Lessons from the history of federal R&D policy for an "Energy ARPA"

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I appreciate the opportunity to appear before the Committee to discuss the legislative proposals for an "ARPA - E" that will support R&D on energy technologies that can reduce U.S. dependence on foreign suppliers of oil, reduce pollution, and reduce emissions of other materials that contribute to global climate change. Overall, I agree with the NAS panel's goals in recommending such a program, although I am skeptical about the usefulness of a "DARPA model" for energy R&D.

The federal government (and agencies including but not restricted to DARPA) has a long history of supporting R&D that has contributed to the introduction and deployment of technologies ranging from the 19th-century telegraph to civilian aircraft, hybrid corn, and the Internet. Moreover, federal R&D programs in energy efficiency and fossil energy between 1978 and 2000 produced significant economic, environmental, and other benefits.[1] This long history raises some important questions for the design of an ARPA – E.

The biggest question concerning the proposal for an ARPA – E concerns the problem that this entity seeks to solve. I share the concerns expressed by the NAS panel and other expert groups over the disparate growth in federal funding for biomedical and physical-sciences R&D during the past two decades, and a case can be made for increased federal investment in energy efficiency and conservation programs in the face of flat funding since fiscal 2001. But these concerns can be addressed through mechanisms other than the establishment of a new entity within DOE. And the proposal for an ARPA – E overlooks some critical features of energy R&D that make the "DARPA model" less tenable in this field.

1. Who should perform the R&D funded by ARPA – E?

The NAS panel's report emphasized the importance of "rebalancing" the national R&D "portfolio." A combination of factors (including the end of the Cold War) has produced a significant shift in the federal R&D budget in favor of biomedical research. The trends are well known, but bear repeating: federal funding for life sciences R&D grew by 6.2% per year from 1982 to 2003, outstripping annual growth rates in federal funding for engineering R&D (2.2%) and physical sciences R&D (1%). "Life sciences" R&D grew from 41% of federal R&D funding in fiscal 1994 to nearly 54% by fiscal 2003, and the

[1] See *Energy Research at DOE: Was It Worth It?*, National Research Council Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy (National Academy Press, 2001).

share of federal R&D spending accounted for by "environmental sciences, physical sciences, mathematics, and engineering" R&D shrank from more than 50% to less than 40% in the same period.[2] In addition, most observers suggest that the "time horizon" of federal and private-sector investments in physical-sciences and engineering R&D has shrunk. The share of overall Defense Department R&D devoted to "basic" research ("6.1") declined from more than 5% in fiscal 1965 to just over 2.5% in fiscal 2003.

A more balanced U.S. R&D portfolio should include greater public funding for R&D in the physical sciences and engineering undertaken by extramural performers, notably industry and higher education. Expanded funding for university R&D in particular could increase the supply of U.S. citizens trained in these fields and attract the "best and brightest" from other nations to conduct research and obtain long-term employment in the United States. Moreover, U.S. research universities transfer knowledge and technology very effectively through the placement of graduates in industrial and academic positions.

Although many components of the DOE laboratory system are closely linked with university education and research, the NAS panel rightly emphasizes the importance of extramural R&D performers (defined in this case as entities other than the DOE labs) in its description of ARPA – E. In fiscal 2003, only 9% of DOE's total R&D budget (including defense programs) went to research universities, while 16% was allocated to industry. Implementing new programs that follow the spirit of the recommendations in the NAS panel report requires an increase in the share of the DOE R&D budget that is allocated to extramural R&D performers.

It is not clear, however, that an ARPA – E is necessary to achieve this goal. For example, DOE might award grants on a peer-reviewed basis to university research teams that commit to using DOE laboratory facilities, incorporating competition among DOE laboratories to attract high-potential academic research teams. Alternatively (and following the example of DARPA in information technology), DOE could commit to multiyear support for "Centers of Excellence" in interdisciplinary energy R&D at universities through a competitive process. Yet another model for expanding financial support for academic research in the physical sciences and engineering is the Engineering Research Centers established at many universities by the National Science Foundation.

2. What types of R&D will ARPA – E focus on?

The NAS panel report's description of the ARPA - E research agenda suggests that this entity will support R&D on "generic" technologies that are slightly "downstream" from basic research, yet are sufficiently long-term and risky that private industry will not fund them. DARPA's research agenda included both long-term and more applied work, but more discussion is needed on exactly what "gap" the ARPA – E research agenda will fill. As I note below, one of the most significant obstacles to the translation of fundamental

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[2] See also *Engineering Research and America's Future: Meeting the Challenges of a Global Economy* (National Academies Press, 2005).

research advances into energy-conserving applications is the lack of incentives for users to adopt such technologies.

