AMERICA'S EMERGING TECHNOLOGY POLICY

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“America's Emerging Technology Policy”[1]

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During the four decades after World War II the United States attained the highest level of scientific and technological achievement in history. With the world's largest economy and strongest military, it defended the superiority of free market democracies with outstanding success. New industries with revenues of hundreds of billions of dollars were created from scratch after the war, born from the creativity of American science and engineering. With stimulation from defense investments the aviation, computer, and microelectronics industries grew to world dominance.

America's universities became the envy of every nation, and still attract one third of all the students in the world who study abroad. In only five years Americans created the organization, the facilities, and the technology for manned exploration of the surface of the moon. Our astronauts' footprints will be there for millennia to come, along with moon-buggy tire tracks to prove this was an achievement of Americans who would rather ride than walk.

The policies under which these achievements were made were clearly articulated in Vannevar Bush's report to President Truman, entitled *Science the Endless Frontier*.[2] The period from the early 1950s to about 1968 (when U.S. science growth came to a halt for ten years) is often called the "golden age of American science." These were Dael Wolfle's years in Washington. A colleague of Vannevar Bush in the Office of Scientific Research and Development during the war, Dael presided over the American Association for the Advancement of Science and published *Science* magazine for this entire period. It was the best of times for scientists in American life.

The essence of the post-war science and technology policy had two parts: (a) government support for research in basic science and (b) aggressive federal agency development of advanced technology in pursuit of their statutory missions.[3] Henry Ergas characterizes this policy, like that of Britain and France, as "mission-oriented" technology policy.[4] He contrasts this approach with "diffusion-oriented" policies of Germany, Switzerland, and Sweden - an alternative approach to national technological development to which I will return.

Each of these elements of U.S. post-War policy entails a tacit assumption about the mechanism through which government R&D investments will contribute to industrial innovation, and hence to competitiveness in world trade. These two assumptions are derived from a "supply-side" picture of how the innovation process works in high-tech industry.

Government support of basic research is justified, economists tell us, because the social returns from basic research exceed its cost, but the private returns to a firm investing in basic science are less than its costs because of low appropriability of the benefits. Ed Mansfield's analysis of all the evidence suggests that the social return from basic science in the U.S. in the late 1980s was about 28 percent.[5]

But the bi-partisan support for science also rests heavily on a "pipeline" model for how that social return arises in the form of industrial innovations.[6] This conventional, but now discredited, model assumes that innovations arise in the research laboratory or the inventor's shop, and are produced after a sequence of steps through applied research, development, design, and production. It is further assumed that this process is more or less automatic and inevitable, in which case a basic-research oriented science policy is, in effect, a successful element of technology policy, assuring a healthy economy.

The pipeline model is not a bad description of how new industries arise from new science -- a process that takes a decade or more, but served the U.S. well during post-war reconstruction when it had no serious overseas competition in the field of advanced technology. It is, however, inapplicable to the way existing industries compete through rapid incremental progress.[7] As we shall see, the pipeline is an even less appropriate description of how successful high-tech firms compete in the 1990s.

A second arm of the post-war policy expresses faith that the technology created in pursuit of government missions will automatically flow to industry and sustain a strong economy. The process through which this is presumed to happen is called "spinoff."[8] A key reason for its appeal is that spin-off, like the pipeline from basic science to innovation, is assumed to be automatic and cost-free. Thus both of these "supply-side" assumptions have the attractive feature that if they are automatic and cost-free the government does not have to "pick winners and losers" in order for the economy to gain the benefits. Government may then claim its policies achieve the goals of industrial policy without interference with the autonomy of private firms.

While spin-off has, in fact, never been either automatic or cost-free, there are examples of commercial products “spun-off” from military developments. A classic case is the Raytheon Corporation's microwave oven, whose trade name, Radarange (tm) gives its military origin. Most cases of successful spin-off occurred soon after World War II, when U.S. military R&D totally dominated U.S. commercial R&D. Even as late as 1960, U.S.military R&D was a third of all the R&D, public and private, in all the OECD nations put together. Today it is only one seventh, and is projected to be more like on tenth by the year 2000.

As a further guarantee against "top-down" political control of the national science and engineering enterprise, the post-war policy called for a highly decentralized responsibility for investing in R&D by federal agencies. Under principles advanced by Vannevar Bush but implemented in the Steelman Report [9] a few years later, all federal agencies were to develop the technology needed for their missions and were also to support a proportionate share of the nation's basic research as a kind of "mission overhead" re-investment in the knowledge base on which their technology depends. Furthermore the autonomy of academic science was to be preserved by competitive selection among unsolicited proposals informed by peer review.

Throughout this period, a social contract between science and the government balanced the government's commitment to respect scientific autonomy with the research community's commitment to a best-efforts performance, fair administration of the competition for funds, and honest stewardship of those funds. This social contract enjoyed bi-partisan support and was essentially unchallenged for four decades. [10]

In short, the post-war policy, and its pipeline and spin-off paradigms, sought to sidestep the business community's abhorrence of industrial policy and the science community's abhorrence of centrally planned science, while still retaining the benefits of technological stimulation of the economy. The political attractiveness of this policy helps explain its persistence, despite the unreality of the underlying assumptions in today's world.

