J. Technol. Manag. Innov. 2007, Volume 2, Issue 2

Journal of Technology Management & Innovation

Received May 17, 2007 / Accepted May 25, 2007

TECHNOLOGY ROADMAPPING FOR COMMERCIALIZING STRATEGIC INNOVATIONS

R. RAY GEHANI
Director, Graduate Programs in Technology Management and Innovation
The University of Akron, College of Business Administration
#358 Management, 259 South Broadway St., Akron, Ohio 44325, USA.
rgehani@uakron.edu; (330) 972-8140

ABSTRACT

In the increasingly globalized world economies, a variety of drivers define the market and regulatory contexts for commercializing the strategic innovations that provide significant competitive advantage in the near-term and long-term future. In this study we examine how technological roadmapping integrates these strategic contextual factors with the organizational capabilities and resources of the firm to commercialize strategic innovations. This is done by first examining four roadmapping case-studies: (1) at Motorola, (2) at Sandia National laboratories, (3) the National and International Roadmaps for Semiconductors, and (3) nanotechnologies. A five stage process is proposed for commercializing strategic innovations. Finally, managerial implications and potential future research are discussed.

Key Words: Technology Roadmapping; commercialization; technology management; innovation; new product; process innovations; globalization

INTRODUCTION

In the past few years, the landscape for market competition has changed rapidly and radically. Markets have become globally connected in the "flat world" (Friedman, 2005). Enterprises In the hyper-competitive global markets must therefore strive to launch their strategic innovations, and strive harder to make their innovations emerge as the dominant designs and technology standards in their industries (Gehani, 1998).

In this study we examine the contexts under which firms commercialize their strategic innovations. These strategic innovations are defined as those innovations which (a) take into consideration the competitive, regulatory and environmental uncertainties of the firm; (b) provide a significant competitive advantage in the near-term and long-term future, and (c) are developed from enterprise-wide cross-disciplinary interactions.

We will first examine the drivers of global markets, the changing organizational capabilities and resources, and the alternate ways strategic innovations can be developed by combing these two domains. We will then describe technological roadmapping, and review four major case studies in different companies and industries. Based on these roadmapping case studies, we will develop a five stage-process to commercialize strategic innovations.

Finally, we will discuss the managerial implications and potential future research.

GLOBAL MARKET DRIVERS

Competitive rivalry between global enterprises has intensified, with customers demanding lower costs, higher quality, demanding delivery times, more value-adding services, and radical innovations. Mergers, takeovers, and collaborations have consolidated market power in the hands of fewer rivals, intensifying their rivalry further.

On November 9, 1989, the Berlin Wall, the symbolic monument to the Soviet communism, fell. This opened new windows to unexplored markets and millions of potential customers in the former Second World. China was inducted into the World Trade Organization in December 2001. Competitors rushed to enter the emerging markets. With diminishing technological barriers, the different parts of the "flat" world are frequently disrupted.

As the end of the millennium got closer, and the year 1999 was about to turn into 2000, the Y2K threatened to disrupt millions of computers around the world. This forced many European and American enterprises to scramble for software service providers in India and elsewhere.

OPERATIONAL CAPABILITIES AND RESOURCE DRIVERS

The globalization of the markets forces enterprises to enlarge, extend, and network into virtual partnerships. With flattening of world markets, innovating enterprises were forced to globalize their operations. China's entry into the World Trade Organization implied that Chinese policy makers would abide by the global trading rules. This reduced the risks of doing business in China. Soon, many global enterprises started transplanting their production facilities and operations to China with lower or non-existent taxes, cheaper labor wages, lower health-care costs, and less regulations. These global enterprises also saw the potential of selling a variety of consumer goods to China's mammoth markets.

Some industries such as automobile and airline industries have local content requirements. These industries must use, integrate and collaborate with suppliers in different parts of the world.

With the bubble-like growth in the IT industry in the 1990s, there was a shortage of skilled IT engineers. The enterprises in Europe and the United States did not have enough skilled engineers and resources to review each line of the software code for every computer. Indian IT companies rescued the world from the Y2K debacle. After the smooth transition to the new millennium, many multinational enterprises were impressed by the capabilities of the Indian IT enterprises developing and delivering complex information systems (often with better quality than what they could develop themselves). Collaborative development of software with Indian software service suppliers grew exponentially. Under-sea fiber optic cable facilitated the globalization of software development.

