description of the new approach. However, the effects of changes to FAR and the attempted reengineering of the procurement culture have yet to be persuasively demonstrated.

The promotion of consolidation in the defense industry was motivated by concerns about fixed costs, particularly investments in physical facilities. Clearly, having fewer producers would lower fixed costs per unit on any given volume of output because of the economies of scale created by the fixed costs. But with fewer producers, there would also be less competition and a greater likelihood that producers would increase profit margins and prices. With fewer producers, there might also be less pressure for them to innovate technologically to win DOD contracts. Clearly, there was a trade-off between economies of scale and competition, but when the policy was first articulated, attention was focused primarily on the cost issues. The competition trade-off only belatedly became a central concern as consolidation proceeded.

Table 1 shows that the numbers of prime contractors for major systems dropped from 25 to 70 percent from 1990 to 1997. Estimates of capacity based on U.S. Census Bureau data also showed significant reductions in physical production capacity in most defense industries through 1997.

After 1997, however, there was little further consolidation among primes—the result of a rethinking of the policy. From 1992 to 1997, acquisition policy was conceived as an "endgame" for the Cold War defense industry infrastructure; restructuring of the industrial legacy was the primary issue on the table. As the numbers in Table 1 show, however, by 1997 the number of primes had dropped to very low single digits in many sectors, raising concerns that consolidation might have gone too far. At that point, DOD discussions of defense mergers began to focus on the effects of consolidation on competition and how low the number of producers (the "N-game") could go before DOD ought to become really concerned.

The change in policy was signaled in 1998 when DOD opposed mergers of Lockheed Martin and Northrop and the acquisition of Newport News Shipbuilding by General Dynamics. At about the same time, because of congressional concerns about "payoffs for layoffs," the overhead savings-sharing incentives were ended. Although mergers continued among subcontractors, the great wave of mergers among large primes ended in 1997. Statistics also show that physical plant capacity began growing steadily again in most sectors after 1997, as savings-sharing was discontinued.

Ironically, the sharp declines in procurement that led Perry and others to propose cost-saving consolidations in the 1990s seem likely to be completely reversed in the next five years. Recent defense budgets show R&D and procurement reaching their Cold War peak in 2009—only there will now be far fewer defense firms competing for many more contract dollars. Needless to say, this was not the desired outcome of the policies of the 1990s.

To some extent, procurement officials, in their zeal to promote consolidation, overstated their case. Although procurement in constant dollars did decline by almost 70 percent in the 1990s from its Cold War peak, outlays (the amount DOD actually spends in a year, a more relevant number for an industry dependent on defense spending) declined only by about 55 percent. This is because lags in spending for different types of items have the effect of smoothing out zigs and zags in budget appropriations. If we consider only arms investments (what DOD actually buys from the defense industry, excluding the substantial spending on

TABLE 1 Declining Number of Primes, 1990–1997

	Number of Contractors		
Sector	**1990**	**1997**	**2000**
Tactical missiles	13	4	3
Fixed-wing aircraft	8	3	3
Expendable launch vehicles	6	2	3
Satellites	8	5	6
Surface ships	8	5	3
Tactical wheeled vehicles	6	4	3
Tracked combat vehicles	3	2	2
Strategic missiles	3	2	2
Torpedoes	3	2	2
Rotary-wing aircraft	4	3	3

non-defense-unique items like paper clips and personal computers), spending was cut by only 40 percent. Coupled with the surge in arms exports discussed earlier, overall defense industry sales declined only slightly, despite forecasts of impending doom.

Procurement in constant dollars, which fell to the level of the mid-1970s at its low point in the 1990s, is now almost back to its Cold War peak. And there will soon be greater output produced by substantially fewer players than there ever were during the Cold War. This was not the anticipated result of the original restructuring, but the current leadership of DOD (understandably distracted with other issues) shows no sign of considering the long-term consequences.

In retrospect, the defense industrial policy initiatives of the 1990s effectively responded to the realities of the moment. The impulse to reform the acquisition system was sound, although long-term results should be monitored. The financial incentives to reduce overhead seem to have worked during their lifetime, but their effects were quickly reversed when they were ended. Thoughtful proposals on export policies and technology cooperation were only partly successful, although the underlying ideas still have some limited impact. Most important, DOD's development of a framework for sorting out policy choices affecting the size and configuration of its industrial base was a laudable first step toward rationalizing its interactions with industry. Perhaps the most significant defect was that not enough consideration was given to framing the underlying trade-off between competition and economies of scale, which ultimately halted the consolidation initiatives.

Should we intervene to improve the performance of producers in commercial markets?

Long-Term Concerns

We now face a rising tide of procurement spending with substantially fewer defense industries. One immediate concern is competitiveness in the aerospace sector. In contrast to computers and semiconductors, this industry never significantly decreased its reliance on DOD support for the development of new technologies. However, aerospace is as important to the strategic advantages of U.S. military forces today as it was decades ago. Like electronics and IT, aerospace is a dual-use technology with many important commercial applications. Unlike IT, however, the relative sizes of the commercial and military aerospace markets have remained in rough parity. This has created unique strategic considerations that complicate economic policy (e.g., trade and technology policy).

Many indicators suggest that the U.S. aerospace industry today is in trouble in commercial markets. However, it is inconceivable that the U.S. military will let its suppliers fail. This raises the specter of a military-only aerospace industry, analogous to the military-only U.S. shipbuilding industry. Can a military-only aerospace industry remain a viable and technologically dynamic sector? Must we intervene to improve the performance of our producers in commercial markets? This is a difficult policy question that we seemed destined to address in the next few years.

IT is transforming the military as it has transformed the rest of our society. Electronics, software, and "other" defense equipment now dominate investment in defense equipment (Figure 2). These technologies, which are primarily driven by commercial suppliers in an increasingly globalized industry, raise some difficult long-term questions. Will the qualitative technological advantage of U.S. systems that we have relied on in the past become less sustainable? Will the export controls we have relied on to deny potential adversaries access to our most advanced technologies become increasingly inadequate and outdated?

Innovation in IT and biotechnology continues to accelerate, and new industries are springing up to commercialize products based on these technologies. Even by the standard of U.S. military procurement budgets, very large sums are being invested in R&D in these areas; however, U.S. defense contractors are barely involved. Given the threat of chemical and biological weapons and the rise of information warfare, this situation must be changed. However, ensuring that the producers of our defense systems are in close contact with technology development in IT and biotech will require that we change the procurement system we inherited from the last century.

Despite the reforms of the 1990s, the procurement system is still basically a World War II-era regulatory system based on administered prices derived from costs. The system was designed to deliver specialized products to a single customer, the government, produced by suppliers with significant monopoly power. Monitoring and audits were necessary to ensure that outcomes were reasonable, but post-Cold War downsizing of the military included downsizing of the government workforce that monitors procurement.

Thus, while procurement is once again increasing rapidly, the monitoring and audit function is not. Indeed, recent well publicized scandals suggest that instances of malfeasance on a spectacularly large scale, which occurred from time to time in the past in the defense sector, may be on the upswing. Consolidation and less competition in the defense industry may aggravate the problem.

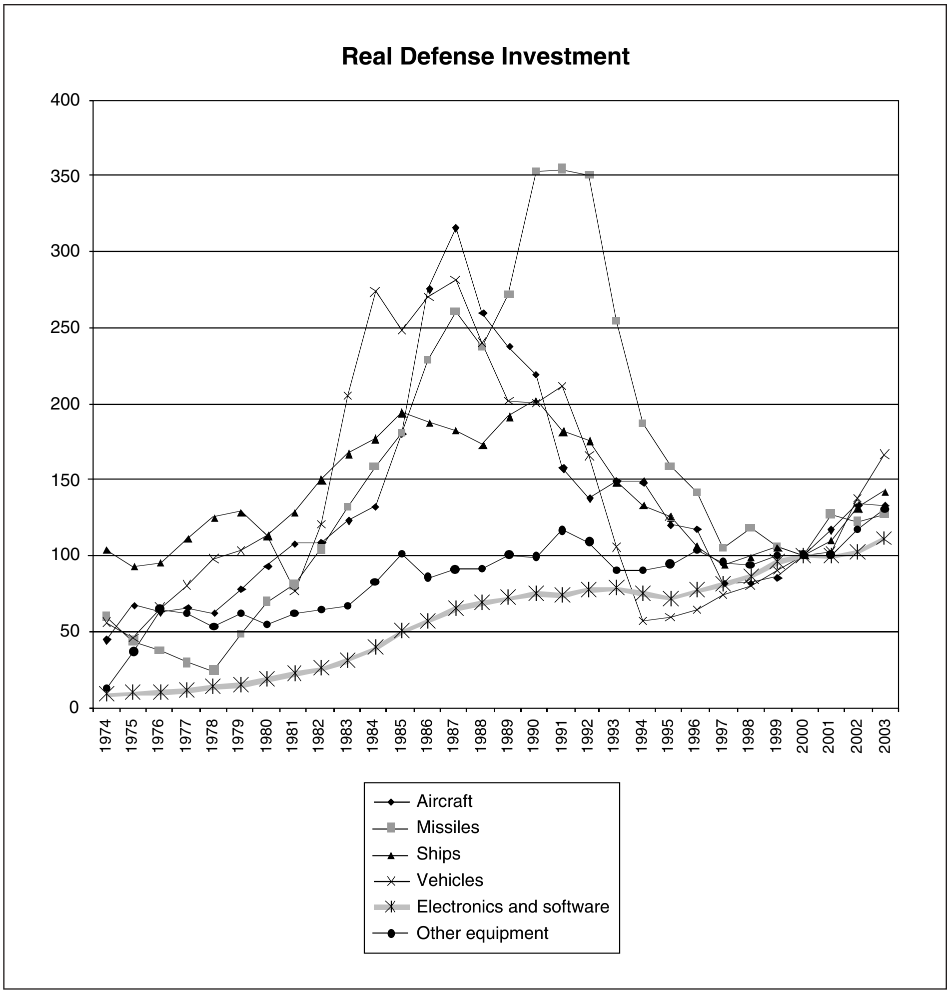


FIGURE 2 Real defense investment, 1974–2003. Source: adapted from Bureau of Economic Analysis, 2005.

This raises the issue of whether it is time to revisit the fundamental design and operation of the procurement system. The last major examination of this system, conducted in the 1980s, two decades ago, led to only marginal changes. Given the significant changes that have occurred in the technological, industrial, and geopolitical environment since then, it would seem appropriate that we reexamine how the government goes about the business of maintaining a technological advantage for U.S. national security.

The globalized production systems currently producing IT, semiconductor, and biotechnology innovations raise serious questions about national advantage in both the military and economic arenas. Private-sector R&D investments in these areas continue to dwarf technology investments by the military. The issue for the military is how to tap into commercial developments while securing closely held technological differentiators for military systems that incorporate commercial technologies.

Specialized software and systems-integration know-how may be the keys to transforming widely understood technology building blocks into closely held military systems. However, the defense industrial base must not be cut off from commercial developments. To make effective use of new commercially developed technologies, defense industries must be part of the commercial world. One solution may be to reengineer the procurement system so military markets will be more attractive to commercially oriented companies and to reduce differences between military and commercial products wherever possible. This would also help alleviate the problems of increasing concentration and decreasing competition in defense industries.

Thus we have come full circle, back to a central theme of the defense industrial policies of the 1990s—commercial-military integration and dual use. In cases where DOD has unique technology requirements and product niches, it must be prepared to bear the full cost of maintaining a separate and unique industrial base. In other cases, however, many problems can be solved by revamping the procurement system to make it easier for commercial companies to sell solutions to military problems using commercial technology. Dual use is back—or at least it should be!

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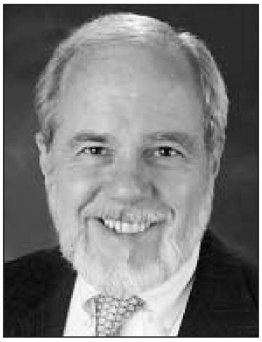
The new industrial revolution will enable people to live where they like and produce what they need locally.

The Transformation of Manufacturing in the 21st Century



Lawrence J. Rhoades is president and chief executive officer of Ex One Corporation.

Lawrence J. Rhoades

Manufacturing has been defined as the human transformation of materials from one form to another, more valuable form. The transformation can be geometric or compositional, or both. Manufacturing encompasses both the production of man-made materials originating from naturally occurring raw materials and the production of discrete parts, usually from those man-made materials. Nearly all discrete parts are made using a series of steps or processes that, with few exceptions, fall into one of four groups:

- *Casting or molding* produces an object by transforming a material from a liquid to a solid. A material in liquid form is poured or injected into a preformed mold (or die), allowed to solidify (normally by cooling, but sometimes by heating or chemical curing), and, once solidified, removed from the mold as a solid object. The mold is typically made from a metal with a higher melting temperature than the formed material. Sometimes the mold is disposable (e.g., sand or ceramic) and is destroyed during the removal of the formed part. In these cases, the mold itself is "molded" from a durable, preformed pattern.

- *Forming* is a process of applying force, and sometimes heat, to reshape, and sometimes cut, a ductile material by stamping, forging, extruding, or rolling. Like the tools used in casting or molding, the tools used in forming are preformed and durable.

- *Machining* is used to "cut" specific features into preformed blanks (e.g., slabs, bars, tubes, sheets, extrusions, castings, forgings, etc.) by manipulating a fast-moving cutting tool relative to the work piece on a special (usually computer-controlled) machine tool, such as a lathe, mill, or grinder. In the machining process, even though the cutting-tool material is considerably more durable than the work piece material, the tool is subject to wear and tear. Typically, many different tools are used, and a specific "cutter path" is programmed for each feature and each tool. Compensation is made for tool wear.
- *Joining* includes welding, brazing, and mechanical assembly of parts (made by molding, forming, or machining) to make more complex parts than would otherwise be possible with those methods. Typically, special fixtures or special tooling and programming of assembly machines or robots are used for each assembled part.