Today both that social contract and those assumptions are seriously challenged. Although the Congress and the Administration have, in the main, shielded government science budgets from the pressures of budget reduction, warning signs that the social contract is fraying at the edges, and may even have some serious rips are at every hand. Three of these difficulties specifically concern the political standing of members of the scientific community and their institutions:

1) The scientific community no longer enjoys the unqualified respect of political leaders that it knew when Dael Wolfle led the AAAS. Last

January, the President-elect of the AAAS, Nobel Laureate Leon Lederman, warned Washington that a crisis of inadequate federal support for basic scientific research seriously threatened American science.[11] His cry of alarm sounded to many politicians more like a cry of “wolf!” Many of them treated Lederman's report as both self-serving and politically naive, given unmet domestic social needs and concerns about lagging national competitiveness.

2) The universities' credibility in Washington is slipping as well. Allegations of scientific misconduct in federally funded research, criticisms of research overhead accounting, and discomfort with solicitations of funds from foreign corporations in return for preferred access to government-funded research feed an increasingly cynical attitude toward U.S. universities.

3) The social contract's protection of meritocracy in allocation of federal research resources is also breaking down. With too many investigators competing for too little money, the Congress is becoming increasingly impatient with the concentration of competitive awards in the most elite research universities. Ignoring long-standing commitments to base grant awards on merit review, Congressional committees each year divert an every larger percentage of R&D funding which favor "pork-barrel" awards to favored constituents through legislative riders.

These concerns are shared by the President's Assistant for Science and Technology, Dr. D. Allan Bromley, who stated in May, 1991:

> It used to be that if you probed someone in the universities about their views of Congress, they would often accuse Congress of being a bunch of crooks. Now if you probe someone in Congress about the universities, Congressmen will frequently claim that the universities are full of crooks."[12]

Another source of pressure on the social contract arises from growing recognition that "supply-side" reliance on the pipeline, on spin-off, and on decentralized allocation of resources no longer meets U.S. economic or defense needs has spurred the call for a rethinking of U.S. science and technology policy in the Congress. Frustrated by the apparent failure of America's world leadership in science to assure the competitiveness of U.S. high-tech industry, the Congress is turning its attention from academic science to lists of critical technologies and presses the Administration into funding "pre-competitive, generic" technologies of direct interest to commercial industry.[13] In Washington today you hear much more talk of technology, much less of research. The "pipeline" and “spin off” mechanisms are fast losing their credibility, as policy makers search for a politically acceptable, economically effective, more "demand-oriented" approach to strengthening the U.S. technology base.

It should come as no surprise that the innovation paradigms on which policy has been based should be re-examined. Put simply, Americans find themselves in a different world from the one they inherited after World War II. There is no reason to believe that policies that worked so well in the 1950s and 1960s will work well today. A multi-polar world is being fashioned in which economic and environmental health are replacing military strength as priority elements of national and global security.

Europe stands on the eve of 1992, when economic integration will take a great stride forward. Its integrated market will be both an opportunity and a competitive challenge for American firms. The Cold War is over. The USSR and the nations of Eastern Europe are rushing to restructure their economies along free market lines. Virtually every aspect of the way industrial innovations occur, technology diffuses, and producers collaborate and compete must be learned and institutions created to support them. The U.S. economy will be challenged to help them succeed, and to make the investments that in the future may allow Americans to benefit from Russian success.

Third world economies are also under great stress, and the industrial democracies can no longer ignore their plight. There is growing appreciation that the world cannot achieve a sustainable global environment, or healthy global trade, unless the needs of the developing nations are also accommodated. This will call for new policies through which developing countries can acquire more environmentally forgiving technology and substantial additional investment.

At the same time there is a massive shift of economic vitality to Asia, where Japan has emerged as a major factor in the world economy. It is astonishing to realize that 40 percent of world GNP is now produced in two nations: the U.S.A. and Japan, with the ratio shifting toward Japan.

Economists argue about whether the U.S. economy is suffering from long-term structural weakness or whether it is only experiencing the pains of structural dislocation in a vibrant world economy. But dramatic losses in U.S. shares of world markets in machine tools, semi-conductors, telecommunications, and office equipment force us to ask, why has our comparative advantage plummeted in such science-intensive industrial sectors in spite of our technical prowess?

The short answer is that American firms, and the U.S. government, have been much too slow to recognize how dramatic changes in the power of modern science and engineering can transform the production function and take advantage of new forms of industrial organization and management for harnessing this power to human needs.