Innovating people are needed to take advantage of the innovative technologies and innovative business practices. The opening of the new geopolitical markets expanded markets with over 3 billion more potential consumers. This also added another roughly 1.5 billion new workers (Friedman, 2005). Entry of just 10 percent of this working population, or 150 million workers into global operations would be equivalent to doubling the US workforce.

With the slowdown in the American economy and the War on Terror, the financial resources available for innovation have been shrinking. The financial stakeholders have shortened the payback periods. They also demand higher returns from their resource allocations to research and development (R&D), product innovations, and process innovations. The upper management echelons increasingly assert that the technological innovations must be linked to the business strategies and strategic intents of the enterprises.

COMMERCIALIZING STRATEGIC INNOVATIONS

The economic and cultural heterogeneity of global markets require customization of product innovations and process innovations. In some parts of the world markets, labor costs are high and innovations using process automation are preferred. In other parts of the world, lower labor wages motivate use of labor-intensive process innovations (Gehani, 1998).

With higher intensity of rivalry, and higher bargaining power of increasingly demanding and segmented buyers, the product life cycles are shrinking. The increasingly complex product innovations must develop from mind to market in shorter periods of time. Yet, these must increasingly meet customized requirements.

Complimentary innovations boost the growth of each innovation. For example, innovation of paper boosted the innovation of pencils and writing instruments. Opening of the Soviet markets, personal computers, the Internet browser, business process outsourcing to India, and manufacturing outsourcing to China complimented together to accelerate the need to innovate. Friedman (2005) proposed that the global world markets are flattened by the complimentary convergence of "ten flatteners". Technological roadmapping helps recognize and capture such convergence for commercializing innovations.

Introducing technological innovations is not enough to gain competitive advantage in global markets. Productivity improves significantly when these technological innovations are coupled with innovative business practices. Wal-Mart emerged as one of the world's largest enterprises by leveraging the innovations in information technology, and coupling these with their streamlined supply-chain operations.

These different drivers must be synergized for successful commercialization of technological innovation. Overall, in global "flat" markets, enterprises must become more agile innovators. Agility implies that the innovative enterprise can readily adapt its capabilities with market shifts. It can also introduce product and process innovations to respond to evolutions of markets, regulations, enterprises, products, processes, and technologies.

USING ROADMAPPING FOR TURBULENT GLOBAL MARKETS

Roadmapping is about aligning production and operational resources for launching a new product innovation, with the long-term strategic vision and market requirements of the firm. It is the hierarchical integration where the strategic visionaries meet the day-to-day foot soldiers; the upper echelon executives meet the down-under operators. This is when birds flying high learn to swim in the trenches of operations, and the fishes find out how to fly (Northern Ohio Live, 2000).

Technological roadmaps align and build bridges between the scenarios planning for technological forecasting, with the strategic vision of the firm. The roadmapping involves collaborative networking among experts from diverse disciplines'

Robert Galvin (1998) of Motorola defined roadmap as,

"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 the field. 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 interpretations and experiments. Roadmaps can also include the identification of instruments needed to solve problems, as well as graphs, charts, and showstoppers.

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."

KEY BENEFITS OF A TECHNOLOGY ROADMAP

1. It links the strategic vision and intent of an enterprise with its product, process, and technology innovations. Roadmapping can be customized at different levels – product, enterprise, industry, economy, or the world (Phaal et al., 2004).
2. Technology roadmap helps synthesize and integrate the expertise and efforts of a team of experts in the specific field of the technology under study.
3. It helps forecast how an emerging technology will be developed and commercialized, and how it will impact the competitive position of the subject entity over time (Willyard and McLees, 1987).
4. When roadmapping is done for a product technology (Beck et al, 1998), it helps to identify the critical supporting technologies and their key drivers; the technology gaps that must be filled to meet the target product or process objectives; the different pathways to develop the alternate technologies, and the alternate technologies and information needed to make these trade-off decisions.
5. In some cases, roadmapping may recommend a single optimum pathway. In case of a technology facing more uncertainty or risk, multiple paths must be pursued concurrently according to the roadmap.