Manufacturers are constantly struggling to achieve an appropriate balance between scale and flexibility.

The common theme in the methods widely used to manufacture discrete parts is a significant up-front effort, which can take several forms: tooling (e.g., dies, molds, cutting tools); special-purpose machining; part-specific programming (e.g., tool selection, "feeds and speeds," cutter paths, tool wear compensation); and "design for manufacturing" (i.e., iterating product designs so that fewer, less expensive manufacturing operations are required to produce a product). To justify the up-front investment of time and money in planning, designing, tooling, buying, programming, installing, and proving out production lines and cells for making products, production volumes must be sufficient to amortize the investment at a reasonable cost per part. Manufacturers are constantly struggling to achieve an appropriate balance between scale and flexibility. "Just-in-time" manufacturing and "flexible manufacturing systems" are two of the best known strategies in that struggle.

The heart of the problem is that there are dozens, sometimes hundreds of steps in the production cycle—even for simple products—that require many different machines and worker skills. High-volume production scale unavoidably limits flexibility, and many machines and people must be gathered in one place to make many, many parts and products with limited variation. Even though individual steps in the production process have been dispersed in recent decades from the centralized, fully integrated factories of the 1950s into the "extended enterprise supply chains" of the 1990s (because the added cost of handling and shipping from component suppliers to assembly sites is outweighed by the flexibility of the supply chain and lower cost of labor), the volume of parts going through each process step at any point in the supply chain is the same (if not higher, thanks to "global" product platform designs). Production is typically done in or near cities where large supplies of labor and supplier networks or, at least, a dependable transportation infrastructure, are available.

Once products are completed, usually in factories where hundreds or thousands of people gather to make thousands or millions of parts, they are shipped great distances, often across oceans, to the customers who want them. In the automotive industry, the most significant manufacturing sector in the United States, the average U.S.-built car is finished 90 days before it is purchased —considerably longer than it takes to make it. A manufactured product has no more value than its untransformed materials and components unless it is purchased by a customer who actually wants it in that form. Products made, but not sold, represent an inventory risk.

Because the cost of distribution often exceeds the cost of production, a better definition of manufacturing might be the creation of value through the transformation of materials from one form to another and *the delivery of that more valuable product to a buyer*. In fact, as Wal-Mart, Dell, and FedEx have all demonstrated in different ways, reducing inventory as a percentage of sales, even by just a few points, can greatly increase profits.

The Challenges Ahead

Creating economic value through manufacturing is far more important than the public and government generally acknowledge, and the more broadly manufacturing is defined, the more this becomes apparent. The world economy is based on three principal activities:

- *Agriculture* is the natural (but increasingly engineered and therefore less natural) transformation of biomaterials from one form to another form more valuable to humans. Advances in biomimetic materials and processes and the promise of biomanufacturing are gradually blurring the line between agriculture and manufacturing.

- *Construction* can be thought of as manufacturing of very large, immobile "products."
- *Manufacturing* of products, as conventionally defined, comprises the bulk of international trade.

Perhaps agriculture and construction can provide lessons for the development of constructive public policy related to U.S. manufacturing. As the result of major investments by the federal government to provide a national transportation infrastructure, the United States has the best road system in the world, which has contributed greatly to U.S. economic efficiency and prosperity. In agriculture, because of advanced technology and equipment and remarkable cooperation among government, universities, and the agricultural industry, 3 percent of the workforce produces more food than the country can consume. Yet, for nearly all of history (and for most of the world today), most of the workforce was engaged in the production of food. The workforces of newly industrialized countries are rapidly moving to manufacturing-related jobs in cities; for example, the population in China is migrating from the countryside to cities at the rate of 1 percent per year—a million people per month.

The reasons for the trend toward manufacturing are apparent in the derivation of the word itself—which literally means handmade. Through manufacturing, both "touch" labor and intellectual labor become transportable through space and time (much more easily than in construction or agriculture) and can be sold in markets that value that labor. Ironically, although the laborer himself may not be permitted to enter those marketplaces, the products in which his or her labor has been invested are welcome there. In recent decades, even though transportation technology has not changed dramatically, the *logistics* of transporting goods and keeping track of them via computers has improved dramatically, consequently lowering the cost and accelerating the movement of products from production sites to markets. With wage differentials between countries of 10 or 20 to 1—a much greater price disparity than for any commodity—products with significant labor content can bear the cost and inconvenience of being transported across borders.

Most important, trade agreements in the past 40 years have reduced tariffs and quotas and opened markets in industrialized countries to previously nonindustrial, low-labor-rate countries, such as China, India, Indonesia, Brazil, Russia, Bangladesh, and Mexico, which together account for some 3.1 billion people, more than half the world population. Products made by workers in those countries, who earn 10 percent (or less) of what workers with the same skills in G7 countries earn, appear side by side on shelves and in showrooms with domestically produced products for purchase by the mere 700 million G7 consumers who currently have most of the world's purchasing power.

More than half the value of a vehicle sold in the United States today is produced elsewhere.

Not surprisingly, the shift to global manufacturing (and what many believe is a lack of concern for the health of the U.S. manufacturing sector) has led to the loss of 2.5 million manufacturing jobs in this country since 2000. One-third of all manufactured products sold in the United States today are imported; the country exports only half that much, which has led to a huge, persistent, and growing trade deficit that for years represented 5 percent of GDP but has recently grown to 6 to 7 percent. This deficit is almost entirely attributable to the trade imbalance in manufactured goods.

In the economically important automotive industry, one-third of all vehicles bought in the United States are imported. In addition, the foreign content in "U.S.-made" cars has increased to about 40 percent. As a result, more than half of the value of vehicles sold in the United States—the largest auto market in the world—is produced elsewhere. At the same time, U.S. auto exports are meager.

Among suppliers of manufacturing technology and equipment, things are even worse. U.S. production of machine tools has fallen by two-thirds since 1998, and two-thirds of the machine tools sold in the United States are imported. In this case, the cause is not low labor rates but a lack of U.S. commitment to

FIGURE 1 Molds for an engine set that can be produced in 36 hours with a build-box the size of a trunk. Source: Extrude Hone/ProMetal, 2003.

investments in manufacturing technology. The U.S. produces about 6 percent of the world's machine tools, about \$2.2 billion worth. Japan, which has half the population, produces more than three times as much (\$7 billion), and the EU, with a population not much bigger than that of the United States, produces more than six times as much (\$15 billion).

As a result of this gap, the United States is no longer the recognized leader in manufacturing innovation, and, compared to its major competitors (particularly Germany), the U.S. government has invested very few taxpayer dollars in improving U.S. manufacturing technology and infrastructure, despite the fact that manufacturing was the largest sector of the U.S. economy until last year, when it was displaced by health care. Clearly, the investment gap must be addressed.

The challenges facing U.S. manufacturing were not unexpected. In 1998, the National Research Council Board on Manufacturing and Engineering Design published *Visionary Manufacturing Challenges for 2020*, a study sponsored by the National Science Foundation. The objective of the study was "to identify challenges and enabling technologies for manufacturers to remain productive and profitable in 2020." The report defined manufacturing in broad terms as "the processes and entities required to create, develop, support, and *deliver* products" and identified six "Grand Challenges":

- *Concurrent* manufacturing, which entails drastically shortening the time between product conception and realization.
- *Integration* of human and technical resources, which requires quick reactions throughout the "extended enterprise" workforce to serve customers with high expectations and many choices.
- *Conversion* of information to knowledge, which means (1) instantaneously transforming captured data into useful knowledge and (2) providing access to knowledge when and where it is needed.
- *Environmental* compatibility, that is, using methods that are environmentally benign, using recycled materials as feedstock, and eliminating wasted energy, materials, and human resources.
- *Reconfigurable* enterprises, which require that intra-organizational and inter-organizational structures be flexible and adaptable.
- *Innovative* processes that decrease production scale to an economical lot quantity of one; decrease dimensional scale to the manipulation of microparticles, or even nanoparticles; and fabricate and use new materials (e.g., functionally gradient materials with different properties in different areas of a single component).

One innovative area of process technology that addresses nearly all of these challenges includes features evolving from "rapid prototyping," "free-form fabrication," "layered manufacturing," "3D printing," and "Innofacturing™." Thanks partly to government support, the United States currently has a significant market and technological advantage in these technologies, all of which directly convert computer design files that describe objects as "3D models" into physical objects constructed layer by layer (i.e., assembling particles of work-piece material digitally on each layer and then adding to the work piece one layer at a time).

The most apparent advantage of these processes is the remarkable product design freedom enabled by layered construction. More important, however, is that parts can be produced, without tooling or programming, in a single, highly flexible production cell, thus eliminating the need for, or even the advantage of, scale, including volume scale. This enables *distributed* digital production, which changes just about everything about manufacturing as we now know it.

Digital Production

Phil Dickens, a professor at Loughborough University in the United Kingdom and an enthusiastic supporter of distributed digital technology, predicts that, "The impact of rapid manufacturing will be so profound, changing the way products are designed, manufactured, and distributed, that it can be described as the next industrial revolution." Unlike the first industrial revolution, which led to a migration to population-dense cities (a trend that continues in emerging industrial economies), this revolution will enable people to live where they like and produce what they need locally. Distributed digital production is the antithesis of the production line (e.g., "a factory in the home" or at least "in the neighborhood") where people will "pay for the plans, not the product," as described by John Canny, a professor at the University of California at Berkeley.

Digital production (or rapid manufacturing) transforms engineering design files directly into *functional* objects—ideally, *fully functional* objects. This technology emerged from rapid prototyping systems that first produced nonfunctional, "appearance models" (limited-use, engineering-design and marketing aids made from nondurable plastic materials). Over time, the plastic materials were strengthened until the models became fairly functional. However, the real-world benchmark materials for full functionality in manufacturing are metals.

Currently, most of the companies in the world that produce systems capable of free-form fabrication of metal components are in the United States. The ProMetal Division of my company (Ex One), for example, produces systems specifically dedicated to making metal components.

At the large end of the spectrum, metal parts can be made by using these processes to produce nonmetal casting molds. The same sand and binder that were used for years in conventional pattern-based sand casting can be 3D printed to provide precise, complex-geometry sand casting molds and cores without patterns; thus, one-off design metal castings for automotive engines can be produced in two days instead of two months (Figure 1). A 1.5 x 1 meter layer can be produced every minute. With 0.2-mm layers, roughly one liter of sand can be processed every three minutes, printed or not; typically, about a liter of printed sand molds and cores can be produced every 10 or 15 minutes.

At the other end of the spectrum, machines with a build-box the size of a matchbox can produce half a dozen gold dental copings (the part of a dental crown that fits precisely on the tooth) every hour. Thus, a dental laboratory can produce a more precise, less expensive dental restoration in one or two days, instead of a week (Figure 2).

Military spare parts can now be made when and where they are needed, as can custom-designed architectural hardware, gold jewelry, customized trophies, and parts for vintage cars. This tool-less process can even be used to make tools. Forging dies for short-run spare parts can often be made faster and cheaper than finding dies that already exist.

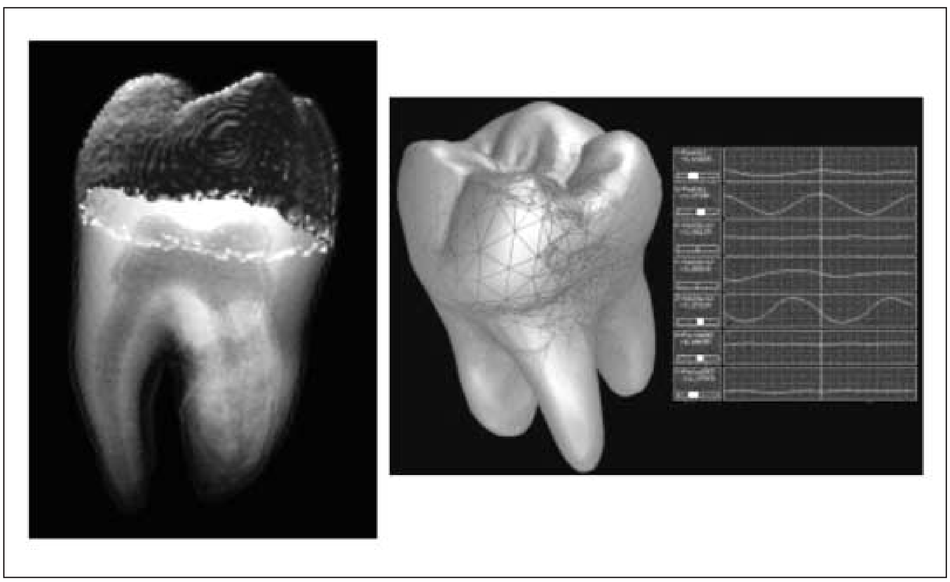


FIGURE 2 Six gold dental copings like the one shown can be produced in an hour with a build-box the size of a matchbox. Source: Extrude Hone/ProMetal, 2003.