In 1986, President Gorbachev introduced the phrase "New Thinking" into political discourse. New thinking is required now in many areas of modern industrial life, for the paradigms we use to think about industrial innovation are rapidly changing. Japan has been a particularly fertile source of these new paradigms, many of which are described in a new, prize-winning book by Prof. Fumio Kodama, entitled *Analyzing Japanese High Technologies: the Techno paradigm Shift.*[14] These changes that have overtaken traditional concepts of product development and mass production owe much to innovations in Europe, North America, and elsewhere, and they are being adopted worldwide.

The new elements of the industrial innovation paradigm are production-centered, not R&D driven. They must be described by an interactive innovation model, not by the pipeline from science to the market. They have changed the level of performance required to be competitive in world markets. Here are seven examples:

1) Computer integrated manufacturing using intelligent tools is breaking the connection between economies of scale in production and the lot size of similar parts.

2) Quality is increasingly controlled through accurate characterization and precise control of industrial processes rather than by post-production testing.

3) Production processes and systems (rather than product R&D) are emerging as the primary elements of the technical strategy for low cost and high quality products.

4) Factory-centered R&D: incremental product improvements are being led by manufacturing and process engineers rather than by design and R&D personnel, a radical departure from the traditional process of sequential development and production.

5) Various forms of industrial alliances and relationships are being used as an alternative to vertical integration for gaining the benefits of technological specialization.

6) Technological diversification is being used as a strategy to guard against competition from unexpected quarters, outside the conventional technology domain for a business.

7) Trickle-up technology: the Japanese are first introducing new technology in a consumer product rather than at the high end of the product line, in order to gain early manufacturing experience at low functional levels and at low cost, gaining a great cost advantage when the technology is introduced in more costly products.

Such new approaches to industrial activity have many consequences:

While most of these new paradigms emerged in so-called "high-tech" industries, we now understand that the correct definition of "high-tech" is not product complexity or novelty of function, but is the choice of a production function that makes the most intelligent use of materials, energy, and human resources. Any business can and should be high tech.

In high tech firms, the production function is rapidly shifting from primary dependence on capital and labor resources to dependence on R&D as the critical resource. In many Japanese high-tech firms today, R&D is exceeding annual investments of capital.

As international diffusion rates accelerate, transnational firms can more easily initiate production simultaneously in many geographic locations. Technology diffusion rates within a national economy must then be even faster if domestic establishments are to have a competitive advantage; accelerating technological diffusion thus becomes a major element of national competitiveness strategy. Technology also diffuses much more rapidly as technical knowledge becomes codified, dramatically increasing the speed of technology transfer compared with the transfer of "imbedded" knowledge.

Most important from the perspective of economic competitiveness is that the new innovation paradigms permit a drastic reduction in time between the appearance of a market need and its satisfaction in volume production, thus enhancing consumer satisfaction and dramatically reducing the cost of product and market innovations.

Furthermore, with accelerating mobility of capital, technology, and people, and the steady erosion of protectionist barriers to trade, national boundaries are rapidly losing their significance as natural domains within which innovations are generated. One consequence is the weakened ability of any government to control technological outcomes unilaterally within the nation's borders.

Attention downstream

An important implication of these new patterns of production-centered high-tech innovation processes is that science enters the innovation stream at many points -- "upstream" in the research laboratory and "downstream" in the factory. Much of the Japanese advantage lies simply in their attitude toward production work. In the U.S. the best engineering students expect to work in R&D; in Japan many of the best engineers are happy to work on industrial processes in the factory.

Although many people in the U.S. may be under the impression that technology is simply the natural consequence of "upstream" research activities, there is much more to creating technology than R&D. In fact, only 30 to 35 percent of the scientists and engineers in industry are engaged in R&D. The rest are engaged in "downstream" activities: refining process technologies, creating production systems, and supporting existing technology through field service.

With rare exceptions[15] these "downstream" activities in technology are not traditionally the province of PhD's or professors. Production processes and other downstream technologies are traditionally mastered by hundreds of thousands of engineers and by millions of skilled workers. The most competitive industrial practices are marked by the marriage of excellent science to an equally sophisticated approach to design and production processes.

Design and production technologies are critical competitive factors in small to mid-sized firms. But such firms cannot afford to do research as it is known in universities, national laboratories, and the biggest companies. They develop their technology through evolutionary engineering on the factory floor, and through relationships with their customers and suppliers. How well these firms find, adapt, and use technology determines how long they will be in business, at least under American ownership.

Very little federally sponsored R&D touches these firms directly. They are at the ends of the paths through which research-generated technology diffuses to the private sector. The torrent of technology unleashed by federal military and space activities is a tiny trickle by the time it reaches the majority of American firms. Government policy should give more emphasis to helping them use technology to better effect, and less emphasis to the trickle-down policies of federal "mission-driven" R&D.

