METHODS IN SCIENCE ROADMAPPING

How to Plan Research Priorities

By

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PREFACE:

Obtaining the right mix of research activities with limited funding and rapidly shifting technologies can vex the best research manager. Deferring to the ebb and flow of competitive grant awards made by distant peer panels fails in many ways to address any well planned research agenda. Balancing the essential need to assure science quality, program relevance, responsiveness to stakeholder needs, and functional integration can be very perplexing.

In 1998 the Experiment Station Committee on Organization and Policy (ESCOP) of the National Association of State Universities and Land-Grant Colleges (NASULGC) was challenged by University of Arizona administrator Colin Kaltenbach to create a science roadmap to help plan the future of Land Grant University (LGU) system agricultural research, with a 10 to 20 year horizon.

Roadmapping as a process was new to the LGU system, but not to many other institutions, especially some outstanding examples from the international organizations, the private sector and some government laboratories (i.e., "World Conference On

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Science: Science Blueprint Is High on Ideals, Light on Details"[2] and "Overview of Technology Roadmapping"[3]). While many of the roadmaps were available over the Internet, the details of the process used were not.

Additionally, funding for the roadmapping activity was not available through ESCOP, thus requiring us to conduct the project entirely with volunteers.

To address these considerations it was decided to "reverse engineer" the products of others and to depend strongly on electronic communications (e.g., e-mail, conference calls), to hold costs to the absolute minimum.

We are not presenting this method as final or perfect. Major portions of the science roadmapping process described herein were done "on the fly', as questions arose, and problems were identified. The intention of this brief manual is to help others to see how our product was developed, and to benefit from what we encountered along the way.

INTRODUCTION[4]:

Technology roadmapping has become a widely used technique during the past decade from the perspectives of both individual companies and entire industries. The use of the term "roadmap" conveys the main purpose of a technology roadmap, namely to chart an overall direction for technology development or usage. However, a standard definition of technology roadmapping does not exist, and an examination of roadmaps that have been created indicates that there is considerable diversity among practitioners as to what constitutes a roadmap and the roadmapping techniques employed.

Broadly defined, a technology roadmap is used to portray a larger context for technology development or usage. In everyday life, a *road map* is a layout of paths or routes that exist (or could exist) in some particular geographical space. They are used by travelers to select among alternative routes in determining how to arrive at a particular destination. Similarly, a technology roadmap serves as a tool that provides essential understanding, orientation, context, direction, and some degree of consensus in planning technology developments and implementations.

Although "roadmapping" has become a popular metaphor for planning technology advancements usages, it is interesting to note that "roadmap" has yet to appear in the dictionary or be recognized by popular spell-checking software utilities. In addition "roadmapping" is a new verb that describes the mechanisms involved in constructing a technology roadmap.

[2] Authored by Robert Koenig. Science. Volume 285, Number 5425, Issue of 9 Jul 1999, pp. 174-175.
[3] Authored by Susumu Kurokawa (Vanderbilt University) and John Meyer (Technologix, Inc.) located at http://www.lebow.drexel.edu/kurokawa/mot/6th_sec/Roadmap1.doc
[4] This Introduction is wholly derived (but edited for brevity) from "Overview of Technology Roadmapping" found at http://www.lebow.drexel.edu/kurokawa/mot/6th_sec/Roadmap1.doc and is an excellent resource for examples of roadmapping in different settings along with a wealth of references.

Robert Galvin[5], former Chairman of the Board of Directors for Motorola, offered this definition of roadmapping:

> "A 'roadmap' is an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field."

Addressing the purpose and benefit of roadmaps, Galvin further stated, "Roadmaps communicate visions, attract resources from business and government, stimulate investigations, and monitor progress. They become *the* inventory of possibilities for a particular field . . . In engineering, the roadmapping process has so positively influenced public and industry officials that their questioning of support for fundamental technology support is muted."