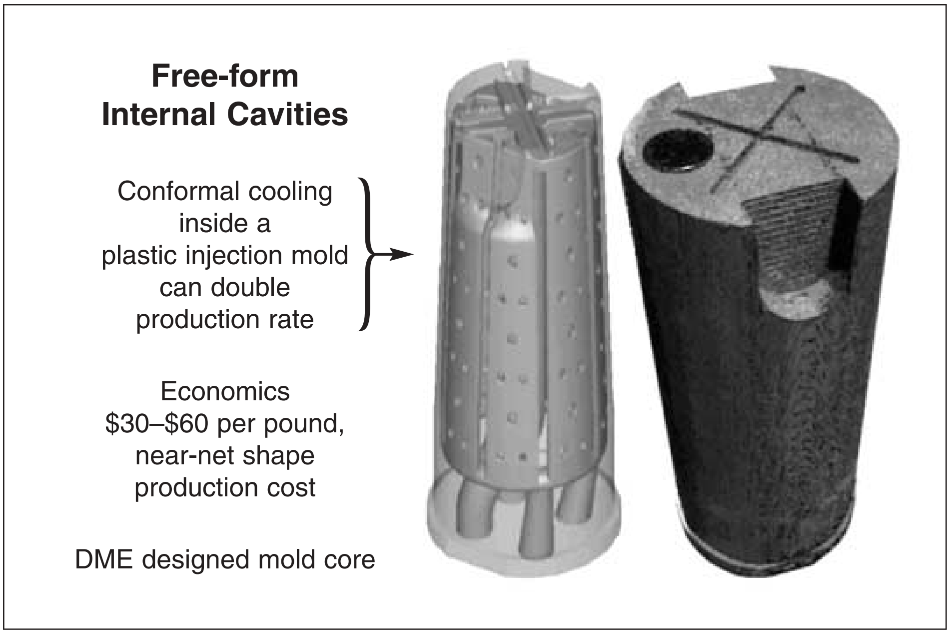


FIGURE 3 Plastic injection molds with conformal cooling passages. Source: Extrude Hone/ProMetal, 2003.

Plastic Injection Molds

For plastic injection molds, the advantages are dramatic. The conventional process of plastic injection molding entails injecting a thermoplastic polymer into a mold at a temperature high enough for the material to be "plastic," that is, capable of flowing. The material must then cool down until it solidifies in place and can be removed and handled without losing its shape. The solidification is neither instantaneous nor uniform, and the "freeze sequence" can affect dimensional precision in critical features of the molded part.

With layered production, digitally produced free-form fabricated products with complex internal geometries can be produced (Figure 3). For plastic injection molds, this means conformal cooling passages that can control and accelerate the freeze cycle of molded parts just beneath the surface of the mold cavities, enabling higher precision and higher production using the same plastic molding machines, floor space, and workforce that previously spent the bulk of the production cycle waiting for molded parts to cool down enough to stop being "plastic" and solidify. These internal geometries can be quite sophisticated and can incorporate advanced cooling features like those used to cool aircraft turbine engine blades.

Using some layered processes, components with functionally gradient materials can be produced. In the 3D printing process, the particles on each layer representing a cross section of the part are assembled by precisely "jetting" droplets of "binder" or glue. Once printing is complete, the unwanted loose particles can be separated from the "glued-together" metal powder part. The droplet-printing device can selectively print different "colors" of droplets (i.e., droplets that contain different types or concentrations of alloying agents) on different areas of the work piece; thus, different materials can be precisely placed at specific locations (Figure 4).

The metal particles in the printed, or glued-together, part are thermally fused in the sintering operation that follows (Figure 5). The alloying agent deposited at the selected sites diffuses into the particle material, altering

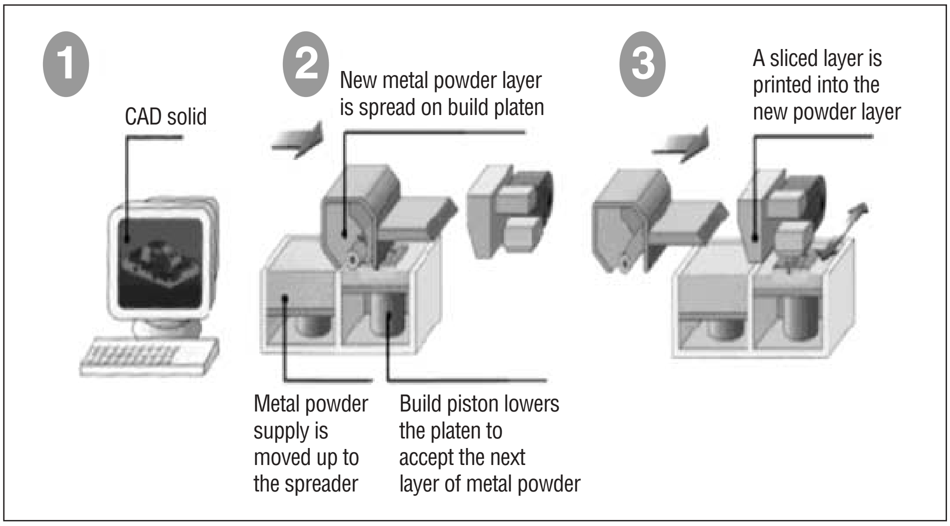


FIGURE 4 3D printing layered production process invented at MIT. Source: Extrude Hone/ProMetal, 2003.

its local physical characteristics. Unlike coating or plating, in which there can be abrupt interfacial strain from loading or temperature, a component with functionally gradient material can be made to gradually transition from, say, a hard but brittle steel surface to a tough, ductile interior without risk of delamination. This can be done by simply varying the concentrations of carbon in the binder droplets selectively printed in the part.

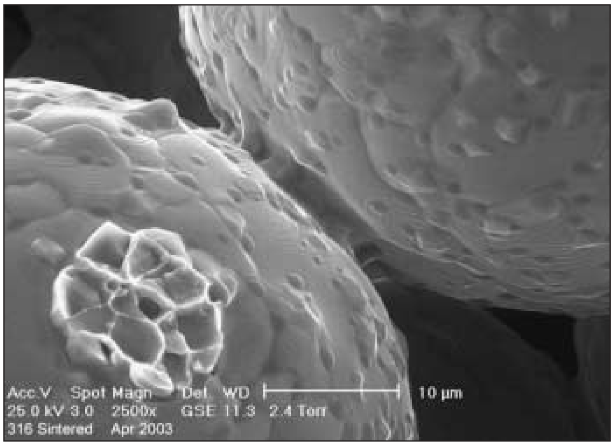


FIGURE 5 Electron micrograph showing a thermal bond produced through sintering to ensure predictable strength and dimensions. Source: Extrude Hone/ProMetal, 2003.

Conclusion

Distributed digital production, a category of processes evolving from rapid prototyping, rapid manufacturing, free-form fabrication, and layered manufacturing, is a harbinger of twenty-first-century production, which is dramatically different from the kind of "manufacturing" we know today. The fundamental nature of distributed-digital processes—the construction of functional metal work pieces by assembling elemental particles, layer by layer, with no instructions other than the computer design files widely used to define objects geometrically—is based on different assumptions than those that drove manufacturing and distribution strategies throughout the twentieth century.

The United States has an early lead in these emerging technologies, partly as a result of creative work at some of the nation's best universities (e.g., MIT, University of Texas, Carnegie Mellon University, Stanford University, University of Southern California, University of Michigan, and Johns Hopkins University) and Sandia and Los Alamos National Laboratories. The U.S. lead is also the result of the visionary spirit of technology-focused entrepreneurs who head and back companies that are pioneering these new technologies. However, the biggest factor has been the impetus provided by the U.S. government, principally the U.S. Department of Defense, which has much to gain from the development of processes for building spare parts and new products flexibly and without cost sensitivity to production volumes. Whether or not the United States maintains and strengthens its leadership position and realizes the benefits of these processes may depend on the outcome of the current debate on the role of government in providing a national "manufacturing technology infrastructure."

As the costs and wait times of tooling, programming, and "designing for manufacturing" are reduced and then eliminated, the perceived advantages of high-production volumes, concentrated manufacturing sites, and complex distribution logistics will yield to the advantages of distributed digital production—products designed to meet the specific preferences of individual customers that can be produced on or near the point of consumption at the time of consumption (e.g., automotive spare parts produced at a dealership).

The design freedom enabled by constructing objects in thin layers from particles with dimensions in microns will significantly reduce a product's component-parts count. This, in turn, will reduce product weight by eliminating attachment features and fasteners and optimize functionality by eliminating excess material and wasted energy. The particles that are not needed for the part produced can be recycled to become the next—maybe very different—part. The metal in older, no longer useful products can be locally recycled to become metal powder feedstock for tomorrow's production. Thus, inventory carrying costs and risks and transportation costs can be dramatically reduced, increasing savings in energy, materials, and labor.

Finally, because these processes are highly automated, the size of the workforce required to produce and deliver manufactured products to the customer will be greatly reduced. Consequently, low-cost, so-called touch labor will lose its competitive advantage in the production of physical objects.

The demand for innovative product designs will expand dramatically. And, because ideas will be delivered electronically, designers can be located anywhere. As design for manufacturing becomes less important, and because design superiority will be gained principally through understanding and responding to customers' tastes, designers might want to be located near their customers.

Even if products are designed remotely, however, production will be done locally. Physical objects will be produced "at home" or "in the neighborhood" from locally recycled materials. Thus, cities will lose their economic advantage, and urban populations will be dispersed.

Although the revolution promised by these technologies could have great benefits for consumers in developing countries, the economic advantages of manufacturing in areas with comparatively cheap labor will be ultimately unsustainable, and workers in poor countries are likely to suffer. Consequently, our energy and creativity must also be focused on finding other paths to economic parity in the value of equivalent human labor to hundreds of millions of low-wage workers throughout the world.

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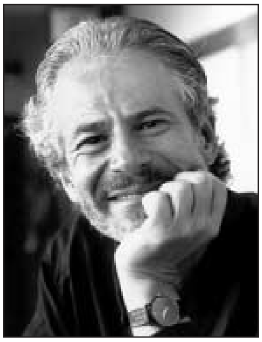
The number of "digital people" (artificial beings and partly artificial beings) is increasing rapidly.

Digital People in Manufacturing: Making Them and Using Them[1]



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Sidney Perkowitz

Robots have played an increasingly prominent role in manufacturing for the past 50 years, and about a million industrial units are in use today worldwide. In a parallel development, the number of humans with bionic units, such as cochlear implants and artificial limbs, is also growing. The presence of these "digital people," a category that includes artificial and partly artificial beings, from mechatronic (mechanical plus electronic) robots to humans with bionic (biological plus electronic) implants, is rapidly increasing in industry and in society as a whole. Digital people represent a new technology that deserves serious attention.

The 1920s play *R. U. R. (Rossum's Universal Robots)* by the Czech author Karel Capek introduced the word "robot," which comes from the Czech word "robota," meaning forced labor. Capek foresaw the widespread use of robots, as he painted a picture of humanoid units made purely to serve humanity. At least two rudimentary humanoid mechatronic robots were built in the 1920s and 1930s (Elektro, a unit designed by the Westinghouse Corporation, was a hit at the 1939 New York World's Fair [Figure 1]); however, true commercial use of robots began with the invention of a

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[1] This paper is based on the author's book, *Digital People: From Bionic Humans to Androids* (Joseph Henry Press/National Academies Press, 2004), which is also available online at *http://www.nap.edu/catalog/10738.html*. Interested readers are invited to consult the book for further details, including a full bibliography.

FIGURE 1 Elektro, designed by Westinghouse Corporation, was exhibited at the 1939 New York World's Fair.

non-humanoid type of industrial robot in 1954. Now, with advances in mechatronics, materials science, artificial intelligence, and other relevant areas, increasingly capable units, some of them humanoid, are becoming available for use in industry, homes, and hostile environments.

The related area of bionics is potentially even more important. The origins of this technology are scattered and diffuse, harking back centuries, and even millennia, to crude prosthetic replacements for missing limbs, such as wooden legs. Bionic technology is now producing sophisticated artificial limbs and bodily organs, as well as devices that connect directly to the neural system or the brain, for example, cochlear implants that restore hearing to the deaf. Bionic additions such as these promise to address important issues for the injured and ill and perhaps someday to enhance human capabilities.

These and other potential results of bionic and robotic technology, however, such as the displacement of human workers, raise complex ethical issues that require careful consideration. Although these technologies are at the beginning stages of development, it is not too early to survey the state of the art and its implications.

Robots for Industry and the Home

The year 2004 marked the 50th anniversary of the patenting of the first industrial robot by George Devol, an engineer. With his partner Joseph Engelberger, Devol began making and selling a one-armed, programmable unit called the UNIMATE. Engelberger envisioned robotic devices as "help[ing] the factory operator in a way that can be compared to business machines as an aid to the office worker." General Motors (GM) bought its first UNIMATE in 1961, but for a variety of economic and societal reasons, the Japanese were the first to widely use robots in automobile factories. In 1978, however, GM installed an assembly line using a PUMA (programmable universal machine for assembly), and robots began to appear in U.S. industry in substantial numbers.

A typical industrial robot is fixed in position and consists principally of a powerful multi-jointed mechanical arm that is nearly as flexible as a human arm and that can be programmed to carry out intricate manipulations of components large and small (Figure 2). Table 1 shows that Japan still leads in the use of these robotic workers, that roughly one million such units are now operating worldwide, and that global use is increasing. This growth can be expected to continue, if only because of the economic imperative—as the costs of human workers are increasing, those of robotic workers are falling. Robots already form some 10 percent of the workforce in the Japanese, Italian, and German automobile industries, illustrating the potential for robotic labor to supplant humans, with consequent disruptions, especially for older workers.

Assembly-line robots will continue to play an important industrial role, and indications are that ongoing technical advances will also produce robots suitable for nonindustrial applications in the home and in dangerous and demanding environments. These advances include new artificial physical, sensory, and mental

FIGURE 2 A typical industrial robot. Source: Precision Engineering Research Group, Massachusetts Institute of Technology.

TABLE 1 World Population of Industrial Robots for Selected Years (in thousands of units)

	1984	1988	2001	2002	2003[a]	2006[b]
Japan	67	176	360	350	344	333
U.S.	13	33	97	104	111	135
Europe	17	53	231	244	259	316
Asia/ Australia[b]	0.7	2	57	60	64	73
Total	100	266	757	772	838	875

[a] Projected

[b] Excluding Japan

Note: Some totals incorporate values for other countries, including USSR/Russia. If estimated uncounted units are included, the total for 2002 and later is thought to exceed 1,000,000 units.

