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Recommendations

Overall, the leadership and investment strategy for the first several years of NNI have been appropriate. The committee has formulated a number of recommendations to further strengthen the implementation and goals of NNI. The following recommendations represent the committee's highest with respect to the current state of the NNI.

Recommendation 1: The committee recommends that the Office of Science and Technology Policy establish an independent standing nanoscience and nanotechnology advisory board (NNAB) to provide advice to NSET members on research investment policy, strategy, program goals, and management processes.

The rapidly changing political and economic climate poses significant challenges for the continued priority of the federal investment in the NNI. With potential applications in virtually every existing industry and new applications yet to be discovered, there is no doubt that nanoscale science and technology will emerge as an important driver of economic growth in the first years of the new millennium. An independent advisory board could provide advice to NSET members on research investment strategy, program goals, and management processes. It could identify and champion research opportunities, particularly ones that do not conveniently fit within any single agency's mission, to ensure that nanoscale science and engineering continue to progress toward their ultimate potential. Such a board should be composed of leaders from industry and academia with scientific, technical, social science, or research management credentials. It might be appointed

by and overseen by the Office of Science and Technology Policy.

Recommendation 2: The committee recommends that NSET develop a crisp, compelling, overarching strategic plan. The plan would articulate short- (1 to 5 years), medium- (6 to 10 years), and long-range (beyond 10 years) goals and objectives. It should emphasize the long-range goals that move results out of the laboratory and into the service of society.

While the FY 2001 and FY 2002 implementation plans for the NNI are quite detailed and ambitious and cover a broad spectrum of good research and development opportunities, they appear to have been developed largely as pieces within individual agencies, each driven by its own mission. While the outcomes of the NNI as a whole have been articulated, the various themes of the NNI are overlapping, and their strategies and goals have not been consistently described.

The strategic plan should include a consistent set of anticipated outcomes for each theme and each Grand Challenge, along with estimated time frames and metrics for achieving those outcomes. The plan should include mechanisms for accelerating ideas into applications. Appropriate mechanisms include pilot projects, the strategic infusion of new dollars into the NNI budget for engineering applications, the development of dedicated SBIR/STTR budgets for nanoscale science and technology in participating agencies, and the development of incentives for university projects in alliance with industrial partners and state and regional incubators. The committee also urges that the NSET, with the advice of the proposed NNAB, prioritize the Grand

Challenges in terms of their relative scientific and strategic importance.

Recommendation 3: The committee recommends that NNI support long-term funding in nanoscale science and technology so they can achieve their potential and promise.

Nanoscale science and technology will have continued and growing impact, with benefits seen in both the short and long-term. Establishing a proper balance between the short-term and long-term funding of nanoscale science and technology will be critical to realizing its potential. If an idea is truly revolutionary and promises higher impact successes, a longer period—and longer-term funding—is needed to demonstrate results. While funding some of these extraordinary ideas for a long time may be risky, achieving success in even a small number of them would produce breakthroughs that more than compensate for those that did not succeed.

Recommendation 4: The committee recommends that NSET increase multiagency investments in research at the intersection between nanoscale technology and biology.

The relevant scientific community currently recognizes the importance of nanoscale biological and biomedical research. NSET, with the advice of the proposed NNAB, must further encourage and promote investment at the intersection between nanoscale technology and biology if it wishes to lead in this area. NSF and NIH report an increase in the number of proposals in nano-bio areas. Since many of these proposals cross the boundaries of individual agency expertise and missions, the creation of multiagency research programs and review mechanisms is critical. The role of NSET, with the advice of NNAB, is to overcome agency barriers that might otherwise prevent the allocation of resources to research that cuts across disciplines and missions.

Recommendation 5: The committee recommends that NSET create programs for the invention and development of new instruments for nanoscience.

NSET must invest heavily in the development of new instruments if it wishes to substantially accelerate breakthroughs in nanoscale science and technology. Historically, many important advances in science

happened only after the appropriate investigative instruments became available. Since one must be able to measure and quantify a phenomenon in order to understand and use it, it is critical that we develop tools that allow for more quantitative investigations of nanoscale phenomena. These should include analytical instruments capable of manipulating, tailoring characterizing, and probing at the nanoscale.

Recommendation 6: The committee recommends the creation of a special fund for Presidential grants, under OSTP management, to support interagency research programs relevant to nanoscale science and technology. These grants should be used exclusively to fund meaningful interagency collaborations that cross mission boundaries, particularly among the National Institutes of Health, the Department of Energy, and the National Science Foundation.

The breadth of NNI and its fields of interest—from new materials development, to quantum computing, to cellular microbiology, and to national security—compels agencies to form more meaningful cooperation in their nanotechnology pursuits and to better leverage their investments for mutual benefit. While the NNI Implementation Plan lists major interagency collaborations, the committee has no sense that there is any common strategic planning occurring in those areas, any significant interagency communication between researchers working in those areas, or any significant sharing of results before they are published in the open literature. All NNI funds are currently directed by each individual agency to the projects and programs of that agency's choice. Currently, NSET agencies have an incentive to collaborate on research only where they do not have and cannot acquire all the necessary skills in-house. This incentive has not been sufficient to develop any meaningful interagency research collaboration. Creation of a special fund strictly for meaningful interagency collaboration should motivate the best possible collaboration and leveraging of resources.

Recommendation 7: The committee recommends that NSET provide strong support for the development of an interdisciplinary culture for nanoscale science and technology within the NNI.