Therefore, in its broadest context, a technology roadmap provides a consensus view or vision of the future technological landscape for decision makers. The roadmapping process provides a way to identify, evaluate, and select strategic alternatives that can be used to achieve a desired technology or business objective.

Practically speaking, many different types of technology roadmaps exist. A variety of technology, product, and related forms of company-specific and industry roadmaps are being implemented. However, to date, the academic literature on roadmapping is sparse; industry practitioners have generated most of the publicly available information on the topic. These applications covered a wide spectrum of uses including:

- Science and research roadmaps (e.g., science mapping)
- Cross-industry roadmaps (e.g., Industry Canada initiative)
- Industry roadmaps (e.g., SIA's *Technology Roadmap for Semiconductors*)
- Technology roadmaps (e.g., aerospace, aluminum, etc.)
- Product roadmaps (e.g., Motorola and others)
- Product-technology roadmaps (e.g., Lucent Technologies, Philips Electronics)
- Project and issue roadmaps (i.e., for project administration)

From this variety of uses comes a taxonomy that classifies roadmaps according to their location in applications-objectives space (see Figure 1 below).

[5] Science. Volume 280, Number 5365, Issue of 8 May 1998, p. 803. (See Appendix 1 for the entire text.)

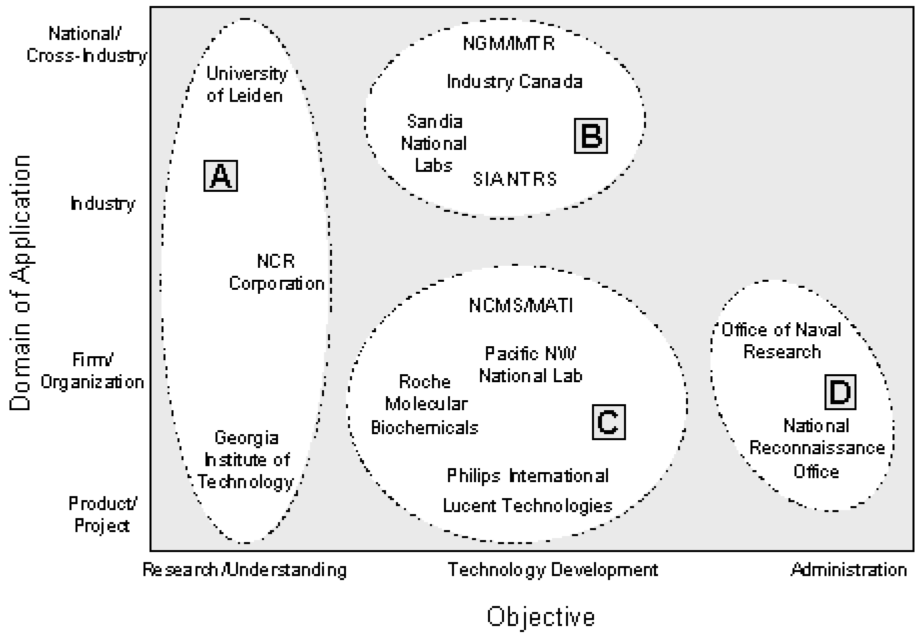

Figure 1 – Roadmapping taxonomy. (Source: Richard Albright and Robert Schaller, "Technology Roadmap Workshop," moderated by the Office of Naval Research, Washington, DC, October 30, 1998).

The independent roadmap applications shown in the above figure, when viewed collectively in this taxonomy scheme, can be broadly classified as follows:

A. Science and Technology Maps or Roadmaps
B. Industry Technology Roadmaps
C. Corporate or Product-Technology Roadmaps
D. Product / Portfolio Management Roadmaps

The major uses of and benefits derived from technology roadmaps are:

- To help develop consensus among decision makers about a set of technology needs,
- To provides a mechanism to help experts forecast developments in targeted areas, and
- To present a framework to help plan and coordinate developments at any level: within an organization, throughout an entire industry, and even across industry or national boundaries.