There are still large differences of opinion in the U.S. about the government's role in technology policy. However, there are few who still advocate centrally planned industrial policy, and both conservatives and neo-classical economists are beginning to accept the fact that basic science and trickle-down technology from federal missions are inadequate tools for assuring American success in growing world competition. As support for the extreme positions fades, a very broad consensus is forming on what government should and should not do in science and technology.[16]

Technology policy recognizes that under certain circumstances technological knowledge as well as basic research can be a "public good," to use the economist's language. When such knowledge has wide ranging applicability, low appropriability to the investor, and high generic value, it is likely to be rapidly shared in the economy and if government - subsidized is unlikely to distort the market. Such knowledge is thus characterized as "generic and pre-competitive."[17] Both President Bush and Dr. Bromley have repeatedly acknowledged the appropriateness of federal investments in pre-competitive, generic R&D.

Spokesmen for private industry are on the same track. Perhaps it is no surprise that the Council on Competitiveness, a private, non-profit body composed primarily of top executives from high-tech industry, have made the case for technology policy very strongly.[18] Even more impressive is the support of the traditionally conservative National Association of Manufacturers for technology policy, known in the past for protecting with great vigor the private sector's freedom from government control. Its president, Jerry J. Jasinowski, described the association's policy in a letter to Senator Bingaman supporting the senator's Advanced Manufacturing Technology and National Critical Technologies Acts of 1991 as follows:

> Federally funded R&D more relevant and useful to meeting the competitive needs of the nation should be considered on its merits, not on the basis of ideology .... Generic manufacturing R&D efforts, focused on base-building technologies and processes rather than specific products should be promoted. ...The federal government should also assist - not control - state and local governments in their efforts to promote local technology development. ...Government and industry should expand their support for manufacturing-related research activities as well. In short, the best and latest R&D must be applied to manufacturing to make and keep U.S. industry the most productive, cost-effective, and market responsive in the world.[19]

These ideas form the basis for what may be called a "capability-enhancing" technology policy for America. The new emphasis is on technological infrastructure, education, skills enhancement, and technology diffusion and absorption. Such a policy is designed for a global economy, for its focus is not so much on foreign vs. U.S. ownership of firms but rather on how to make the U.S. the best place in the world for good working conditions and competitive, environmentally sensitive industry. [20] In short, it is a policy that does not accept declining U.S. comparative advantage as inevitable, but seeks actively to enhance it.

Defense technology policy

Because any discussion of U.S. technology policy must start with the reality that defense-related R&D comprises two thirds of all federal R&D, one must first examine the implications of the dramatic shift in defense priorities, and the reduction in total resources. Although still very important, defense technology will continue its decline as a primary source of stimulation of the nation's technology base, a decline which has been underway for many years, primarily because commercial R&D has grown 2.5 times faster than defense R&D since 1960.

Technological infrastructure is rising in importance as a source of industrial vitality. While defense and commercial products may continue to diverge from one another, the supporting technologies will more and more become "dual use."[21] Increasingly dependent on technology developed commercially, the Defense Department will need to change its acquisition policies in order to gain access to the commercial technology base. It will also have to put more emphasis on "downstream" technologies required to achieve low cost, high reliability production in the interest of keeping its own costs down.

Three policy conclusions follow:

1) Defense agencies should not be given responsibility for helping commercial industry become more competitive; defense will have to focus its reduced resources on staying modern, flexible, and economical.

2) Defense agencies will have to pay more attention to dual use technologies, both because defense technology now lags commercial technologies in many militarily critical areas and because it is through partnerships in dual use technology that defense has the best chance to gain access to leading commercial technologies.

3) More emphasis must be given, by both defense and civil agencies to process technology and manufacturing systems to bring these areas of technology in balance with "upstream" emphasis on product-oriented R&D. This emphasis is expressed in pending legislation introduced by Senator Bingaman.[22]

DARPA's demonstrated capability to develop pathbreaking dual use technologies will be even more needed in the future. But the correct rationale must support that mission, a rationale that puts defense needs first in DARPA's budget, but sees those needs in terms of a national technology base, not a defense industry "ghetto." An important indirect effect of that policy will be that even as DARPA becomes a smaller fraction of the nation's technical effort, and focuses on long-term defense needs, its positive contribution to the national technology base can grow.

Civilian technology policy

Thus with defense influence in the nation's economy decreasing, [23] the government must learn how its civilian agencies can play more constructive roles. The so-called mission-oriented agencies, such as NASA and the Department of Energy (DoE), contribute in specified areas of technology. But in the past they have tended to follow the pattern of defense agencies, focusing their investments in massive federal projects for which they have operational responsibility. Except in their supporting research role, which has always been *very* important to the economy, they have not attempted to go much beyond superficial technology transfer programs in helping industry improve its process technologies, increase productivity, and accelerate commercialization.

The National Institute for Standards and Technology (NIST),[24] on the other hand, has a unique track record of 90 years of service to commercial industry, emphasizing non-proprietary ("pre-competitive') generic technologies of particular importance to manufacturing productivity and economic efficiency. NIST develops test methods and helps firms use them in consensus industrial standards, which are a foundation for quality assurance. NIST researchers are experts on characterization of processes and materials, which are essential to automated production. NIST support for the national system of measurement and its international compatibility speeds up technical progress and reduce costly errors and poor quality.