Nanoscale science and technology are leading researchers along pathways formed by the convergence of many different disciplines—biology, physics, chemistry, materials science, mechanical engineering,

electrical engineering, and others. A critical factor in enhancing interdisciplinary research is the establishment of more academic laboratories in which interdisciplinary science is practiced. The agencies have done a good job of structuring multidisciplinary collaborations through their funding opportunities, but these collaborations do not necessarily lead to self-contained interdisciplinary groups in academia. Further, the overall value system used by the community to judge scientific quality continues to discourage interdisciplinary research, with negative impact on tenure, promotion, and the awarding of research grants. It is expected that the number of interdisciplinary groups will grow as it becomes evident that an interdisciplinary approach is necessary to tackle the interesting and complex problems that are part of nanoscale science and technology. However, creative programs that encourage such groups will accelerate this growth and must be part of NSET's agenda.

Recommendation 8: The committee recommends that industrial partnerships be stimulated and nurtured, both domestically and internationally to help accelerate the commercialization of NNI developments. NSET should create support mechanisms for coordinating and leveraging state initiatives to organize regional competitive clusters for the development of nanoscale science and technology.

Nanoscale science and technology promise to bring about important changes in industries based in biology, medicine, chemistry, and information technology during the next decade and beyond. Governments around the world have followed the lead of NNI by creating their own nanoscale science and technology programs, generally aligned with the industries in their countries and targeting specific advances in nanoscale science and technology that will improve the competitiveness and technological capability of those industries. Governments are fostering nanoscale science and technology mainly to enhance the competitive position of their industries, and the defining benefit is economic, as new capabilities in technologies and products move from laboratories to commercial reality.

As other countries aggressively pursue international partnering opportunities in nanoscale science and engineering, the United States should continually be positioning itself as the collaborator of choice in order to retain its world leadership not only in nanoscale science and technology development but also in commercial deployment. NNI must embrace efforts that fully

engage industrial partnerships both here and abroad, rapidly moving developments from laboratories to novel applications, through product design and into the marketplace. The United States is most likely to realize economic benefits from nanoscale science and technology developments when the technology and its underlying intellectual property comes from U.S.-based laboratories, institutions, and corporations.

Coordinating and leveraging state-level initiatives with national funding is critical to the rapid deployment of nanotechnology advances. States are willing to match large federal research grants to their state universities. Several states already have efforts specifically targeting nanoscale science and engineering. NSET should establish appropriate mechanisms for monitoring state and local investments in nanoscale science and engineering in order to form partnerships that would leverage federal assets and infrastructure.

Recommendation 9: The committee recommends that NSET develop a new funding strategy to ensure that the societal implications of nanoscale science and technology become an integral and vital component of the NNI.

Our nation's success in developing, deploying, and exploiting new nanotechnologies will require synchronous innovation in how we educate and train our workforce, manage our R&D system, and prepare for and adjust to the expected and unexpected social and economic impacts of these new technologies. Activities supported by the societal implications theme are supposed to help ensure that this "second industrial revolution" produces social, economic, and technical benefits. Although some progress has been made, particularly with respect to educational initiatives, the disappointing level and diversity of efforts within this theme leads the committee to conclude that NSET has not given sufficient consideration to the societal impact and developments in nanoscale science and technology.

Agencies *willing* to engage in assessing societal implications must be given a budgetary incentive to do so. The committee believes that NSET should develop a funding strategy that treats societal implications as a supplement or set-aside to agency core budget requests.¹ In this vein, the committee suggests that

¹Such a funding strategy is not new. For example, most federal agencies resisted involvement in the SBIR program until Congress required agencies to set aside a certain percentage of their budget for the program.

NSET should request funding for societal implications activities and then award that funding directly to agencies willing to do this kind of work and capable of doing it.

The societal implications theme has three components: educational, outreach, and social science. However, unless things change dramatically during FY 2002, the social implications theme will simply be a fancy title for a relatively straightforward educational initiative targeted at graduate and undergraduate students. While not every agency may want to address all three components, they should all be required to budget for, or at least report about, these areas separately.

Agencies willing to engage in outreach or social impact studies should allocate funds directly to the office or division that typically engages in or supports these kinds of activities. These divisions could then pursue focused intramural studies or develop solicitations targeted at the appropriate social science community. These NNI agencies should also be encouraged to consider focusing on the topics and funding strategies highlighted in NSF and NSET-sponsored workshops on societal implications.

Recommendation 10: The committee recommends that NSET develop performance metrics to assess

the effectiveness of the NNI in meeting its objectives and goals.

The committee sees a need to measure the progress of the NNI as a whole, under the aegis of the OSTP, with measurable factors including quality, relevance, productivity, resources, and progress in moving research concepts toward applications. To date, NNI programs have been evaluated as part of the Government Performance and Results Act (GPRA) procedures of the individual participating agencies.

Despite a long history of efforts to define and improve evaluation criteria, the academic, industrial, and government sectors continue to struggle with the problem of measuring the effectiveness of research activities. The challenge of evaluation is compounded in the case of the NNI, since the program spans multiple agencies with varying missions. However, once the participating agencies have agreed upon program goals, evaluation and exit criteria can be developed to appropriately measure effectiveness or success in achieving the goals. These criteria should be developed jointly by an appropriate council and with the various agencies under NSET. One possibility for such council could be the suggested NNAB.