Finally, it should be noted that the true extent of the benefits of roadmapping has yet to be proven. What is clear, however, is that the use of technology roadmapping will continue to increase because of its proven effectiveness in helping to structure joint industry-government research programs and facilitate collaboration within industries and among companies.

ROADMAPPING AGRICULTURAL SCIENCE:

Agricultural research program directors' expectations are shifting from considerable independence in program planning to more reliance on outcome relevance and responsiveness to stakeholder needs. For instance, the 1998 U.S. Farm Bill required the Secretary of Agriculture to promulgate formal rules for stakeholder listening. This statutory requirement, supplemental to the existing processes of determining research priorities, caused some institutional leaders to reflect on what might be done to rationalize otherwise divergent expectations for priority setting. New Jersey State Agricultural Experiment Station (SAES) Associate Director Dan Rossi chaired a northeast regional committee[6] that proposed four criteria for allocating public sector agricultural research resources to gain the largest possible returns on research investment:

- *Need:* Resource allocations should directly reflect the needs of the intended stakeholders and customers. This requires listening to the "customers".

- *Feasibility:* Judgments are needed on what is technically feasible (i.e., what can be accomplished through agricultural research), and this judgment needs to be grounded in the best possible science. This in turn mandates some evaluation of the scientific potential of proposed research approaches by knowledgeable scientists.

- *Importance:* There must be congruence between the dimensions of the intended topic and the allocation of research resources. Larger impacts can be expected by investing in topics that already have a large base in agriculture, forestry or rural development (e.g., wheat, hardwoods, community services), rather than trying to start from a smaller base (e.g., edible amaranth) or a regionally distributed environmental issue rather than a local or state issue. This requires that some congruence analysis be done.

- *Impact:* Projections of expected benefits are needed to permit informed choices of alternative allocations. These projections must be done with a set of assumptions that are understood by the participants and the claimants to the system, and are broadly agreed upon. *Ex ante* estimations need to go beyond economic consequences to the non-economic benefits and consequences of technologies (i.e., social, health, environmental). Assigning premium or discount coefficients to economic projections can do this.

The judgments on research feasibility are the subject of science roadmapping. This is not to discount planning activities in the other three criteria (need, importance and impact) those will be the topics of future documents.

[6] http://www.agnr.umd.edu/users/nera/workshop/PrioritySetting-Feb99.html. Note: The original list has been modified here for editorial purposes.

THE PROCESS:

To describe the roadmapping process we have elected to break down the activities into steps. This is possible in the process of developing a science roadmap as it takes time and much of the activity must be done in sequence. Ideas must be gathered, opinions sorted, censuses built, and agreements prepared into readable documents. The advent of easy, low-cost communication greatly facilitates this synthesis of scientific perspectives into a collective vision.

One should plan on at least six months to a year to complete the following 10 steps. We took almost a year, but we could find no shortcuts. Communicating with dispersed sets of individuals and weaving a consensus takes time.

Step 1. Identify a leader with commitment and influence at or near the top of the organization[7]. Provide the leader with adequate staff support to assure that the project gets initiated early, and tasks get accomplished on time.

There is a tradeoff here that must be resisted. Asking a national leader to assume the roadmapping responsibilities and not providing adequate staff support may cause the project to languish, as national leaders are, almost by definition, busy people. Asking a lieutenant to become the roadmapping leader and thus assume all the staff duties can doom a project, in our view. In our project the five regional Executive Directors were assigned the staffing responsibilities.

Step 2. Organize what is already known about stakeholder needs. In our activity much of what had been learned about stakeholder-expressed needs was available in multiple documents and summaries prepared by the Secretary of Agriculture's advisory board, and others.

Step 3. Form a small working group (3 or 4 people) to inventory information and summarize relevant reports. This working group should assess the importance of the stated stakeholder needs. They should also plan a timetable, looking at task assignments over a 6 to 9 month horizon. Finally, they should solicit names of scientific experts across the broad areas of the scientific "terrain" they expect to map.