These activities have enjoyed participation by guest workers from private industry for many decades. However, because NIST (NBS) budgets have always been severely constrained, NIST did not in the past support this kind of work in industry. Almost all of NIST's work was conducted in-house until recently. The 1989 Omnibus Trade and Competitiveness Act authorized NIST to cost-share industrially-useful generic research and accelerate its diffusion.[25] The Advanced Technology Program established by this statute is still in its early learning phase. NIST is still defining what "generic, pre - competitive technology" means.[26]

Criteria for federal investments in industrially-relevant technology.

In fact, "generic, pre-competitive technology" is insufficiently specific for defining the kinds of federal investments in technology that are appropriate to support the national industrial base. Current federal policy results under-investment in four categories of technology.[27]

The first is <u>pathbreaking</u> technology, usually arising from new science, in which the technical risks are very high, and the prospect of commercial returns are remote in time but potentially large in magnitude. Industrial lasers, computers, genetic engineering have all led to new industries after a decade or two of government-funded research and development.

This kind of federal investment was the hallmark of defense research in the 1960s, when the commercial impact was high because high-tech industry was still immature and the U.S. faced little foreign competition in high technology. DARPA has been particularly effective in making pathbreaking technology investments, many of which have had dual usage, stimulating both new military capabilities and new commercial industries as well.

A recent report of the Carnegie Commission on Science, Technology, and Government[28] recognizes this fact and notes that DARPA's experience in this area could be made available to civil agencies, which would be expected to underwrite the costs so they would not detract from military capability. This is the rationale for the Commission's proposal that DARPA evolve to NARPA, the National Advanced Projects Agency, as an early step that would take advantage of management efficiency and dual use synergy.

The second category of appropriate federal investment in commercially relevant technology is infrastructural or generic technologies -- where technical risk and business risks are usually moderate and underinvestment arises more from low appropriability than from high risk. NIST's in-house research program, described above, constitutes a good example of such research. The ATP program in Commerce purports to support generic technology, but many of the initial projects look more like pathbreaking, DARPA-style projects than generic technology. Nevertheless, among government agencies, NIST's technical capability and knowledge of commercial industry provides the best model for managing a program of investment in infrastructural technologies.

Much of the materials research in the Department of Energy or the aeronautics work in NASA (and especially in NASA's predecessor agency, the National Advisory Committee for Aeronautics) is infrastructural, as is much dual use technology created by defense expenditures. The primary defense-commercial synergy in subsonic aircraft, for example, arises from common tools and materials, such as design automation technology, from flight simulation and high-strength, low-weight composites. Much, perhaps most, of such infrastructural technology was financed from defense procurement and commercial sales, rather than from defense R&D.

The third category of underinvestment is the most politically sensitive: strategic technology investments. In this case a determination is made that technological support to a specific, vital sector of industry is in the national interest. The best current example is SEMATECH, a consortium of microelectronics firms which, with DARPA-industry cost-sharing, is attempting to insure that the U. S. microelectronics manufacturing tool industry is able to remain competitive with Japanese firms as technical requirements become increasingly severe. In such cases technical risk should be contained; business risk is clearly high.

Strategic technology programs come closest to industrial policy of the three categories, for two reasons: a specific sector of industry is identified as intended beneficiary and other provisions of law, trade, or economic policy may be necessary to ensure that the entire effort succeeds. As a result such projects will be the exception, not the rule.

The fourth area of under-investment is perhaps most serious of all: investment in the diffusion and application of both new and existing knowledge. One of the most powerful arguments for conducting a larger fraction of federal research in universities rather than in national laboratories rests on the effectiveness of graduate student and post-doctoral research as mechanisms for diffusion of new scientific knowledge to the industries in which those young researchers find permanent employment. Enhancing capabilities to absorb and use technology also rests on education -- both in school [29] and during working life. So too is industrial extension, particularly to help smaller and middle-sized firms use technology to improve manufacturing quality and costs. Expanded science and technology information services, including the evaluation and dissemination of technical knowledge to enhance access and usability, should also be encouraged.

Both the Administration and the Congress are pursuing investments in knowledge infrastructure[30] such as the National Research and Education Network (NREN) computer network, which, like the INTERNET on which NREN is based, will enhance the accessibility of technical information services, thereby aggregating a national market, and encourage cross-sectoral collaboration as well.

Where does the Administration stand on the move toward a more diffusion-oriented technology policy?

On Sept. 26, 1990 the White House sent to Congress a document describing the *U.S. Technology Policy*,[31] which represents an important shift in emphasis, from a focus on federal missions and basic science to insuring that U.S. workers and managers have effective access to the best and most appropriate technology, and can use it quickly and economically.