Another question for an ARPA – E concerns funding levels. Where does the proposed first-year funding of $300 million for ARPA – E fit into the President's requested increase of $391 million for nondefense DOE R&D in fiscal 2007?[3] Would the $300 million in first-year funding for ARPA – E consist entirely of "new money" in addition to the $391 million in increases for R&D requested in the FY 2007 budget document, or would this new entity be funded from a reallocation within the DOE R&D budget? Since one goal of an ARPA – E appears to be a substantial net increase in DOE support for extramural research, the answers to these questions are crucial.

3. Is R&D investment a sufficient condition for advancing U.S. energy goals?

Along with other expert groups, the Committee on Prospering in the Global Economy of the 21st Century highlighted the urgency and significance of energy-related challenges faced by the United States. The development of new technologies is an essential step in addressing these challenges. But realizing the benefits of these technologies requires more than their development by public- or private-sector researchers; widespread adoption of these technologies is necessary.

Indeed, more rapid adoption by users of new technologies can accelerate innovation, as users learn to operate, maintain, and improve them (the Internet in the United States is a classic example). And the need for widespread adoption highlights an important issue for ARPA – E that DARPA did not face: the creation of a market for new technologies. Federal programs supporting technological innovation have proven especially effective when funding for R&D was combined (often through different programs or policies) with complementary policies supporting the adoption of the innovations flowing from publicly funded R&D.

The Defense Department has been an important early purchaser of new technologies ranging from semiconductor components to computer hardware since the late 1940s. This "lead purchaser" role had several important effects: (1) the military market generally paid premium prices, enabling new suppliers to quickly achieve profitability; (2) the military market was sufficiently large that suppliers could exploit learning in production to reduce their manufacturing costs and eventually, lower the prices on new technologies sufficiently to make them competitive in civilian markets; and (3) suppliers used military markets to improve the design and ease of use of new products in ways that further enhanced their attractiveness to civilian purchasers. The procurement budget of the Defense Department aided in the translation of DARPA-supported military innovations into technologies that penetrated large civilian markets, increasing demand and accelerating improvements in the reliability and price-competitiveness of these technologies.

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[3] This estimate is taken from the AAAS 2/24/06 R&D funding report for FY 2007 DOE R&D, and includes "facilities" funding in addition to R&D. See www.aaas.org/spp/rd; accessed March 7, 2006.

The translation of DOE-funded innovations (whether funded by an ARPA – E or another entity) into technologies that are deployed extensively within the U.S. economy will require cost reduction and quality improvement of these innovations. Moreover, this "translation" will rely on investments from private firms and entrepreneurs seeking to profit from the commercialization of these technologies. DOE-supported R&D therefore should be complemented by policies that support end-user demand for these new technologies. Examples of such policies include mileage standards for automobiles and energy-efficiency requirements for other technologies; taxes on the carbon content of energy sources; and other mechanisms that create market signals to guide and create incentives for the long-term investment decisions of entrepreneurs and the purchase decisions of consumers.

Indeed, policies supporting the adoption of existing technologies could produce significant near-term improvements in U.S. energy efficiency and, potentially, reductions in pollutants. Wider adoption of these technologies would contribute to more rapid incremental improvements in their reliability and cost-effectiveness. And the cumulative effect of such incremental improvements can be very large indeed.

4. ARPA – E faces a very different political environment than DARPA

Another contrast with ARPA – E is DARPA's single customer and clear mission. Although its relationship with the uniformed services has not been free of conflict, DARPA enjoyed relatively close links with a clear primary "customer." In addition, of course, the broad mission of DARPA--enhancing U.S. military capabilities--was widely accepted across the political spectrum. By comparison, the energy policy arena in which an ARPA – E would be a central actor is characterized by a higher level of political conflict over ends and means, as well as a large number of user constituencies whose needs and priorities may be mutually inconsistent.

Investment in the commercialization of new technologies takes substantial funds and substantial time. Private-sector investment will respond to market-based incentives created by federal policy only to the extent that these federal policies are perceived to be credible, i.e., lasting and reasonably stable. Partly because of wide swings in energy prices and partly because of a lack of political consensus on ends and means, U.S. energy policy has experienced frequent change in goals, political saliency, and program content. Policy instability has raised the risks of investments by private firms in commercializing alternative energy technologies, and almost certainly has reduced the flow of capital into R&D and commercialization in these fields. Although one cannot describe U.S. defense R&D policy as "nonpolitical," the fact remains that the higher level of political consensus on external threats and responses to them since the 1950s has meant that DARPA has operated in a more stable policy environment that enhanced the credibility of its policies and meant that public investments effectively complemented private-sector funding.