Here are some important points-to-consider:

- Representation on the Task Force (see the next step) will very much determine the flavor of the final report, if not the content. Consider the different types of printed maps (topography, roads, waterways, or flight paths) to which we have access. Each is a reflection of the intended user, but as well the individuals who prepared the map.

[7] In our case the choice was clear, in that the original challenge came from one of the most respected leaders in our national community.

- Scientific disciplines differ significantly in how they see the future, and these differences must be preserved during the roadmapping process.
- The original dimensions of the scientific terrain to be mapped will be very important to the final product of roadmapping, and in turn the types of representatives that will need to be recruited. For example we could have selected to focus on emerging technologies (e.g., biotechnology, nano-technology, information technology). Instead we elected to focus on agriculture sectors (e.g., rural communities, crop agriculture, animal agriculture, etc.). We are confident that this choice dictated the character of the final report as much as any other element.
- Soliciting the names of potential scientific contributors must be a broadly cast net. The need to have a robust list of names with very diverse interests, professional experiences, political perspectives, geographic representation, institutional membership, and cultural backgrounds which will require a rich list of nominees from which to work. And, without a diverse set of roadmap contributors the critics of the final products may have grounds to complain that their views were not consulted or considered.

Step 4. Form a task force of 16 to 24 members, with representation that gives diversity and scientific coverage. It is important to remember that some science disciplines are typically underrepresented with respect to other sciences within an agricultural research portfolio. Thus, attempts to democratically appoint a task force may be counter to any interest to find balance. Specifically, we were aware that the social sciences are a small fraction of contemporary research investments, relative to the biophysical sciences. But we also knew that much of what we would hope to achieve in the major landscape features of agriculture would depend on understanding considerations such as human and social behavior (e.g., the acceptance of new technologies by consumers), economic consequences (e.g., farm profitability) and community vitality (e.g., rural development).

We selected a very diverse task force that represented the majority of the scientific disciplines of contemporary agriculture science, spanned the professorial ranks, and included some members of the National Academy of Science as well. Research management and professional societies were also represented. Admittedly, not every facet of agricultural research was covered in depth by the task force, but invariably someone on the task force knew something about everything we addressed. In certain cases task force members were asked to check ideas, issue or technical perspective with colleagues.

Not every nominee agreed to serve on the task force, for a variety of reasons. Surprisingly, we did get a high rate of agreement to serve, and the reasons to decline were always unrelated to the topic or task. We were “up front” about the commitment to be made: the duration of the roadmapping process would be at least 6 months; the forms of communication would be electronic, and there would be no remuneration.

By the end of the project we counted 24 members among the active participants, having added individuals along the way.

Step 5. Convene the Task Force to explain the roadmapping process and develop the plan of activities. We accomplished this through a conference call, but it could have been done as well through an Internet chat room, or the exchanges of e-mails. Some sense of community may have been developed using conference calling, but it would be a stretch to claim humanization through this process. Since there were no funds to pay for a face-to-face meeting, this tradeoff was deemed acceptable.

During the first conference call we described the agricultural science landscape as we saw it, and discussed the major features. We set the expected time horizon as "10 to 20 years" to partition more immediate considerations from the mapping process. We directed the participants to sources on stakeholder needs, but we did not require that they read reports on the subject, fearing that burdening the task force with additional chores might cause some to resign. We trusted that we could maneuver the discussion back to the needs of stakeholders whenever it veered too far off track. That approach worked well, in out estimation.

We were able to obtain agreement on the major features of the terrain to be mapped (i.e., considered to be essential), and got a volunteer to write up these features along with what needed to be considered when assessing that feature. These points-to-consider were stated as a conceptual framework consisting of the following seven surface features (i.e., needs) of the terrain we were mapping:

1. The need to be competitive in a global economy;
2. The need to add value to our future harvests;
3. The need to adjust agriculture to a changing climate;
4. The need to be good stewards of the environment and natural resources;
5. The need to make our agricultural enterprises profitable;
6. The need to make our families and communities strong; and,
7. The need to modify our foods for improved health and safety.