Washington wags said that the most important thing about this little-publicized report was its title page. But a team headed by James Ling staffed from Dr. Bromley's Office of Science and Technology Policy (OSTP) and Richard Darman's Office of Management and Budget (OMB) spent 14 months crafting the policy and gaining its acceptance. Building a consensus in the White House for any document with the words “technology policy” in the title was no small achievement, in view of continued skepticism on the part of other senior White House staffs, especially the Council of Economic Advisers.

Much of Dr. Bromley's technology policy report is not novel. It sketches the current menu of federal technology activities and their budgetary allotments for fiscal year 1991. In this description of current reality one sees a continuation of policies the U.S. has followed since World War II. The federal government continues to fund high levels of basic scientific research along with ambitious national engineering projects intended to maintain the nation's superpower status in matters technological. Examples include the space station, the Strategic Defense Initiative, the superconducting supercollider, and the Human Genome Project. This "mission - oriented" strategy still takes a supply-side approach to the development of new technology; it assumes that the innovations generated by new projects will eventually trickle down to other sectors.

The conceptual part of the White House technology policy, however, breaks important new ground. It prepared the way for a shift to a demand-side strategy that would help U.S. enterprises find, adapt, and put to use the best technology available. The report reaffirmed the administration's intention to "participate with the private sector in pre - competitive research on generic, enabling technologies that have the potential to contribute to ... commercial applications." The policy also committed the administration to investments in an "efficient technological infrastructure, especially in the transfer of information." For instance, it contained a request for funding to upgrade and rationalize the INTERNET, a collection of over 2000 computer networks, into an NREN serving schools, universities, government, and industry.

A strong emphasis on technology absorption also represents a departure from past dependence on "trickle down" of technology from federal missions to commercial firms. The new policy suggests the establishment of cooperative research projects to enable small and mid-sized companies to build on state and regional technology initiatives. It calls for improved public education in math and science as well as worker retraining, so that the workforce can keep pace with technological change.

Dr. Bromley's report provides no details on how these new objectives should be carried out, how the agencies involved will acquire the competence to manage them, or where funds are to be found to invest in the new diffusion-oriented activities. Moreover, the budgets involved represent only a small share of federal science and technology funding, most of which is still devoted to large, mission-driven projects. Finally, because the report was prepared as the rationale for the science and technology content of the FY 1991 budget, especially those items that contribute to the economy, the report did not address important issues of international policy such as defense dependency on foreign technology suppliers, U.S. - Japan science and technology relations, or defense constraints on information diffusion.

Despite these shortcomings, OSTP has accomplished a significant first step in gaining clearance through a skeptical White House for a policy that gives the Congress and the nation a more direct approach to enhancing and applying American science and technology capabilities. The technology policy put forth by OSTP would move the U.S. policy in the direction of strategies followed by Germany, Switzerland and Sweden, which emphasize bringing the benefits of new technology more quickly and broadly to manufacturing firms and their workers.

Although scholars describe these kinds of policies as "diffusion-oriented," the term "capability-enhancing" is perhaps more descriptive. They are not so much distributive in their objectives as they are aimed at enhanced power to absorb and employ technologies productively. Capability-enhancing policies are designed to prepare workers for an increasingly sophisticated work environment and develop their problem-solving abilities, to accelerate the commercialization of innovative ideas, to increase productivity and lower costs. The net effect of a capability-enhancing policy is to diffuse economic benefits and increase competition not by "picking winners" but by increasing innovative capacity.

So what might the next steps be in implementing a capability-enhancing strategy for the U.S.?

The starting point is a <u>changed attitude toward the technical achievements of others.</u> A good diffusion strategy, by contrast, gives as much emphasis to importing knowledge and adapting it for use as it does to accessing home-grown knowledge.

The next step is to <u>restructure the defense technology strategy,</u> reducing weapons production, but sustaining or even increasing investments in the technology base to preserve a long-term option to rebuild strategic defenses if circumstances require. Today we support two weakly connected economies: Defense draws its technology from government funding, while commercial companies remain largely dependent on their own investments. As the defense budget declines, the government will become more dependent on access to an increasingly sophisticated commercial high-tech industry. <u>This suggests that commercial and defense programs will need to share a common technological base.</u>

Given the relatively small fraction of the manufacturing economy defense purchases represent, and the atmosphere of public distrust that permeates defense-industrial relations, major changes in policy, institutional structure, and even culture will be required in defense agencies to gain the collaboration of the commercial firms that increasingly control the most advanced technologies. The traditional "top down," requirements-driven style of technology acquisition will have to evolve to more of a partnership relationship, in which it is understood that both military and commercial products will be derived from the jointly developed, dual-use technology.

The increased focus on critical, dual-use technologies means that R&D projects will have to be broadly applicable, producing generic or enabling technologies that have the potential for broad use in many sectors of industry. A new class of "public good" technologies -- new tools, test methods, processes, and materials -- will thus emerge. Such infrastructural research may not be as glamorous as path-breaking discoveries leading to new industries, but it contributes directly to the capability of today's laboratories and plants to achieve the lowest-cost, highest-quality, and quickest response to market signals.