Sources: NRC, 1996; UNECE, 2003.

capabilities, as illustrated by three particular units designed and built in the last few years: ASIMO (advanced step in innovative mobility), a child-size humanoid robot from the Honda Corporation; QRIO, a two-foot tall humanoid robot created by the Sony Corporation; and KISMET, a robotic humanoid head and face designed and built by robot engineer Cynthia Breazeal at MIT. Together these three units display a range of physical abilities that also draw on artificial sensory capabilities, such as vision, walking, climbing stairs, adjusting gait for different surfaces, avoiding obstacles while walking, recovering from a fall, dancing, carrying objects, and responding to humans by shaking hands, showing facial expressions, and waving goodbye (Figure 3).

These abilities also require a degree of intelligent behavior, defined as behavior that helps an organism survive and thrive by providing effective responses to changing circumstances. According to Harvard psychologist Howard Gardner, this adaptive property in humans encompasses seven different types of intelligence: logical-mathematical, linguistic, musical, bodily-kinesthetic, spatial, interpersonal, and intrapersonal (Gardner, 1999). The latter (intrapersonal) touches on the perplexing issue of whether an artificial brain can be truly conscious of itself as we humans are, a question that is unlikely to be answered in the near future. That question aside, ASIMO, QRIO, and KISMET clearly display the low-level rudiments of intelligent behavior. For instance, they can memorize and recognize human names and faces, and even hold limited conversations.

With advances in mobility and physical versatility, sensing abilities, and intelligence, robots are becoming suitable for home and office use, although many are not humanoid. The most popular examples are robotic pets, such as the artificial dog AIBO made by Sony. Designed purely for entertainment, AIBO was introduced in 1999 and quickly enjoyed brisk sales. The AIBO dogs display sufficient intelligence and manipulative ability to be formed into soccer teams, which roboticists use to study how groups of robots interact. A more practical example is Roomba, a robotic vacuum cleaner that uses intelligent decision making to avoid furniture as it vacuums every square inch of a floor, without human guidance.

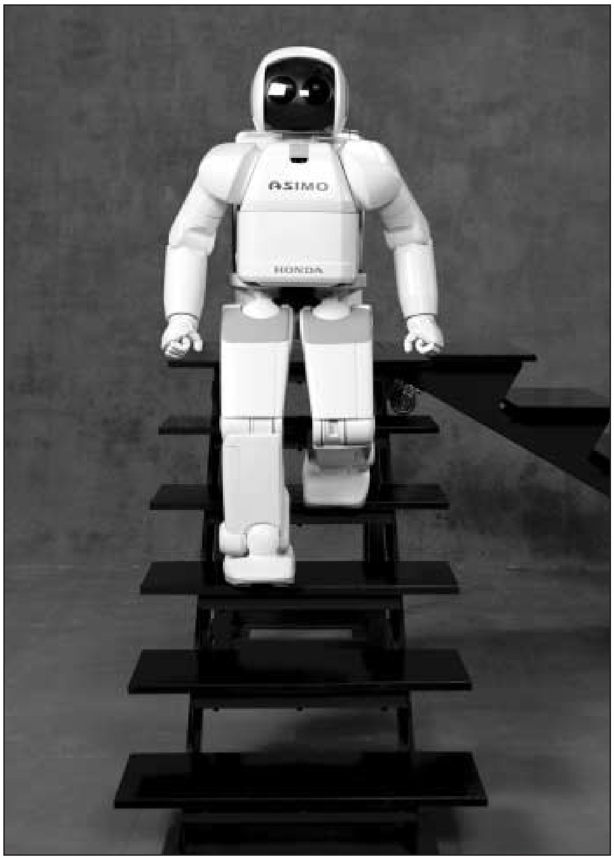

FIGURE 3 ASIMO (advanced step in innovative mobility), a child-size robot made by Honda Corporation, shown walking down stairs.

The humanoid robots ASIMO and QRIO are not yet on sale for general use, but ASIMO can be rented from Sony as a robot receptionist and guide and has been designed to interact with humans in future applications; and QRIO has clear possibilities for entertainment. Table 2 shows the recent spectacular growth in these and other nonindustrial applications, with the

TABLE 2 World Population of Nonindustrial Robots for Selected Years (in thousands of units)

	2002	2006[b]
Household (vacuum, lawn)	50	500
Professional services[a]	19	49
Entertainment	545	1,500
Total	625	2,200
Value (billions of $)	3.6	6.0

[a] These include surgical devices, units for underwater exploration, surveillance, and hazardous duty, units that assist disabled people, etc.
[b] Projected
Source: UNECE, 2003.

number of units already far outstripping the number of industrial robots. With other developments on the horizon, such as intelligent manipulation of objects by robot hands and fingers (driven by research at the National Aeronautics and Space Administration and by the development of surgical robots for delicate medical procedures) and high-speed object recognition and obstacle avoidance (exemplified by projects sponsored by the Defense Advanced Research Projects Agency [DARPA] and the Daimler Chrysler Corporation), a multitude of new applications may be expected to develop, including many for the military, such as self-guided, intelligent weapons.

Bionic Humans

As robots are becoming more natural by taking on human physical and mental characteristics, humans are becoming more artificial. At present, bionic technology is less well developed than robotic technology, and there seems to be no compilation of worldwide activity in bionics comparable to the summaries for robotics. However, according to one recent estimate from the National Institutes of Health, 8 to 10 percent of the U.S. population—that is, about 25 million people—has artificial parts, from breast implants to coronary stents to prosthetic limbs to cochlear units, suggesting a substantial economic impact. A list of recent highlights in the development of bionic additions, including the growing area of neural (or brain-machine) interfaces, indicates some present and future possibilities for this technology:

- More than 30,000 cochlear implants are in use, including some placed in deaf children as young as 1 to 2 years of age.
- Several research laboratories and corporations are pursuing the implantation of electronic devices in the retina or the cortex of the brain to restore sight to the blind.
- DARPA is funding research in brain-machine interfaces for direct mental control of military aircraft, powered exoskeletons that give soldiers increased strength and mobility, and other applications.
- Living monkey brains have been used to operate robotic arms, and a sea-lamprey brain has been used to operate a wheeled robotic body. The aim is to make artificial limbs and other devices for humans that function under direct mental control.
- At least one research group has made it possible for a fully paralyzed person to operate an external device, a computer, by mental control alone.
- Researchers are developing the "neuron on a chip," that is, a living neuron grown on a standard electronic computer chip so that the neuron and the chip can directly exchange electrical signals and hence information.

The potential to relieve a variety of human ills and injuries is clear, and the science-fictionish aspiration of actually improving human physical, mental, and even emotional capabilities by artificial additions may be attainable someday.

Ethical and Societal Issues

Despite these potential benefits, robotic and bionic technologies also have troubling aspects. In robotics, replacement of expensive human workers by cheaper robots may loom large in the automobile industry and other applications, such as using intelligent robots as caregivers for the ill and elderly. The latter application raises another fundamental question: do we really want a society where human needs are met by machines, not people?

For bionic humans, ethical issues arise from the use of neural connections and brain-machine interfaces, centered around the question of what it means to be human. Certainly, a person who has a natural limb replaced with an artificial one has not become less human or lost a significant degree of "personhood." But suppose a majority of organs in an injured person is replaced by artificial components; or, suppose the artificial additions change mental capacity, memory, or personality. Is such a heavily artificial person somehow less than human? Would the established legal, medical, and ethical meanings of personhood, identity, and so on, have to be altered?

We are only in the early stages of understanding brain-machine interfaces and do not grasp all of the potential side effects. Neural implants have been shown to change the brain through its plasticity, that is, the innate ability of neurons to reform the connections among themselves to record new knowledge as the brain learns. Although this could be beneficial—for instance, by enabling a person to incorporate an artificial limb into his or her overall body image—we do not yet know if all such changes would be desirable.

Another, more subtle issue is suggested by some experiences with cochlear implants, which usually restore only partial hearing. Most implantees welcome even this incomplete restoration, but some find themselves uncomfortably suspended in a gray area between two cultures—that of the fully deaf and that of the fully hearing. Hence, psychological and even spiritual factors may prove to be barriers to the development of bionic technology. Finally, the process of surgical implantation can raise medical issues, such as infection and rejection by the body or poorly understood side effects. For instance, in 2003, U.S. government agencies issued a warning that young children with cochlear implants might be at increased risk for meningitis.

For both robotic and bionic technology, projected uses in warfare raise a host of issues. Would self-guided weapons violate the Geneva Conventions? Would a heavy dependence on robotic or bionic military units lead to the perception that wars can be fought at minimal human cost, a potentially destabilizing factor in international affairs? These and other issues have already been discussed at one major conference, the International Symposium on Roboethics, held in 2004 to address the ethical, social, humanitarian, and ecological questions raised by robotic technology (Roboethics, 2004).

Conclusions

Although it will be years before we understand the ultimate technological limits for robots and bionic implants, we can already draw some conclusions:

- The population of established types of industrial robots has grown eightfold or more in the last 20 years and will have an increasing impact on manufacturing industries.
- The latest extensions in robotic capabilities offer new opportunities for household and entertainment robots, with enormous growth projected in the near future, and may offer new manufacturing uses.
- A potentially huge impact will come from medical uses of robots and human-machine hybrids. These include surgical and caretaking units and the replacement, and even enhancement, of human physical and mental abilities.
- We must begin considering the many ethical challenges and societal changes that would accompany the widespread introduction of robotic and bionic technology.

Any new technology can have both positive and negative outcomes for society. Because robotics and bionics involve simulating, altering, and perhaps even changing the essential nature of humans, they have a special significance. Only the best efforts of everyone involved, from technological and medical experts to political decision makers and ordinary citizens, can ensure that these rapidly evolving areas will bring more good than harm.

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To prosper in the global marketplace, semiconductor companies are developing new business models.

Semiconductor Manufacturing: Booms, Busts, and Globalization

Alfonso Velosa

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The semiconductor industry presents something of a conundrum to the outside observer. Products based on amazing technologies are developed in huge, sophisticated, very expensive facilities. The majority of these products are then sold for a few cents or a few dollars each in mass markets. This market approach is driven by business decisions that (1) maximize profits and minimize risks in a high-technology market that is extremely capital intensive and subject to severe industry cycles and (2) respond to increasing globalization that started more than 20 years ago. In this paper, I analyze these trends and identify the major business models semiconductor companies have developed to profit in this environment.

Semiconductor Product Markets

The electronics and semiconductor industries, key building blocks of the global economy, combine macro- and microeconomics in many ways. To understand the importance of these industries, consider the size of the global economy in relation to the electronics industry. According to current estimates, the global gross domestic product (GDP) was approximately US$33 trillion in 2003, and the U.S. GDP was approximately US$10.4 trillion. Electronic equipment sales worldwide were estimated at US$1.04 trillion in 2003, and if one includes software, services, and telecommunications, global spending for information technology (IT) was

US$2.26 trillion, or about 7.5 percent of total global economic activity.

Semiconductors are the basis for the electronics and IT industries, the crucial building blocks for key elements. The semiconductor industry reached US$178 billion in 2003 and is estimated to have reached US$223 billion in 2004. Not only is the semiconductor industry large, it also represents 15.5 to 21.5 percent of the value of the electronics industry, depending on where it is on the industry cycle in any given year.

Since its beginning as a laboratory experiment, the semiconductor industry has grown to more than $200 billion, employing slightly less than half a million people worldwide. This exciting increase has taken place in many technology areas, involves many companies, and has undergone numerous business cycles, which have regularly shaken up the industry and caused it to change its competitive structure and the way management addresses the market and invests in new facilities and technology. In the past 20 years, the cumulative effect has been to compress the business cycle, thus necessitating short-term planning at the corporate level.

The pressures of the semiconductor business cycle have been compounded by a decrease in the industry's core growth rate, from approximately 15 to 17 percent through the mid-1990s to 10 to 12 percent in the past decade. The fundamental change in expectations for the industry has complicated risk management, as executives assess investments for new facilities. When the cost of a fabrication facility exceeded the billion dollar mark, executives were forced to develop new business models to minimize their risk.

The cyclical nature and slow growth patterns of the industry also reflect the evolution of core electronics markets. As electronic equipment proliferated and reached the trillion-dollar sales level, it reached the limits of market penetration and brought the rate of growth closer to that of overall global economic growth. The core electronics markets also illustrate the "bullwhip" effect on the supply chain, whereby small changes in orders, say, for computers by end users propagate through the system affecting retailers, distributors, manufacturers, and so on. Eventually, these changes have large, volatile effects on the suppliers of semiconductors, wires, and other building blocks. Thus, the business cycles in the computer, telecommunications, and consumer electronics industries have strong effects on the business cycle of the semiconductor industry. In the debacle of 2001, for example, the semiconductor industry shrank by more than 30 percent.

These end-market shifts reflect the manufacturing shift towards Asia, as firms search for integrated electronic supply chains and lower manufacturing costs. In 2000, the consumption of semiconductors by region was roughly equal among the Americas, Asia, Europe, and Japan. Beginning in 2001, however, consumption shifted towards Asia, and expectations are that Asia will eventually constitute more than 50 percent of the market.

Semiconductor Device and Process Technology

As electronics markets adapt to shifting business cycles and changing geographic manufacturing patterns, semiconductors remain the key technological element in electronic systems. Researchers have developed a technology spectrum for maintaining a full semiconductor pipeline and business processes and intellectual property rights regimes for the next 10 years.