The following seven challenge statements were used to organize the roadmapping activities, and they were subsequently used to report the group's findings. The seven challenge statements were:

- **Challenge 1.** *We can develop new and more competitive crop products and new uses for diverse crops and novel plant species*. These crop products would include pharmaceuticals; designer foods; and plant-based renewable resources for fuels, other sources of energy, building materials and industrial feedstock. Through increases in production and processing efficiencies, some of these products will replace fossil fuel-based products. In other cases, new niche markets will emerge in response to the availability of these new products.

- **Challenge 2.** *We can develop new products and new uses for animals.* These products include, *inter alia*: value-added products, new uses, new markets, new configurations and contents, and better foods.

- **Challenge 3.** *We can lessen the risks of local and global climatic change on food, fiber and fuel production.* Socioeconomic and biophysical models are needed to better predict the consequences and opportunities related to anticipated global warming. We believe that more research is needed to uncover methods to reduce greenhouse gas emissions and discover whether carbon can be sequestered in significant amounts in forests, farmlands and grasslands to lessen the consequences of the coming climatic changes. We also believe crops and livestock can be genetically modified and managed to remain productive with the predicted increases in ambient temperatures. We anticipate that the predicted changes in water availability and soil fertility can be accommodated through genetic modification of crops and livestock. Thus, we believe this area of research represents a valuable opportunity to ease the predicted consequence of greenhouse gases on our food and fiber supplies.

- **Challenge 4.** *We can provide the information and knowledge needed to further improve environmental stewardship.* This can be done through new agricultural practices while continuing to enhance the quantity and quality of food and fiber production through genetics. Our nation's dependence on natural resources and a clean environment mandates attention to preserving soil, air and water quality. Moreover, the values placed by society on open spaces and ecosystem services, including the conservation of biodiversity, need to be assured. We need to move as a nation toward new policies and programs that protect and preserve both the natural resource base and the environment.

- **Challenge 5.** *We can improve the economic return to agricultural producers.* This can be done through the development of new knowledge and technologies that improve harvest quality and quantity; product differentiation and diversification, with opportunities for specialization; and enhanced market competitiveness (both domestically and internationally), while reaping the benefits of the emerging 21st century's bio-based economy.

- **Challenge 6.** *We can strengthen our communities and families.* The socioeconomic health in rural, peri-urban and urban settings can benefit greatly from more research on individual, family and community economic development, labor utilization strategies, and enhanced understanding of the social dynamics in our communities.

- **Challenge 7**. *We can ensure improved food safety and health through agricultural and food systems.* Both malnutrition and obesity are contemporary, widespread problem of U.S. citizens. New foods and better eating practices are two of the known strategies that can be used to address the poor dietary health of much of the U.S. population. Other emerging strategies will need to include: functional foods, nutriceuticals, designer foods and "pharm foods.

Step 6. In the next conference call the goals for each terrain feature were developed. As an example, for crop agriculture it was agreed that the following four goals should be targeted if agricultural research was to address stakeholder needs in that domain area.

- Improving crop biomass quantities, qualities and agricultural production efficiencies;
- Conceiving new markets for new plant products, and new uses for these crops;
- Developing technologies to improve the processing efficiency of crop bio-products (e.g., bio-fuels, pharmaceuticals, functional foods); and,
- Supporting the development of marketing infrastructure for crop bio-products.

Seven terrain features each with four goals gave us 28 areas to map in considerable detail.