In addition, federally-funded R&D should begin to <u>focus on the "downstream" phases of the innovation cycle,</u> as noted earlier. Most government agencies, primarily interested in research to create new capabilities, contribute little to process or manufacturing technology. But quality of products can only be assured if production processes are themselves innovative and continuously improved.

NIST is experimenting with other ways to enhance "downstream" performance, notably through provision of industrial extension services to help smaller companies identify and take advantage of technological opportunities to improve their manufacturing performance. These services are offered through a growing array of state-initiated programs that promote innovation and productivity growth.[32] Taken together, the states are spending over a billion dollars on such programs. But many of them enjoy a few years of exceptional success, only to die when a political change in state government accompanies a recession year, as happened recently in Massachusetts. The federal government should help stabilize what is otherwise a very innovative set of state initiatives by matching the funds spent on these programs.

To provide better access to science and technology information (STI), the federal government should pay more attention to how the economy can capture greater benefits from its $70 billion annual R&D investment by paying more attention to quality, adaptation, and dissemination of R&D results. The government's investment in the NREN--a central part of the strategy to develop the nation's information infrastructure--will make expanded information services accessible to thousands of laboratories in universities, industry, and government. By aggregating a national market for such services, additional investment by private information vendors will be attracted.

Information and extension services are two ways to enhance R&D productivity. The speed and skill with which Americans use the output of their own science, relative to the rate of exploitation of that science by competitors overseas, will determine whether the American science is seen as a competitive asset for American establishments or a "free ride" for the rest of the world. Thus, more attention given to a capability-enhancing science and technology policy would create more enduring political support for investments in original research as well.

In summary, new paradigms for high-tech innovation call for new policies for how a government encourages the creation, diffusion, and application of technical knowledge. That there are specific circumstances in which technology, as well as science, may be a public good, and government investments in their development may be justified as an appropriate contribution to the capability of U.S. industrial establishments to innovate competitively. Although the U.S. federal administration is still uncertain how those circumstances should be defined, cautious steps down this new path are already underway. Consensus behind a capability-enhancing technology policy may not be far behind.

ENDNOTES

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1. This paper is based on the 1991 Dael Wolfle Lecture, Graduate School of Public Affairs, University of Washington, October 14, 1991. The work was supported by a grant from the Alfred P. Sloan Foundation. This paper draws on several other manuscripts: Lewis M. Branscomb, "Toward a U.S. Technology Policy," Issues *in Science and Technology,* Vol. 7, No. 4, Summer 1991, pp 50 -55; testimony by LM. Branscomb to the Joint Economic Committee

of the U.S. Congress, Sept. 12, 1991; an address to the World Standardization Summit in Madrid Spain, October 7, 1991; and John Alic, Lewis Branscomb, Harvey Brooks, Ashton Carter, and Gerald Epstein, of *Beyond Spinoff: Military and Commercial Technologies in a Changing World,* to be published by Harvard Business School Press in early 1992.

2. Bush, Vannevar, *Science, the Endless Frontier,* Washington DC: National Science Foundation, pp 5-40, July 1945, reprinted 1960, and in 1983.

3. Bruce L R Smith, *American* Science *Policy Since World War 11,* Washington DC: Brookings Institution, 1990, pp 48-52 and 164166.

4. Henry Ergas, "Does Technology Policy Matter?" in Guile, Bruce R and Harvey Brooks, *Technology and Global Industry: Companies and Nations in the World Economy,* National Academy Press, 1987. page 192.

5. Edwin Mansfield, "Academic research and industrial innovation," *Research Policy,* vol. 20, (1991), pages 1-12

6. Stephen Kline, "Models of Innovation and their Policy Consequences," in H. Inose, M. Kawasaki, and F. Kodama, eds., *Science and Technology Policy Research: "What should be done? What can be done?"* Tokyo: Mita Press, 1991, pp. 125-140. For background, see Kline, S., and Rosenberg, N., "An Overview of Innovation," in Ralph Landau and Nathan Rosenberg, eds., *Positive Sum Strategy: Harnessing Technology for Economic Growth,* Washington DC: National Academy Press, 1986. pp. 275-306.

7. Gomory, Ralph, "From the Ladder of Science' to the Product Development Cycle," *Harvard Business Review,* Nov.-Dec 1989, pp. 99-105.

8. J. Alic, L M. Branscomb, H. Brooks, A Carter, and G. Epstein, *Beyond Spinoff. Military and Commercial Technologies in a Changing World,* Boston: Harvard Business School Press, in press for early 1992

9. President's Scientific Research Board, *Science and Public Policy: Administration for Research,* 3 vols., U.S. Government Printing Office, 1947, vol. 1, page 26, usually referred to as the "Steelman Report." These recommendations were implemented by President Eisenhower in Executive Order 10521, March 17, 1954.

10. There were of course a number of counter examples: the Mansfield Amendment, which required academic scientists to accept accountability for the value of their work to defense missions; and the RANN program at NSF, which applied the test of social value to science. Neither survived more than a few years.