Let's look at a few of the initiatives for the near term, midterm, and long term. In the near term (less than two years), products that will reach their critical market volumes include silicon-germanium chips, radiofrequency complementary metal-oxide semiconductors (CMOS) chips, and platform application-specific integrated circuits (ASICs). Multiple competing firms are bringing these products and technologies to market, and customers are starting to integrate them into electronic systems. In the midterm (two to five years), technologies such as embedded field programmable gate array (FPGA) cores and organic light-emitting devices will address significant customer issues and will attract funding for product development. In the long term (five to 10 years or more), technologies such as micro-fuel cells, gallium-nitride (GaN) devices, and polymer memory have shown significant promise. However, these technologies must overcome many barriers, such as lack of a supply chain infrastructure and

In the past decade, the industry's core growth rate has dropped from 16 percent to about 11 percent.

the absence of demonstrated large-scale products, and they may require further development before they can be integrated into high-volume manufacturing facilities.

This 10-year time scale is critical to the industry because semiconductor companies are increasingly adopting smaller scale manufacturing process technologies. The largest and most capable semiconductor manufacturers are developing products based on small line-width technologies with the objective of reaching the market ahead of their competitors. New forecasts for semiconductor fabrication facilities by these leading-edge companies show them to be two to three years ahead of the rest of the market, and their lead appears to be growing. Thus, Moore's law continues to reflect and influence decision making in the semiconductor industry.

The key metric for the industry is feature size or line width (i.e., the size of the wires embedded in the silicon to channel electrons). Leading-edge companies, such as Intel and TSMC, implemented 90-nanometer production facilities in 2004; 65-nanometer processes are expected to be in volume production by 2006. The wholesale adoption of new technologies continues to shift the industry's center of gravity towards smaller and smaller process technologies, forcing leading older facilities to close as they become less and less cost effective. However, companies that move away from the cutting edge of high-volume manufacturing are finding business models that continue to leverage older (500-nanometer and larger) processes for all electronic markets.

New Business Models

As companies invest in new fabrication facilities to produce new technologies, the risks inherent in these business investments continue to increase. In 1983, it cost $200 million to manufacture 1,200-nanometer chips in a leading-edge semiconductor facility. In 1997, it cost approximately $1.3 billion for a 350-nanometer facility, and in 2003, it cost as much as $3 billion for a 130-nanometer facility. Because of the large fixed costs of fabrication facilities and the significant volumes and capital resources necessary to justify them, the number of firms with leading-edge technology has been restricted to the largest semiconductor firms in the world. By 2003, even firms in the top 10 had to consider carefully where and how to invest in facilities (Table 1).

Tier 2 and 3 firms must have clear strategies or well defined market niches to compete in this arena. The decision to build a new facility or set up a laboratory must be based on business factors, such as which city or region in the United States or Germany or China offers the most money and the best incentives, what the markets are demanding, and the cost of capital to build a $1.5 to $3 billion facility.

The semiconductor foundry market, a model developed in the past decade, is made up of specialized contract manufacturers (foundries) that perform wafer-fabrication services for semiconductor companies that do not have fabrication facilities, integrated device manufacturers, and original equipment manufacturers.

TABLE 1 Top 10 Semiconductor Firms (in US$ millions)

2003		2000		1997	
Intel	$27,103	Intel	$30,298	Intel	$21,746
SAMSUNG Electronics	$10,502	Toshiba	$10,866	NEC	$10,222
Renesas Technology	$7,936	NEC	$10,643	Motorola (Freescale)	$8,067
Texas Instruments	$7,410	Samsung	$10,585	Texas Instruments	$7,352
Toshiba	$7,356	Texas Instruments	$9,202	Toshiba	$7,253
STMicroelectronics	$7,180	STMicroelectronics	$7,890	Hitachi	$6,298
Infineon Technologies	$6,864	Motorola (Freescale)	$7,678	Samsung	$5,856
NEC Electronics	$6,312	Hitachi	$7,286	Fujitsu	$4,622
Motorola (Freescale)	$4,628	Infineon Technologies	$6,732	Philips Semiconductor	$4,440
Philips Semiconductors	$4,513	Micron Technology	$6,314	STMicroelectronics	$4,019

Source: Company reports, 2003.

In the majority of cases, the customer creates a design for an integrated circuit and transmits it to the foundry, where it is fabricated on silicon wafers and delivered to the customer or another contract manufacturer for packaging, assembly, and testing. By 2003, the center of gravity of the foundry market was in Asia with TSMC with $5.9 billion and UMC with $2.5 billion in revenue, and IBM positioned as a strong technology developer at $0.8 billion in revenue.

The emergence of the foundry business model facilitated the rapid increase in "fabless" start-up companies (i.e., companies that do not have their own fabrication facilities), which no longer had to raise enough capital to build a facility. By definition, the fabless sector is highly dynamic, with many start-ups, many failures, and a few companies fortunate enough to hit on a successful product or emerging market and "ride the wave" as long as they can. Predicting which fabless companies will be winners is all but impossible. Nevertheless, the fabless model is successful, and the growth of fabless companies as a whole is likely to continue and to outpace the general semiconductor market. By 2003, six fabless semiconductor firms had exceeded $1 billion in sales (Qualcomm, NVIDIA, Broadcom, Xilinx, ATI Tech, and MediaTek Inc.)

The intellectual property industry complements the integrated, foundry, and fabless industries, providing solutions to issues related to specific products. Intellectual property has been developed for specific process technologies for chip modules, such as the compute engine, logic, input/output, memory, and so on. By 2003, the intellectual property market had reached critical mass, with several firms close to or exceeding $100 million in sales (ARM-$175 million, Rambus-$118 million, and Synopsys-$82 million).

Conclusion

For several decades, the semiconductor industry has been making significant adjustments to adapt to globalization, providing an instructive example for other industries contemplating full-scale globalization. Both semiconductor production and consumption have become global activities, with centers of excellence spread across the world. The coveted advantages of having a modern semiconductor facility in one's community has led local governments around the world to provide semiconductor firms with increasing financial and infrastructure incentives to build new facilities in their locales. Semiconductor firms seeking to minimize their risks for these investments in large facilities are negotiating extensively with flexible, responsive local governments.

At the same time, semiconductor firms continue to develop a technology pipeline that complements the current infrastructure, as well as newer approaches, such as the fabless and intellectual-property business models. The flexibility shown by the industry in the pursuit of end markets, collaborations with partners and governments, and the leveraging of technology are grounds for optimism about the future of the semiconductor industry.

NAE News and Notes

NAE Newsmakers

Zdenek P. Bazant, McCormick School Professor and W.P. Murphy Professor of Civil Engineering and Materials Science at Northwestern University, received the **Lifetime Achievement Award** from the Illinois Structural Engineering Section of ASCE (American Society of Civil Engineers).

Charles Elachi, director of the Jet Propulsion Laboratory in Pasadena, California, received the NASA **Outstanding Leadership Medal** for "outstanding leadership of the Jet Propulsion Laboratory, whose legacy of excellence in planetary exploration continues with the awe-inspiring Spirit and Opportunity missions to Mars."

Herbert Gleiter, professor at the Research Center Karlsruhe, Institute of Nanotechnology, recently received the **Husun Lee Lecture Award** of the Chinese Academy of Science.

Mary L. Good, Donaghey University Professor and dean, Donaghey College of Information Science and Systems Engineering, University of Arkansas at Little Rock, received the lifetime achievement **Vannevar Bush Award**. Dr. Good was recognized for "her achievements as an educator and industrial research manager. An extraordinary statesperson, a distinguished public servant, and a remarkable scientist, she has contributed broadly to the understanding and promotion of the value of science and technology."

John L. Hennessy, president of Stanford University, received the **NEC C&C Award for Lifetime Achievement in Computer Science and Engineering**. The Foundation for C&C Promotion was established to encourage and support technological study and development related to the integration of computers and communications technologies, or C&C. The presentation was made at a gala event to mark the 20th anniversary of the award on January 26, 2005, in Tokyo, Japan.

Jack Keller, chief executive officer, Keller-Bliesner Engineering, has been named by *Scientific American* as one of the world's 50 leading contributors to science and technology for the benefit of society. Dr. Keller was recognized for designing low-cost, small-scale irrigation and water-conservation systems that have boosted harvests for farmers in developing countries.

James K. Mitchell, University Distinguished Professor Emeritus, Virginia Polytechnic Institute and State University, was selected by ASCE Geo-Institute to receive the 2004 **H. Bolton Seed Medal** for "contributions to the fundamental understanding and professional practice of geotechnical and geo-environmental engineering."

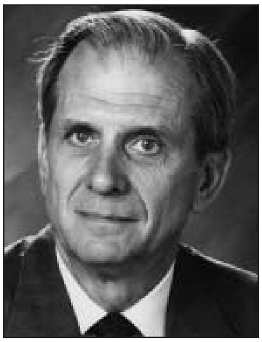
Eugene W. Myers, professor in the Department of Electrical and Computer Science, University of California, Berkeley, won the **Max Planck Research Prize** from the Alexander von Humboldt Foundation and the Max Planck Society. Dr. Myers received $900,000 to promote international cooperation in bioinformatics.

Courtland Perkins, past president, NAE, is the 2004 recipient of the **Daniel Guggenheim Medal**. The award is jointly sponsored by the American Institute of Aeronautics and Astronautics, American Society of Mechanical Engineers, AHS International, and Society of Automotive Engineers. Dr. Perkins was honored for "outstanding contributions to aeronautics in research and teaching in stability and control and superlative leadership at the national and international levels." Dr. Perkins was president of NAE from 1975 to 1983.

The National Academy of Sciences (NAS) will honor **Elbert L. Rutan**, president and CEO, Scaled Composites LLC, Mojave, California, with the **NAS Award in Aeronautical Engineering**. The $15,000 prize is awarded every five years for distinguished contributions to aeronautical engineering. Mr. Rutan was chosen "for leadership in engineering design and construction of SpaceShipOne, Voyager, and other successful experimental aircraft." The award will be presented on May 2 at a ceremony in Washington, D.C., during the NAS 142nd annual meeting.

Jerry M. Woodall, professor, School of Electrical and Computer Engineering, Purdue University, is the recipient of the Institute of Electrical and Electronics Engineers (IEEE) 2005 **Jun-ichi Nichizawa Medal** for "pioneering contributions to the liquid-phase epitaxy in the GaAs/AlGaAS systems, including applications to photonic and electronic devices."

From the Home Secretary



W. Dale Compton

Colleagues: I want to share with you some of my concerns about recent activities related to our election processes. NAE prides itself on being an honorific society and maintaining the highest standards for the election of members. To this end, we have followed a number of procedures that have stood the test of time. My intent is to encourage the continuation of these procedures.

First, the entire election process is confidential, that is, not open to individuals who are not members of the academy. I feel certain that many of you know of instances when confidentiality has been compromised. If someone asks you for a nomination, I encourage you to tell him (or her) politely that the process is confidential and is handled by active academy members. I encourage you to ensure the confidentiality of your nominations and recommendations.

Second, the deliberations of the Committee on Membership (COM), which makes the final decisions about which candidates appear on the ballot, are also confidential. The environment in which the committee operates must encourage frank and open discussion. Divulging information about those discussions makes it difficult for committee members to maintain the openness that is critical to the successful operation of this committee. I encourage members to refrain from asking about discussions that have taken place in the committee, and I encourage committee members to maintain the confidentiality of the discussions.

Third, the election process involves several steps, beginning with the receipt of nominations and letters of recommendations. The NAE Council, usually at its August meeting, establishes the number of slots available to the peer committees and the number of at-large slots to be filled by the COM. The number of slots allocated to each peer committee is influenced by several factors: the number of nominees assigned to each peer committee; the distribution of nominees among the work sectors; the age of nominees; and the number of nominees from underrepresented groups in the academy. Although the number of slots allocated to each committee varies, all peer committees are urged to consider only the quality of nominees in determining which ones to forward to COM for consideration. I believe that the peer committees have been careful to follow this procedure.

I want to reiterate that careful screening has been done in assembling the names that appear on the ballot. I must, therefore, take issue with the practice of sending letters to members encouraging them to vote for or against a given candidate, to vote for candidates from a given geographical area, or to vote for certain candidates because they might join a particular section when elected. I find these practices to be at variance with our high standards and encourage members not to indulge in them. I hope we continue to follow our carefully crafted system to ensure quality and do not try to impose personal opinions on the process. Each of us can express an opinion by voting for or against individuals on the ballot.

W. Dale Compton
Home Secretary

NAE Announces Million-Dollar Challenge to Provide Safe Drinking Water

On February 1, NAE announced the establishment of the Grainger Challenge Prize for Sustainable Development, a $1 million prize for the development of a practical technology that can prevent the poisoning of people throughout the world from arsenic contamination in their drinking water. Arsenic contamination affects tens of millions of people, especially in developing countries where existing treatment technologies are too expensive for widespread use. The prize will be awarded for the development of a small-scale, inexpensive technique for reducing arsenic levels in drinking water.

A quarter of the population of Bangladesh drinks water from some 10 million tube wells—a cheap, low-tech way of accessing groundwater. Most of the tube wells were built with international aid to provide an alternative to bacteria-tainted surface water. Unfortunately, these wells frequently tap into aquifers contaminated by arsenic from natural sources.

Treating drinking water with high levels of arsenic is not a major problem in the United States where many communities have the resources to install expensive, centralized water treatment facilities. "Different solutions are required in the developing world, and the solution has to work in the field," explained Alden Henderson of the U.S. Agency for Toxic Substances and Disease Registry. "The idea of sustainability is to offer communities choices and an opportunity to have a hand in finding a solution." "Sustainable development is not just about conservation and the wise use of the Earth's resources, but also about improving the quality of life for all people," said NAE President **Wm. A. Wulf**.

The goal of the Grainger Challenge Prize is to encourage the development of a household- or community-scale water treatment system that can remove arsenic from contaminated groundwater. The system must have a low life-cycle cost and must be robust, reliable, easily maintainable, socially acceptable, and affordable. As a sustainable technology, the system must also be within the manufacturing capabilities of a developing country and must not degrade other water quality characteristics or introduce pathogens.