Step 7. Twenty-eight writing teams were formed, initially by volunteerism, supplemented by team member assignments by the Chair to assure diversity of perspectives, especially for scientific disciplines. Drafting team memberships in many cases overlapped, with some task force members serving on several drafting teams. Each team was asked to prepare an essay, using a prescribed outline reflecting a consensus on what needed to be described and evaluated. Each identified a drafting team chair that was responsible for delivering the essay to a central clearinghouse. The agreed outline was:

- Background and Rationale
- Consequences of Ignoring the Need
- Specific Objectives of a National Research Program
- Potential Impacts of the Research

Teams were given about a month to submit their draft essays. The resulting essays averaged four pages in length, for a grand total of about 112 pages of text.

Step 8. One writer was given the task of synthesizing the 28 essays into a single "first draft" document. Some material was redundant, as expected. Some material was missing, also as expected. Some material was out of place. Writing styles were very different. The Chair of the Task Force granted license for the single writer to assemble the material into a consistent style.

Follow up information was requested from several essay writing teams. To be transparent we elected to send the requests to the general list serve, but addressed to the essay writing team. That proved to be a mistake, as unsolicited responses and comments flowed from other task force members, giving the impression of under-cutting the essay writing team. It would have been much better to have contacted the team leader directly for any additional information. The final editing strategy was to merge the essays within the seven thematic areas, rather than having 28 such segments. It was a decision mostly based on the content and a view to the reader. So the four issues in a thematic area were merged into one thematic statement.

The first draft of our roadmap was completed in two weeks, and sent to the entire task force along with plans for the next teleconference, with an agenda to discuss the draft section by section. Written comments on the first draft were also requested with suggestions that the teams give focus to their assigned areas, and were asked to be aware of the entire document. This engagement strategy permitted detailed comments to be returned in the text (using Microsoft Word's tracking option) and general comments on the overall roadmap in the conference call.

Step 9. The review of the first draft allowed general comments on the overall draft during this conference call, and some surprising exchanges surfaced at this point. Strong disciplinary positions were expressed, some to the extent of proposals to drop some themes. These conflicts were primarily along the lines of the biophysical science versus the social sciences, with the biophysical scientists expressing strong reservations about stating the relevance of investing in social science research. The task force Chair strongly supported the divergence of views in the roadmap, and consensus was reestablished.

We note this conflict to point out that at several points in the process the potential exists for separation of interests. Divisions of interest can occur along any one of the points of fracture, and strong leadership is required to hold the task force together.

Comments from the submitted text notes and from the teleconference were worked into a revision, and again shared with the task force, as Version 2.0. Those comments were again worked into a Version 3.0, with the help of a professional editor.

Step 10. The final conference call with the editor included, focused on Version 3.0. Comments from the entire task force were considered, but the number of comments was far fewer than for earlier iterations. The final edits were incorporated and then sent to layout and printing. We elected to have 1000 copies printed for distribution to advocates for the Land Grant University system. Soon there was a call for more copies, so several thousand more copies were printed. This was in addition to placing the document on the World Wide Web (www.nasulgc.org/comm_food.htm).

SUBSEQUENT STEPS:

Once the roadmap was completed ESCOP's Planning Committee was asked to assess the current research capacities of the collective institutions using the USDA's Current Research Information System (CRIS) and to project the needed additional scientific capacities by fields of science. The ESCOP Planning Committee then sent a survey to all experiment station directors with the responses used to determine the mix of additional scientific capacities needed to achieve the objectives set out in the roadmap. In turn, ESCOP's Budget and Legislative Committee was asked to look at the needed capacities in terms of annual budget costs to adequately support existing positions and add new positions with adequate financial support. These budget figures were then developed into a 4-page summary of the roadmap's terrain with graphs of the investments needed to "travel" the science roads depicted in the roadmap. Advocates for the Land Grant University system then had at hand a focused summary of what science could do for them with the projected costs for implementation, backed up with substantial information on the scientific opportunities, anticipated impacts, needed research capacities, and projected costs. (See http://www.escop.msstate.edu/draftdoc.htm).

FINAL NOTE:

The sequence we developed for our science roadmapping activity should not be viewed as fixed. In fact, if we were to undertake the task again we would do some things differently, such as narrowing the theme areas, restructuring the essay teams, and relying more heavily on referenced documentation.