It seems likely that the political conflicts that characterize U.S. energy policy will remain significant and that the instability in policy will persist. Such policy instability compounds the technological risks faced by an ARPA – E and will complicate the development of complementary policies to support the adoption of energy-efficient technologies.

Conclusion

I support the broad goals of the Committee on Prospering in the Global Economy of the 21^{st} Century in recommending an ARPA – E. I believe that expanded federal investment in long-term R&D that supports the training of tomorrow's scientists and engineers is needed, and I share the Committee's view that the energy field is one in which the public interest would be well served by greater investment in new technologies. I also believe that the track record of federal R&D investments in the energy field, like many other fields of technology, is a mixed but on the whole positive one. But I am not convinced by the Committee's arguments that a new entity within the Department of Energy is the best means for achieving these goals.

On balance, I believe that a stronger case for an ARPA – E should be based on a clearer analysis of the deficiencies in the current energy R&D structure that includes more detail on how an ARPA – E will address these problems. And as I noted above, there are very important differences between DARPA and the proposed ARPA – E (some of which reflect the differences in their missions) that seem likely to impede the effectiveness of an ARPA – E.

The members (and staff) of the NAS panel should be congratulated for producing an important report (and doing so very quickly) that contains numerous policy recommendations in addition to that for an ARPA – E that merit serious consideration by Members of Congress. It is especially important for members of the Science Committee to attend to the NAS panel's overall analysis of the health of the U.S. innovation system. Actions that reduce federal support for basic research, such as potential cutbacks in NASA space science programs, or policies that may reduce access to higher education, such as cutbacks in federal support for student higher-education loans, do not advance the goals of *Rising above the Gathering Storm*. All decisions concerning the allocation of public resources are difficult, and the current (and prospective) environment of revenues and spending pressures has created unusually severe challenges. But federal investments in the future are essential to maintaining the living standards and global leadership that this nation has enjoyed for much of the past century, and a consistent commitment to funding these investments in the future is no less essential.

BIOGRAPHICAL STATEMENT

David C. Mowery is William A. and Betty H. Hasler Professor of New Enterprise Development at the Walter A. Haas School of Business at the University of California, Berkeley and a Research Associate of the National Bureau of Economic Research. He received his undergraduate and Ph.D. degrees in economics from Stanford University and was a postdoctoral fellow at the Harvard Business School. Dr. Mowery taught at Carnegie-Mellon University and served in the Office of the United States Trade Representative as a Council on Foreign Relations International Affairs Fellow. He has been a member of a number of National Research Council panels, including those on the Competitive Status of the U.S. Civil Aviation Industry, on the Causes and Consequences of the Internationalization of U.S. Manufacturing, on the Federal Role in Civilian Technology Development, on U.S. Strategies for the Children's Vaccine Initiative, and on Applications of Biotechnology to Contraceptive Research and Development. During 2003-2004, he was the Marvin Bower Research Fellow at the Harvard Business School. His research deals with the economics of technological innovation and with the effects of public policies on innovation; he has testified before Congressional committees and served as an adviser for the Organization for Economic Cooperation and Development, various federal agencies and industrial firms.

Dr. Mowery has published numerous academic papers and has written or edited a number of books, including the Oxford Handbook of Innovation; Ivory Tower and Industrial Innovation: University-Industry Technology Transfer Before and After the Bayh-Dole Act; Paths of Innovation: Technological Change in 20th-Century America; The International Computer Software Industry: A Comparative Study of Industry Evolution and Structure; U.S. Industry in 2000; The Sources of Industrial Leadership; Science and Technology Policy in Interdependent Economies; Technology and the Pursuit of Economic Growth; Alliance Politics and Economics: Multinational Joint Ventures in Commercial Aircraft; Technology and Employment: Innovation and Growth in the U.S. Economy; The Impact of Technological Change on Employment and Economic Growth; Technology and the Wealth of Nations; and International Collaborative Ventures in U.S. Manufacturing. His academic awards include the Raymond Vernon Prize from the Association for Public Policy Analysis and Management, the Economic History Association's Fritz Redlich Prize, the Business History Review's Newcomen Prize, and the Cheit Outstanding Teaching Award.