Historically, prizes have stimulated interest in finding creative approaches to engineering challenges. Examples include aviation prizes, such as the Orteig Prize won by Charles Lindbergh and the recent Ansari X-Prize for the builder(s) of a private spaceship. "A challenge prize does more than just reward an individual for achieving a technical goal," Wulf explained. "It also focuses the talents of a particular community on solving a problem."

The Grainger Challenge Prize for Sustainable Development, made possible through the generous support of the Grainger Foundation, is administered and managed by NAE. More information about the Grainger Challenge Prize for Sustainable Development is available at <*www.graingerchallenge.org*>.

New Engineering Education Fellows

David P. Billington, Gordon Y.S. Wu Professor of Civil Engineering at Princeton University, has been selected NAE 2005 Walter L. Robb Engineering Education Senior Fellow. During his 24-month appointment, Billington will improve and expand instructional materials related to his highly acclaimed introductory engineering course, "Engineering in the Modern World," for use by faculty at other institutions. The current version of the course, which focuses on engineering in a historical context, satisfies university-wide requirements in both history and science or technology at Princeton. About 40 percent of the non-science liberal arts majors at Princeton have enrolled in this course, significantly advancing the understanding of engineering among undergraduates.

During the summers of 2005 and 2006, Billington and several colleagues will offer workshops for selected faculty, who will then report their experiences using the course materials prepared by Billington. Their papers will be included in a report published at the end of Billington's second year and presented at the annual meeting of the Center for the Advancement of Scholarship on Engineering Education (CASEE).

Billington is the author of more than 160 journal articles and eight books, including *The Innovators: The Engineering Pioneers Who Made America Modern* (Wiley, 1996). His research interests include thin-shell concrete structures, the history of technology, and scholarship for introductory courses in engineering.

Three Boeing Company Engineering Education Senior Fellows began 12-month terms on January 1. Each of them will issue a white paper and make an oral presentation at the CASEE annual meeting in October 2005.

Christine Grant, an associate professor of chemical engineering at North Carolina State University in Raleigh, will focus on advancing the success of engineering faculty members from underrepresented populations (e.g., African Americans, Hispanics, Native Americans, and women). She plans to work with scholars from these populations to develop guidelines for faculty and administrators of all backgrounds in mentoring future faculty. Grant is a recipient of the 2003 Presidential Award for Excellence in Science and Engineering Mentoring administered by the National Science Foundation (NSF) on behalf of the Executive Office of the President of the United States and codirector of the NSF Green Processing Research Program. Her research is focused on surface and interfacial science. She is a frequent speaker on technical topics before national and international audiences.

Gary Downey, professor of science and technology in society at the Virginia Polytechnic Institute and State University in Blacksburg, and **Juan Lucena**, associate professor of liberal arts and international studies at the Colorado School of Mines, Golden, Colorado, will engage in a joint project documenting international diversity in engineering and developing assessments of learning outcomes in courses on practicing engineering in an international context. Their efforts will be documented in the publication of a report and journal articles.

Downey is the author or coauthor of three books, 15 refereed journal articles, and eight book chapters. He is the 2004 recipient of the William F. Wine Award for teaching excellence at Virginia Tech and a member of Virginia Tech Academy of Teaching Excellence. He was elected a fellow of the American Anthropological Association in 1993.

Lucena is finishing a book on the history of U.S. policy making in science and engineering education, researching the impact of globalization on engineering education in the United States and Europe, and coauthoring (with Downey) multimedia modules on engineering cultures. He is also director of the McBride Honors Program in Public Affairs for Engineers at the Colorado School of Mines.

More information about CASEE is available at <*http://www.nae.edu/casee*>.

New Christine Mirzayan Science and Technology Policy Fellows Join Program Office

Nancy Adams

John Chase

Eileen Gentleman

Nancy Adams will be awarded her Ph.D. in geology from the University of Hawaii in May 2005. Her dissertation work has concentrated on the exsolution of volatiles during the catastrophic eruption that created the Valley of Ten Thousand Smokes in Alaska. Nancy received an M.A. in geology from Indiana State University and a B.S. in geosciences from Trinity University. While working on her master's degree, she studied large-scale volcanic eruptions in Peru. Nancy previously worked as a project geologist for Environmental Resources Management where her work included monitoring bioremediation sites, assisting with well installations, and sampling groundwater.

At NAE, she is working on projects for the Center for the Advancement of Scholarship on Engineering Education (CASEE). She hopes her fellowship at the National Academies will provide first-hand experience in policy-related work. Nancy enjoys swimming and surfing, but looks forward to her first real winter in five years.

John Chase is working on an M.A. in international science and technology policy at George Washington University (GW). In May 2002, he received a B.S. in computer science and Japanese language and literature from the University of Michigan, which included one year of study at the University of Tokyo in Japan. Between graduation and enrollment as a graduate student at GW, John was an assistant language teacher with the Japanese Exchange and Teaching (JET) Program. He taught English and helped develop English-language curriculum at the elementary and middle-school levels in Kanasago-machi, Ibaraki-ken, Japan. During his two years in Japan, John participated in various youth-orientated community programs and coordinated international exchange activities. After completing his education, he hopes to pursue a career in the public sector advocating policies based on sound science.

At NAE, John is working with Randy Atkins and Cecile Gonzalez on media and public relations. In his free time, he enjoys reading, sailing, and hiking and is an active volunteer with the Boy Scouts of America.

Eileen Gentleman is working with the NAE Technological Literacy Program. Eileen expects to earn her Ph.D. in biomedical engineering from Tulane University in May 2005. She received her B.S. from Tulane in the same area. Eileen is an insatiable science buff with basic knowledge in everything from astrophysics to zoology, which she hopes will help in her work at NAE. She currently works part-time as a master tutor and curriculum developer for Test Masters, LLC, and as a master tutor for Tutors of Greater New Orleans, LLC. She also teaches test preparation for Kaplan Educational Centers and lectures on test-taking strategies. After graduate school, Eileen plans to work as a postdoctoral fellow and then take a faculty position at a major research university. She hopes her fellowship at NAE will give her a chance to be involved in science from "the other side of the lab bench."

NAE, Northrop Grumman, and Penn State College of Engineering Team Up to Improve the *EngineerGirl!* Website

A freshman course at Pennsylvania State University, "Introduction to Engineering Design," exposes first-year students to the engineering design process, including customer assessments, product specifications development, concept generation, concept selection, and embodiment design. This year, student teams were asked to market research, design, prototype, and field test material to be added to the NAE *EngineerGirl!* website (*http://www.engineergirl.org*) to stimulate interest among middle-school girls in pursuing careers in engineering. The corporate sponsor of the course for this year, Northrop Grumman, specified the assignment.

The NAE *EngineerGirl!* website, the only website of its kind, is designed to inform girls about the full range of engineering careers. The site brings together descriptions of women engineers, provides real-world examples of how women have become engineers, and provides information about gender equity and ideas for introducing engineering curricula for parents, teachers, and counselors. The main theme of the site is that girls who become engineers can make a difference in society. In the fourth quarter of 2004, the site received more than 4 million "hits" and 94,042 visits. Although the target audience is middle-school girls, research shows that teachers, girls and women of all ages, and some boys and men also use the site.

The more than 100 student teams in the Penn State course were competing for four awards: (1) best design process; (2) best design communication; (3) best engineering design; and (4) most innovative design. Students were required to produce electronic materials and to prototype/model their materials and user test them. At the end of the semester, 12 teams (selected by class vote) demonstrated their projects at an Engineering Design Project Exhibition. The winning projects were selected by two teams of judges from NAE, Northrop Grumman, and Penn State.

The winner of the Best Design Process Award provided instructions for building and safely launching a rocket based on aeronautical and chemical engineering principles.

The Best Design Communication Award was given to a flash-driven website with instructions for teachers and students on building a balloon-driven car based on principles of mechanical engineering.

The Best Engineering Design Award went to a website featuring multiple projects that incorporated principles of architectural, civil, and chemical engineering. The projects were a crossword puzzle on engineering majors and instructions for building a structure from gumdrops, making rock candy, and making soda pop.

The winner of the Most Innovative Design Award showed how principles of electrical and electronic engineering could be used to build a simple, inexpensive burglar alarm with a buzzer that turns on when the door is opened and remains on when the door is closed again and an arming switch that turns the system on and off. The device operates on a single 9-volt battery at very low amperage and can be adapted to protect a window or any object.

The winning designs will be incorporated into the *EngineerGirl!* website. Project designs that did not win an award may also provide new material for the site.

Ralph J. Cicerone Elected President of the National Academy of Sciences

Ralph J. Cicerone

Ralph J. Cicerone, chancellor of the University of California Irvine campus, will succeed Bruce Alberts as of July 1, 2005, when his second six-year term as NAS president ends. An atmospheric chemist, Dr. Cicerone received his bachelor's degree from the Massachusetts Institute of Technology and his master's and doctoral degrees from the University of Illinois. He has conducted research on the plasma physics of Earth's ionosphere, the chemistry of the ozone layer, radiative forcing of climate change, and sources of atmospheric methane and of methyl halide gases. He is the recipient of the James B. Macelwane and Roger Revelle medals from the American Geophysical Union, and the Bower Award and Prize for Achievement in Science from the Franklin Institute. His work has also been recognized by the United Nations.

Dr. Cicerone has served on the faculty at the University of Michigan and as a research scientist at both the Scripps Institution of Oceanography and the National Center for Atmospheric Research. He was dean of physical sciences at the University of California at Irvine from 1994 to 1998 and was named chancellor in April 1998. He also holds the Daniel G. Aldrich Jr. Chair in Earth System Science and is a professor of chemistry.

Dr. Cicerone was elected to the NAS in 1990 and was a member of the governing Council from 1996 to 1999. He has served on more than 40 NAS and National Research Council committees since 1984; in 2001, he chaired the landmark study, *Climate Change Science: An Analysis of Some Key Questions*, conducted at the request of the White House. He is currently a member of the Committee on Women in Science and Engineering, Advisory Board for the Koshland Science Museum, and Advisory Committee for the Division on Earth and Life Studies.

Manhattan College Recognizes Alumni Elected to NAE

Manhattan College, a small private college in Riverdale, New York, has established the William J. Scala Academy Room in the School of Engineering to recognize distinguished alumni who have been elected members of NAE. At the dedication ceremony in September 2000, 11 alumni/ae were honored. On Wednesday, December 1, 2004, **James W. Cooley**, **Thomas E. Romesser**, and **Richard L. Tomasetti**, three recent NAE inductees, brought the number of NAE members to 14. Dr. **George Bugliarello**, NAE foreign secretary, represented the academy at the ceremony.

Message from the Vice President and Development Committee Chair

Sheila E. Widnall

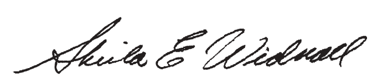
Shaping the Future: The Campaign for the National Academies ended on December 31, 2004. With the generous support of more than 1,000 NAE members and many friends of the academy, as well as foundations and corporations, NAE raised $54.8 million, exceeding our $50 million campaign goal. Together, we continue to strengthen NAE's finances and independence.

Individual donors, the majority of whom are NAE members, were the leading sources of support, followed by foundations and corporations. Unrestricted support totaled $10.1 million; $22.4 million was designated for specific projects; and $22.2 million was given to NAE's endowment.

This is an opportune time to step back and consider what we have accomplished and where we go from here. First, the campaign will enable NAE to pursue more projects independent of government sponsorship. This is a valuable capability in a rapidly changing world where disruptions such as 9/11 require an immediate response and where priorities for the engineering enterprise may not yet be recognized by the federal government. The campaign has also helped to create a culture of philanthropy in NAE, which bodes well for privately funded future projects that are significant for the well-being of society. And this campaign will enable NAE to improve programs that cover engineering education, public understanding of engineering, diversity, frontiers of engineering research, ethics, and other areas.

The campaign was just a beginning, however. There are many more opportunities in the programmatic areas listed above, as well as in areas for new projects and studies. To increase NAE's flexibility and independence and take advantage of these opportunities, the *unrestricted* endowment must continue to grow. You will hear more about NAE's priorities in the coming months, but, for now, please join me in celebrating the accomplishments of the campaign and the work NAE performs for America. The academy is grateful for the time so many of you have freely given and the financial support you have provided. We remain dedicated to providing authoritative, unbiased advice to the nation and developing the resources that enable us to do so.

Contributions by Source		Contributions by Allocation	
Individuals	$26,968,251	Unrestricted	$10,166,151
Foundations	$14,567,059	Projects	$22,402,459
Corporations	$11,233,117	Endowment	$22,219,241
Other	$ 2,019,424		
TOTAL:	$54,787,851	TOTAL:	$54,787,851



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The Einstein Society recognizes members and private donors who have made cumulative lifetime donations of $100,000 or more to NAE, National Academy of Sciences, Institute of Medicine, or National Research Council. In appreciation of their exemplary commitment, members of the Einstein Society will receive replicas of the original maquette of the Einstein Monument created by sculptor Robert Berks that stands on the front lawn of the National Academies building on Constitution Avenue in Washington, D.C. The Einstein Society honorees will be recognized at annual meetings and by the National Academies' Presidents' Circle, and their names will be listed on a plaque at the headquarters building in Washington, D.C., and in annual reports and donor-recognition issues of academies publications.

The Heritage Society of the National Academies recognizes all members and friends who have contributed to the future of the academies through life income, bequest, and other estate and planned gifts. Heritage Society members receive a medal bearing the likeness of the National Academies building in the nation's capital and special mailings. They will also be recognized in annual reports and invited to special events. If a donor wishes to remain anonymous, this wish will be honored.

For information on becoming a member of the Einstein Society or Heritage Society, please contact the Office of Development at 202-334-2431.