11. Leon M. Lederman, *Science: The End of the Frontier?,* A report from the President-elect to the Board of Directors of the American Association for the Advancement of Science, Jan. 1991.

12 D. Allan Bromley, "Science and Technology Policy: An Agenda for the Future," George Washington University Science and Technology Policy Seminar, May 7 1991 (unpublished).

13. *Gaining New Ground: Technology Priorities for America's Future,* Washington DC: Council on Competitiveness, March 1991. *Report of the National Critical Technologies Panel,* Washington DC: U. S. Government Printing Office, March 1991. President's Council on Competitiveness, *Achieving Competitiveness in National Critical Technologies: Policies in Support of Technology Development in America,* (undated: about April 1991) office of the Vice President, 8 pages.

14. Fumio Kodama, *Analyzing Japanese High Technologies: the Techno-paradigm Shift,* London: Pinter Press, 1991 (in English). In Japanese: *The Paradigms of High Technology,* Tokyo: Chuou-Kouon, 1991, which won the 1991 Yoshino Sakuzo Prize.

15. A most interesting exception is chemical engineering, the only academic field of engineering or science in which students understand that they are being trained to develop processes and design production facilities. Significantly, the U.S. chemical industry is highly competitive with those of both Japan and Germany.

16. Lewis M. Branscomb “Toward a U.S. Technology Policy," *Issues in Science and Technology,* Volume VII, No. 4, Summer 1991.

17. One might better say "non-competitive," or better still "non-proprietary' since its value may apply to downstream

engineering activities such as quality control or field service as well as upstream before proprietary products are developed. The key feature of non-competitive or non-proprietary technologies is that firms are generally willing to share or publish them.

18. *Gaining New Ground: Technology Priorities for America's Future,* Washington DC: Council on Competitiveness, March 1991.

19. Jerry J. Jasinowski, President, National Association of Manufacturers, letter to Senator Bingaman dated June 18, 1991, released June 19, 1991 by Senator Bingaman.

20. Robert Reich, "Does Corporate Nationality Matter?", *Issues in Science and Technology,* Vol. 7, No. 2, Winter 1990-91, pp. 40-45.

21. The changing relationship of military and commercial technology and its implications for technology policy in the U.S. are explored in considerable depth in a book now in press: J. Alic, LM. Branscomb, H. Brooks, A. Carter, and G. Epstein, *Beyond Spinoff. Military and Commercial Technologies in a Changing World,* Boston: Harvard Business School Press, in press, 1992. See Lewis M. Branscomb, "The Case for a Dual-Use National Technology Policy," Aspen Quarterly, Vol. 2, No. 3, Summer 1990, pp 3352

22. *Advanced Manufacturing Technology Development, Deployment, and Education Act of 1991,* and the *National Critical Technologies Act of 1991,* as embodied in the National Defense Authorization Act for Fiscal Years 1992 and 1993, Calendar No. 169, 102nd Congress, first session, U.S. Government Printing Office, Report 102-113, July 19, 1991.

23. It is striking that already the U.S. spends twice as much on health care as it does on defense -- both technologically intensive sectors of the economy. Biotechnology growth is expected to outpace defense industry growth for a good many years.

24. Located in the Department of commerce, NIST was formerly the National Bureau of Standards. It was renamed and its mission broadened in the 1989 Omnibus Trade and Competitiveness Act.

25. The 1989 Act (P.L 100-418) created the Commerce Department's Technology Administration and established three important new activities at NIST: the Advanced Technology Program (ATP), the establishment in cooperation with states of Manufacturing Technology Centers and an industrial extension program.

26. A useful study of this question was made for the Department of Commerce office of the Undersecretary for Technology by Vincent J. Ruddy of the John F. Kennedy School of Harvard University, entitled "Criteria and Processes to Support Generic, Pre -competitive, and Enabling Technology Development," April 9, 1991.

27. *Beyond Spin-off* chapter 12.

28. *Technology and Economic Performance: Organizing the Executive Branch for a Stronger National Technology Base,* New York: Carnegie Commission on Science, Technology, and Government, Sept. 1991.

29. The federal role in reform of pre-college math and science education is dealt with in another Carnegie Commission report released on Monday, Sept. 16, 1991. See *In the National Interest: The Federal Government in the Reform of K-12 Math and Science Education,* New York: Carnegie Commission on Science, Technology, and Government, Sept. 1991.

30. Lewis Branscomb, "A Public Policy Perspective," in Brian Kahin, ed., *Information Infrastructure for the Nineties,* New York: McGraw Hill, to appear November, 1991.

31. *The U.S. Technology Policy,* Washington DC: Executive Office of the President, Sept. 26, 1990. This important document was prepared by OSTP with participation from OMB and was cleared through the White House staffs.

32. Megan Jones, "Helping; States Help Themselves," *Issues in Science and Technology,* Vol. 6, No. 1, Fall 1989 pp. 56-60.