REFERENCE:

Authored by the Task Force on Building a Science Roadmap for Agriculture. "A Science Roadmap for the Future." National Association of State Universities and Land-Grant Colleges, Experiment Station Committee on Organization and Policy. November 2001.

Appendix 1.

SCIENCE ROADMAPS
by
Robert Galvin

Former Chairman of the Board of Directors for Motorola in Schaumburg, IL.

"Technology roadmaps are gaining acceptance in industry and government laboratories, and now there are signs that the application of roadmapping to the sciences may grow even faster. *A "roadmap" is an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field*. (Italics added) Roadmaps can comprise statements of theories and trends, the formulation of models, identification of linkages among and within sciences, identification of discontinuities and knowledge voids, and interpretation of investigations and experiments. Roadmaps can also include the identification of instruments needed to solve problems, as well as graphs, charts, and showstoppers.

The optimal process for gathering and selecting the content of roadmaps is to include as many practicing professionals as possible in workshops periodically in order to allow all suggestions to be considered and to objectively evaluate the consensuses that will more often than not emerge. Equal treatment should be given to minority views and individual advocacies.

Roadmaps communicate visions, attract resources from business and government, stimulate investigations, and monitor progress. They become the inventory of possibilities for a particular field, thus stimulating earlier, more targeted investigations.

They facilitate more interdisciplinary networking and teamed pursuit. Even "white spaces" can conjure promising investigations. In engineering, the roadmapping process has so positively influenced public and industry officials that their questioning of support for fundamental technology support is muted.

Motorola has prolifically used sophisticated engineering roadmaps to great advantage over several decades. Other corporations such as Intel have also benefited.

In the early 1990s, U.S. semiconductor competitors decided to work together to solve some of the more basic, confounding, but precompetitive, technical barriers whose impact was a concern to our companies over a 15-year time horizon. The solution to many of these problems was likely to be beyond one company's affordability. Most competitors assigned their brightest engineers to meet in common, in committees, and in ad hoc specialist reviews. Over a few weekends, 150 to 175 of them convened to flesh out the broadest agendas. A Roadmap Coordinating Group was formed to oversee the process of determining target values for device and circuit specifications. Technology working group teams were then assigned to flesh out tasks more fully. The result was a 200-page roadmap, now in its third edition. This dynamic document is the basis for assigning various initiatives to certain companies or institutions. Self-forming alliances tackle others. These alliances include Sematech, a consortium specializing in developing the most productive, quality driver manufacturing equipment, and Semiconductor Research Corporation, through which the industry pools funding for advanced research to centers of excellence in university science laboratories.

Roadmaps allow our industry leaders to communicate convincingly with those in government and business regarding their support of our goals. I believe a similar use of roadmaps in the sciences would allow a fresh, positive approach to science to emerge among public officials. Similarly business leaders would have a renewed interest in financially supporting science.

The roadmap process as used by industry reveals that industry is "idea limited." For example, industry roadmaps do not answer questions such as what increments of, or breakthroughs in, the fundamentals of nature can we learn from? This is where science roadmaps can play a key role. Fortunately, examples of science roadmaps are blossoming.

NASA has used roadmaps built on basic themes for years and encourages others to do the same. The leadership of the National Science Foundation encourages experiments with roadmapping in science and engineering, while cautioning that history tells us that the most important discoveries cannot be predicted. The Department of Energy is launching science roadmaps and the Electric Power Research Institute has committed to them as well. The Santa Fe Institute has given its unqualified support to science roadmapping and is preparing a Novel Computational Roadmap to synthesize and guide the research needed now to create the computing technologies needed 15 years hence.

Roadmaps are working now in industry and they are beginning to gain a stronghold in science. Just as engineers first scoffed at them, so will some scientists. But who better than scientists to experiment with an experiment that can strengthen sciences' support and accelerate its generation of knowledge."

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