One knows from daily life that one exists for other people—first of all for those upon whose smiles and well-being our own happiness is wholly dependent, and then for the many, unknown to us, to whose destinies we are bound by the ties of sympathy.

A hundred times every day I remind myself that my inner and outer life are based on the labors of other men, living and dead, and that I must exert myself in order to give in the same measure as I have received and am still receiving.

—Albert Einstein
The World As I See It

Class of 2005 Elected

In February, NAE elected 74 new members and 10 foreign associates, bringing the number of U.S. members to 2,195 and the number of foreign associates to 178. Election to NAE, one of the highest professional distinctions accorded an engineer, honors those who have made outstanding contributions to "engineering research, practice, or education, including, where appropriate, significant contributions to the engineering literature" and to the "pioneering of new and developing fields of technology, making major advancements in traditional fields of engineering, or developing/implementing innovative approaches to engineering education." A list of the newly elected members and foreign associates follows, with their primary affiliations at the time of election and a brief statement of their principal engineering accomplishments.

New Members

Rodney C. Adkins, vice president of development, IBM Systems and Technology Group, Somers, New York. For contributions to the development of world-class computer products, from personal computers to supercomputers.

Kurt Akeley, senior researcher, Microsoft Research Asia. For contributions to the architecture of 3-D graphics systems and the definition of Open GL, now the industry standard.

Paul G. Allen, chairman of the board of directors, Vulcan Inc., Seattle, Washington. For contributions to the creation of the personal computer software industry and the development of innovative technologies.

Ken E. Arnold, senior executive vice president, AMEC Paragon Engineering Services, Houston, Texas. For contributions to the safety, design, and standardization of hydrocarbon production.

Ivo M. Babuska, Robert Trull Chair in Engineering, Department of Aerospace Engineering and Engineering Mechanics, University of Texas, Austin. For contributions to the theory and implementation of finite element methods of computer-based engineering analysis and design.

Marsha J. Berger, professor of computer science, Courant Institute of Mathematical Sciences, New York University, New York City. For developing adaptive mesh refinement algorithms and software that have advanced engineering applications, especially the analysis of aircraft and spacecraft.

Dimitris J. Bertsimas, Boeing Professor of Operations Research, Massachusetts Institute of Technology, Cambridge. For contributions to optimization theory and stochastic systems and innovative applications in financial engineering and transportation.

Paul M. Bevilaqua, manager, Advanced Development Programs, Lockheed Martin Aeronautics Company, Palmdale, California. For theoretical contributions and practical innovations that have improved the operational utility of vertical takeoff and landing aircraft.

Harvey W. Blanch, professor of chemical engineering, University of California, Berkeley. For scientific, engineering, and educational advances in enzyme engineering, bioseparations, and biothermodynamics.

Ilan Asriel Blech, president (retired), Flexus Corporation, Pasadena, California. For contributions to analyses, characterizations, and solutions of materials problems in semiconductor device technology.

Mark T. Bohr, senior fellow and director of process architecture, Intel Corporation, Hillsboro, Oregon. For leadership in defining, developing, and implementing a manufacturable CMO/BiCMOS technology for microprocessor and logic products.

John Edward Bowers, professor of electrical and computer engineering, University of California, Santa Barbara. For contributions to the development of high-speed semiconductor lasers and other devices for optical switching and communications systems.

A. Robert Calderbank, Professor Emeritus, Princeton University, Princeton, New Jersey. For leadership in communications research, from advances in algebraic coding theory to signal processing for wireline and wireless modems.

William J. Chancellor, Professor Emeritus, Department of Biological and Agricultural Engineering, University of California, Davis. For engineering innovations and for advancing the understanding of agricultural technology in the United States and developing countries.

Chau-Chyun Chen, technology fellow, Aspen Technology Inc., Cambridge, Massachusetts. For contributions to molecular thermodynamics and process-modeling technology for designing industrial processes with complex chemical systems.

A. James Clark, chairman of the board and chief executive officer, Clark Enterprises Inc., Bethesda, Maryland. For the development of project controls and construction equipment, the creation of a major construction firm, and support for engineering education.

Edmund M. Clarke, FORE Systems Professor of Computer Science, Carnegie Mellon University, Pittsburgh, Pennsylvania. For contributions to the formal verification of hardware and software.

James Q. Crowe, chief executive officer, Level 3 Communications Inc., Broomfield, Colorado. For contributions to the development and deployment of Internet-based communication technologies and services.

David E. Culler, professor, Computer Science Division, University of California, Berkeley. For contributions to scalable parallel processing systems, including architectures, operating systems, and programming environments.

Joseph M. DeSimone, William R. Kenan Jr. Distinguished Professor, Department of Chemistry, University of North Carolina, Chapel Hill. For the development of environmentally friendly chemistries and processes for the synthesis of materials, especially new fluoropolymers.

Dominic M. Di Toro, Edward C. Doris Professor and Evironmental Engineer, Department of Civil and Environmental Engineering, University of Delaware, Newark. For leadership in the development and application of mathematical models for establishing water-quality criteria and making management decisions.

Per Kristian Enge, professor and associate chair, School of Engineering, Stanford University, Stanford, California. For leadership in the development of augmentations to marine and aviation global positioning systems that have become worldwide standards.

Michael J. Fetkovich, senior principal reservoir engineer (retired), Phillips Petroleum Company, Bartlesville, Oklahoma. For the development of widely used techniques for determining future oil and gas production and recoverable reserves.

Alexander G. Fraser, president, Fraser Research, Princeton, New Jersey. For contributions to the development of packet-switched networks, including virtual circuit switching and window flow control.

Gerald G. Fuller, professor of chemical engineering, Stanford University, Stanford, California. For contributions to our understanding of the rheology of complex fluids and fluid interfaces and the development of unique rheo-optical techniques.

George Georgiou, Joe C. Walter Jr. Endowed Chair, Department of Chemical Engineering, University of Texas, Austin. For protein engineering, especially the development of therapeutics to biological warfare agents, protein manufacturing technologies, and combinatorial library screening methodologies.

Richard D. Gitlin, senior vice president, Communications Sciences Research (retired), Bell Labs, Lucent Technologies, Princeton, New Jersey. For contributions to communications systems and networking.

Steven A. Goldstein, Henry Ruppenthal Family Professor of Orthopaedic Surgery and Biomedical Engineering, University of Michigan, Ann Arbor. For contributions to our understanding of bone micromechanical and remodeling behaviors and their translations into gene therapies and fracture fixations.

Shafrira Goldwasser, RSA Professor of Computer Science and Engineering, Massachusetts Institute of Technology, Cambridge. For contributions to cryptography, number theory, and complexity theory and their applications to privacy and security.

Carol K. Hall, Alcoa Professor of Chemical Engineering, North Carolina State University, Raleigh. For applications of modern thermodynamic and computer-simulation methods to chemical engineering problems involving macromolecules and complex fluids.

James Robert Harris, president, J.R. Harris & Company Structural Engineers, Denver, Colorado. For contributions to the development, improvement, and implementation of modern standards for the design of buildings.

Allan S. Hoffman, professor, Department of Bioengineering and Chemical Engineering, University of Washington, Seattle. For pioneering work on the medical uses of polymeric materials.

Gerard J. Holzmann, principal computer scientist, NASA Jet Propulsion Laboratory, Pasadena, California. For the creation of model checking systems for software verification.

Roger T. Howe, professor, Department of Electrical Engineering and Computer Science, University of California, Berkeley. For contributions to the development of microelectromechanical systems in processes, devices, and systems.

John R. Howell, Ernest Cockrell Jr. Memorial Chair, Department of Mechanical Engineering, University of Texas, Austin. For the development and dissemination of methods of addressing complex radiation heat-transfer problems.

J. Stuart Hunter, Professor Emeritus, School of Engineering and Applied Science, Princeton University, Princeton, New Jersey. For the development and application of statistical methods for efficiently designed experiments and data interpretation.

Kenneth A. Jackson, Professor Emeritus of Materials Science, University of Arizona, Tucson. For advancing the science and technology of single crystal growth and materials made by casting.

Leah H. Jamieson, Ransburg Professor of Electrical and Computer Engineering and associate dean for undergraduate education, Purdue University, West Lafayette, Indiana. For innovations in integrating engineering education and community service.

Lawrence L. Kazmerski, director, National Center for Photovoltaics, National Renewable Energy Laboratory, Golden, Colorado. For leadership in U.S. and global research in photovoltaics and solar technology.

Ilan M. Kroo, professor, Department of Aeronautics and Astronautics, Stanford University, Stanford, California. For new concepts in aircraft design methodology and for the design and development of the SWIFT sailplane.

David A. Landgrebe, Professor Emeritus of Electrical and Computer Engineering, Purdue University, West Lafayette, Indiana. For contributions to the development of multispectral technology for remote Earth sensing.

James O. Leckie, Peck Class of 1906 Professor, Department of Civil and Environmental Engineering, Stanford University, Stanford, California. For advances in our understanding of metal and oxyanion adsorption on environmental surfaces that have led to novel strategies for soil and groundwater remediation.

Michael E. Lesk, professor of library and information studies, Rutgers University, New Brunswick, New Jersey. For contributions to UNIX applications, information systems, and digital libraries.

Marc D. Levenson, editor in chief, Micro-Lithography World, Campbell, California. For the introduction of phase-shifting methods to improve optical lithography and for contributions to quantum spectroscopy.

Frances S. Ligler, UNS Senior Scientist, Naval Research Laboratory, Washington, D.C. For the invention and demonstration of portable, automated biosensors for fast, on-site detection of pathogens, toxins, pollutants, drugs of abuse, and explosives.

Subhash Mahajan, chair, Department of Chemical and Materials Engineering, Arizona State University, Tempe. For advancing our understanding of structure-property relationships in semiconductors, magnetic materials, and materials for light-wave communication.

Arunava Majumdar, Almy and Agnes Maynard Professor of Mechanical Engineering, University of California, Berkeley. For contributions to nanoscale thermal engineering and molecular nanomechanics.

Robert M. McMeeking, professor of mechanical and environmental engineering, University of California, Santa Barbara. For contributions to the computational modeling of materials and for the development of codes widely used by industry.

Terence P. McNulty, president, T.P. McNulty and Associates Inc., Tucson, Arizona. For technical direction and leadership in mineral processing and hydrometallurgy.

R. Shankar Nair, principal and senior vice president, Teng & Associates, Chicago, Illinois. For contributions to the art and science of engineering through the design of innovative bridges and building structures.

Andrew J. Ouderkirk, corporate scientist, 3M Film and Light Management, St. Paul, Minnesota. For the development and commercialization of multilayer polymer films with unique optical properties.

Tresa M. Pollock, L.H. and F.E. Van Vlack Professor of Materials Science and Engineering, University of Michigan, Ann Arbor. For contributions to our understanding of the processing and performance of advanced metallic materials.

Howard Raiffa, Professor Emeritus, Harvard University, Boston, Massachusetts. For contributions to decision analysis, negotiation analysis, and engineering decision making.

Raja V. Ramani, Professor Emeritus, Mining and Geoenvironmental Engineering, Pennsylvania State University, University Park. For improvements to the health and safety of miners through a better understanding of the nature and control of airborne particulates.

Danny David Reible, Bettie Margaret Smith Chair of Environmental Health Engineering, University of Texas, Austin. For the development of widely used methods of managing contaminated sediments.

Howard B. Rosen, vice president of commercial strategy, Gilead Sciences Inc., Foster City, California. For the invention of bioerodible polymers and contributions to the development of drug-delivery systems.

Jonathan J. Rubinstein, senior

vice president, iPod Division, Apple Computer Inc., Cupertino, California. For the design of innovative personal computers and consumer electronics that have defined new industries.

Thomas L. Saaty, University Professor, Katz School of Business, University of Pittsburgh, Pittsburgh, Pennsylvania. For the development and generalization of the analytic hierarchy process and the analytic network process in multicriteria decision making.

Geert W. Schmid-Schoenbein, professor of bioengineering, University of California, San Diego. For improvements to our understanding of how white blood cells are activated and the medical and pharmacological effects of white blood cell activation.

Roger R. Schmidt, Distinguished Engineer, IBM Corp., Poughkeepsie, New York. For advances in thermal technologies for the cooling and temperature control of electronic equipment.

Neil G. Siegel, vice president of technology, Northrop Grumman Mission Systems, Carson, California. For the development and implementation of the digital battlefield, an integral part of U.S. Army operations.

Subhash C. Singhal, Battelle Fellow and director of fuel cells, Pacific Northwest National Laboratory, Richland, Washington. For the development and promotion of solid-oxide fuel cells for clean and efficient power generation.

Pol D. Spanos, L.B. Ryon Chair in Engineering, Rice University, Houston, Texas. For the development of methods of predicting the dynamic behavior and reliability of structural systems in diverse loading environments.

Jason L. Speyer, professor, Mechanical and Aerospace Engineering Department, University of California, Los Angeles. For the development and application of advanced techniques for optimal navigation and control of a wide range of aerospace vehicles.

Brian Stott, president, Stott Inc., Scottsdale, Arizona. For contributions to the analysis of the reliability and security of electric power systems and for leadership in education and research.

Carson W. Taylor, principal engineer, Bonneville Power Administration, Vancouver, Washington. For the development and application of methods to enhance reliability and dynamic performance of large interconnected electrical power systems.

Spencer R. Titley, professor of geosciences, University of Arizona, Tucson. For contributions to our understanding of the genesis of porphyry copper deposits.

Jeffrey Wadsworth, director, chief executive officer, and president, UT-Battelle, LLC, Oak Ridge National Laboratory, Oak Ridge, Tennessee. For research on high-temperature materials, superplasticity, and ancient steels and for leadership in national defense and science programs.

Frederick D. Weber, chief technology officer, AMD, Sunnyvale, California. For contributions to the design and implementation of mainstream and scalable microprocessor architectures.

George M. Whitesides, Woodford L. and Ann A. Flowers University Professor, Harvard University, Cambridge, Massachusetts. For the development and promulgation of methods of self-assembly and soft lithography.

Jennifer Widom, professor of computer science and electrical engineering, Stanford University, Stanford, California. For contributions to the design and implementation of active and semi-structured data management systems.

Bruce F. Wollenberg, professor of electrical and computer engineering, University of Minnesota, Minneapolis. For contributions to control centers for electric power grids and to power engineering education.

Ralph T. Yang, Dwight T. Benton Professor of Chemical Engineering, University of Michigan, Ann Arbor. For the development of the theory, methods, and materials for the removal of environmentally hazardous compounds from transportation fuels and other difficult separations.

Thomas Leslie Youd, Professor Emeritus, Brigham Young University, Provo, Utah. For contributions to assessments of hazards from liquefaction, leadership in earthquake engineering, and service to the government and educational communities.

New Foreign Associates

Genevieve M. Comte-Bellot, Professor Emeritus, Ecole Centrale de Lyon, Ecully, France. For contributions in fluid mechanics and acoustics.

Rik Huiskes, professor of biomedical engineering, Eindhoven University of Technology, Eindhoven, Netherlands. For advancing the understanding of how bone prostheses affect the functioning of the living human skeleton.

Michael B. Jamiolkowski, professor of geotechnical engineering, Department of Structural and Geotechnical Engineering, Technical University of Torino, Torino, Italy. For the design and engineering of major projects on difficult soils and for international leadership in education and research in geotechnology.

William M. Kahan, professor, Computer Science Division, University of California, Berkeley. For the development of techniques for reliable, floating-point computation, especially the IEEE Floating Point Standards.

Ora Kedem, professor, Weizmann Institute of Science, Rehovot, Israel. For contributions to the thermodynamics of irreversible transport processes and the development of separation processes for the treatment of water and wastewater.

Nikolay P. Laverov, vice president, Russian Academy of Sciences, Moscow. For leadership in the uses of uranium and for the direction of national and international programs for the management of radioactive waste.

John D. Rhodes, executive chairman, Filtronic PLC, Shipley, United Kingdom. For research, entrepreneurship, and commercial applications in circuit and microwave theory.

Fernando Samaniego, professor of petroleum engineering, Universidad Nacional Autonoma de Mexico, Mexico City. For studies of the effects of non-idealized properties and multiphase conditions on reservoir performance and well testing.

Raymond E. Smallman, Emeritus Professor of Metallurgy and Materials, University of Birmingham, United Kingdom. For fundamental studies of defects in solids produced by irradiation damage and plastic deformation.

Walter M. Wonham, University Professor Emeritus, electrical and computer engineering, University of Toronto, Canada. For work on the geometric theory of linear systems and for bridging the gap between control theory and computer science.

Calendar of Meetings and Events

February 7	*EngineerGirl!* Website Advisory Subcommittee
February 7–8	NRC Governing Board Irvine, California
February 9	NAE Council Meeting Irvine, California
February 10	NAE National Meeting Irvine, California
February 21	NAE Awards Dinner Ceremony and Presentation
February 24	NAE Finance and Budget Committee Conference Call
February 25	NAE Congressional Luncheon
March 15–16	Workshop on Engineering Studies at Tribal Colleges
March 16	NRC Executive Committee Meeting
March 22	NAE Regional Meeting University of Southern California
March 31	NAE Regional Meeting University of Minnesota
April 12	NRC Executive Committee Meeting
May 5–7	German-American Frontiers of Engineering Symposium Potsdam, Germany
May 9–10	NAE Convocation of Professional Engineering Societies
May 10–11	NRC Governing Board Meeting/ Executive Committee Meeting
May 12–13	NAE Council Meeting

All meetings are held in the National Academies Building, Washington, D.C., unless otherwise noted. For information about regional meetings, please contact Sonja Atkinson at *satkinso@nae.edu* or (202) 334-3677.

In Memoriam

ROBERT AVERY, 82, retired senior scientist, Argonne National Laboratory, died on August 29, 2004. Dr. Avery was elected to NAE in 1978 for his contributions to reactor design and analysis and fast-reactor safety.

RICHARD T. BAUM, 85, partner emeritus and consultant, Jaros Baum & Bolles, died on January 30, 2005. Mr. Baum was elected to NAE in 1983 for innovative cost-efficient designs of mechanical systems, including energy-efficient heating and air-conditioning systems, for large buildings.

SEYMOUR M. BOGDONOFF, 84, Professor Emeritus and Senior Research Scholar, Department of Mechanical and Aerospace Engineering, Princeton University, died on January 10, 2005. Mr. Bogdonoff was elected to NAE in 1977 for contributions to the development of gas dynamics and the mechanics of viscous fluids, especially in hypersonic flow and shock boundary-layer interactions.

JACOB H. DOUMA, 92, retired hydraulic engineer, died on October 4, 2004. Mr. Douma was elected to NAE in 1971 for contributions to federal and private practice in hydraulic engineering here and abroad.

LLOYD E. ELKINS SR., 92, petroleum consultant, died on December 17, 2004. Mr. Elkins was elected to NAE in 1976 for his pioneering work on increasing oil and gas production from low-grade reservoirs.

GERARD M. FAETH, 68, Arthur B. Modine Professor of Aerospace Engineering, and head, Gas Dynamics Laboratories, University of Michigan, died on January 24, 2005. Dr. Faeth was elected to NAE in 1991 for seminal contributions to our understanding of the structure of combustive and noncombustive sprays.

JOSEPH J. JACOBS, 88, chairman, Jacobs Engineering Group Inc., died on October 23, 2004. Dr. Jacobs was elected to NAE in 1994 for the application of chemical engineering construction principles and for service to the engineering profession.

DONALD O. PEDERSON, 79, Professor Emeritus of Electrical Engineering, Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, died on December 25, 2004. Dr. Pederson was elected to NAE in 1974 for his leadership in research on integrated circuits and for innovation in related computer-aided design.

CORNELIUS J. PINGS, 75, professor of chemical engineering, University of Southern California, died on December 6, 2004. Dr. Pings was elected to NAE in 1981 for his work on the properties of liquids and for his leadership as a teacher and administrator.

GEORGE S. SCHAIRER, 91, retired vice president, research, The Boeing Company, died on October 28, 2004. Dr. Shairer was elected to NAE in 1967 for his contributions to aircraft design and development.

ASCHER H. SHAPIRO, 88, Institute Professor Emeritus, Massachusetts Institute of Technology, died on November 26, 2004. Dr. Shapiro was elected to NAE in 1974 for contributions to fluid-mechanics research and education.

AL F. TASCH JR., 63, Cockrell Family Regents Chair Emeritus in Engineering and Professor Emeritus of Electrical and Computer Engineering, University of Texas, died on November 30, 2004. Dr. Tasch was elected to NAE in 1989 for outstanding contributions to semiconductor memory technology.

PAUL K. WEIMER, 90, retired fellow, RCA Laboratories, died on January 6, 2005. Dr. Weimer was elected to NAE in 1981 for contributions to the development of television camera tubes, thin-film active devices, and solid-state image sensors.

Publications of Interest

The following reports have been published recently by the National Academy of Engineering or the National Research Council. Unless otherwise noted, all publications are for sale (prepaid) from the National Academies Press (NAP), 500 Fifth Street, N.W., Lockbox 285, Washington, DC 20055. For more information or to place an order, contact NAP online at <*http://www.nap.edu*> or by phone at (888) 624-8373. *(Note: Prices quoted by NAP are subject to change without notice. Online orders receive a 20 percent discount. Please add $4.50 for shipping and handling for the first book and $0.95 for each additional book. Add applicable sales tax or GST if you live in CA, DC, FL, MD, MO, TX, or Canada.)*

Assessment of Department of Defense Basic Research. The U.S. Department of Defense (DOD) supports basic research to advance fundamental knowledge in fields important to national defense. Over the past six years, however, concerns have been raised about whether all of the research meets DOD's definition of basic research; whether reporting requirements have become cumbersome and onerous; and whether basic research is defined and handled differently by the three services. To address these concerns, Congress requested a study from the National Research Council (NRC) on the nature of research funded by DOD. Specifically, NRC was asked to determine if the programs in the DOD basic research portfolio are consistent with DOD's definition of basic research and with the characteristics associated with fundamental research. NAE member **C. Dan Mote Jr.**, University of Maryland, served as vice chair of the committee. Other NAE members on the study committee were **Charles B. Duke**, Wilson Center for Research & Technology; **John S. Foster Jr.**, Northrop Grumman Space Technology; **Mary L. Good**, University of Arkansas at Little Rock; **Robert J. Hermann**, Global Technology Partners LLC; **James C. McGroddy**, IBM Corporation; **James G. O'Connor**, Pratt & Whitney (retired); and **Fawwaz Ulaby**, University of Michigan. Paper, $18.00.

Endangered and Threatened Species of the Platte River. The Platte River flows across three states—Colorado, Wyoming, and Nebraska—and is home to several endangered species—the whooping crane, interior least tern, and pallid sturgeon—and a threatened species—the piping plover. This report, focused on the central Platte River in Nebraska, reexamines the current "critical habitat" designations for the piping plover and whooping crane to determine if they are supported by existing science. The committee concludes that the designations were scientifically valid at the time they were made but that future designations should be based on newer scientific approaches that take into account human activities and increased attacks by predators on nests. The committee also finds that other agency decisions, such as habitat-suitability guidelines and instream-flow recommendations, were based on valid science. NAE member **Hsieh W. Shen**, University of California, Berkeley (emeritus), was a member of the study committee. Hardcover, $54.00.

Firearms and Violence: A Critical Review. For years, gun control and the ownership of firearms have been contentious political issues. Policy makers must take into account the relationship between guns and violence, as well as conflicting constitutional claims and divided public opinion. Legislators need adequate data and research on the effects of firearms on violence and the efficacy of different violence-control policies. In the current literature on firearms research, it is sometimes difficult to distinguish scholarship from advocacy. There is a pressing need for a clear, unbiased assessment of existing data and research. *Firearms and Violence* uses conventional standards of science to examine three major themes—firearms and violence, the quality of research, and the quality of available data. The authoring committee assesses the strengths and limitations of current databases and reviews current research studies on the use of firearms and efforts to reduce unjustified firearm use. NAE member **Alfred Blumstein**, Carnegie Mellon University, was a member of the study committee. Hardcover, $47.95.

Government/Industry/Academic Relationships for Technology Development: A Workshop Report. The National Aeronautics and Space Administration (NASA) Human Exploration and Development of Space (HEDS)

Program in the Office of Space Flight has proposed a new framework for space technology and systems development—advanced systems, technology, research, and analysis (ASTRA)—for future spaceflight capabilities. To assist in the development of this framework, NASA asked the National Research Council to convene a series of workshops on the interests of various stakeholders in advancing the human and robotic exploration and development of space. The second workshop, which is summarized in this report, was focused on interrelationships between government, industry, and academia in the development of technology. The discussion of best practices for cooperative efforts was based on examples from the Defense Advanced Research Projects Agency, the U.S. Department of Defense, and the National Science Foundation. NAE member **Charles R. Trimble**, U.S. Global Positioning System Industry Council, was a member of the study committee. Print on Demand, $18.00.

Methodology for Estimating Prospective Benefits of Energy R&D Programs. Since its inception in 1977, the U.S. Department of Energy (DOE) has invested substantial sums in research and development (R&D) on energy efficiency and fossil fuels. Over the years, the agency and Congress have had these R&D programs evaluated in terms of cost and benefits. However, it is difficult to incorporate the full range of public benefits in these evaluations or to estimate how funding from nongovernmental sources would affect R&D. At the direction of Congress, DOE asked the NRC to develop a methodology for evaluating the prospective benefits of these R&D programs by focusing on program management and funding decisions. This letter report provides an overview of this approach and compares it to previous retrospective studies. NAE member(s) **Wesley L. Harris**, Massachusetts Institute of Technology; **Maxine L. Savitz**, Honeywell Inc. (retired); and **John J. Wise**, Mobil Research & Development Company, were members of the study committee. Available online at: *http://www.nap.edu/catalog/11176.html.*

Review of the U.S. Army Corps of Engineers Restructured Upper Mississippi River-Illinois Waterway Feasibility Study: Second Report. The U.S. Army Corps of Engineers (USACE) has proposed doubling the length of as many as a dozen locks on the Mississippi River-Illinois Waterway. The National Research Council first reviewed the feasibility study for this multibillion dollar project when questions were raised about the accuracy of the models of barge transportation used to justify the expansion. This second review of the restructured proposal concludes that USACE has included many creative and potentially useful ecosystem restoration measures but has not adequately considered how the ecology might affect, or be affected by, navigation, recreation, or other activities. In addition, the economic justifications for expanding the locks on the rivers are still inadequate because of flaws in the models of existing and projected barge traffic. NAE member(s) **Gerald E. Galloway Jr.**, University of Maryland, College Park, and **Soroosh Sorooshian**, University of California, Irvine, were members of the study committee. Paper, $18.00.

The Role of Experimentation in Building Future Naval Forces. The U.S. Department of Defense is in the process of transforming the nation's armed forces to meet the military challenges of the twenty-first century. During this process, experiments at the individual-service and joint-service levels—analyses, war games, modeling and simulations, small focused experiments, and large field events—could enhance naval and joint-force development. The Chief of Naval Operations asked the National Research Council (NRC) to conduct a study of the role of experimentation in configuring future naval forces to operate in a joint-force environment. NAE members **Ruzena K. Bajcsy**, University of California, Berkeley; **L. David Montague**, L. David Montague Associates; and **William B. Morgan**, Naval Surface Warfare Center (retired), were members of the study committee. Paper, $50.75.

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