ROADMAPPING CASE STUDIES

Technology Roadmapping has evolved and become more effective since its introduction and popularization by Motorola in 1987 (Willyard and McLees, 1987). Technology roadmapping has helped industries and firms of different types and sizes, innovate faster and more cost effectively. They achieve a more precise strategic focus with a better cross-functional integration.

In this section we discuss four landmark case studies for technology roadmapping for (a) mobile telephony technology at Motorola, .(b) Sandia National Laboratories, (c) National and International Technology Roadmaps for Semiconductrs, and (d) nanotechnology.

Case Study - A: TECHNOLOGY ROADMAPPING AT MOTOROLA

In 1987, Robert Galvin, CEO of Motorola, provided the highest level commitment to using technology roadmapping at Motorola (Willyard and McLees, 1987). Galvin (1998) declared that the primary purpose of technology roadmaps was to "put in motion today what is necessary in order to have the right technology, process components, and experience in place to meet the future needs for products and services" He shared that over several decades Motorola prolifically used sophisticated engineering roadmaps to gain great competitive advantage. (Richey and Grinnell. 2004)

The early roadmapping at Motorola involved drawing roadmaps on paper, which were taped on conference room walls (Willyard and McLees. 1987). Then, these roadmaps were generated and stored in a common architecture. More recently, with digitization, these roadmaps were streamlined and created based on on-line interviews with associates in different parts of Motorola.

At Motorola, the Chief Technology Officer, the Motorola Innovation Leadership Forum, and senior technology leaders use Enterprise Roadmap Management System (ERMS) to integrate their strategic vision and business strategy with its technological choices.

Gradually, Galvin's strategic vision was infused into Motorola culture by using ERMS (Richey and Grinnell. 2004). ERMS annually shares information gathered globally to represent the 720^0 environment in and around Motorola. ERMS includes a library of a series of internal roadmaps developed from many different experts and departments. There is also a series of external roadmaps developed from information captured from customers, suppliers, and competitors. These external roadmaps with competitive intelligence are posted weekly on a portal for the Motorola associates worldwide to review.

These different internal roadmaps and external roadmaps, in the common ERMS repository, interact together to collaborate across different divisions and sections of Motorola. This helps identify strong alignments and misalignments with the overall strategic intents and technology plans for the product and process innovations for mobile telecommunication technology at Motorola.

Case Study-B: TECHNOLOGY ROADMAPPING AT SANDIA NATIONAL LABS.

Sandia National Laboratories, operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy (under Contract DE-AC04-94AL85000). Sandia played a historic role in developing America's nuclear weapons stockpile, and it is responsible for its safety and security. To do so, Sandia was forced to invest in electronics technology, and therefore Sandia felt the need to develop its technology roadmap. Sandia has developed two other technology planning tools in addition to developing technology roadmapping: knowledge maps, and Prosperity Games (Beck et al., 1999).

Technology roadmapping at Sandia National Laboratories collaboratively identifies process and product targets, obstacles, and the technology alternatives available to reach those desired targets (Beck et al., 1999). This helps track the best strategic pathway to get to the target future state.

One example of Sandia's involvement in industry-level technology product roadmap is the National Electronics Manufacturing Initiative (NEMI) Technology Roadmap (http://www.nemi.org website). This roadmap was developed to define electronics manufacturing technology for semiconductor makers and designers. Sandia helped build roadmaps for electronic interconnection substrates, photonics manufacturing, board assembly, and precision electromechanical assembly (Beck et al., 1999). The board assembly roadmap identified that flexible chip placement capacity per square foot, IC placement accuracy, and IC lead pitch are the critical requirements.

The knowledge landscape for Sandia National Lab's relationship to other government and corporate entities is graphically represented in a knowledge map. This uses a variety of information sets, such as patent or citation databases. With the help of knowledge management and data mining tools, a large array of information is searched, synthesized, and visually represented. Sandia uses VxInsight knowledge visualization tool developed internally (Beck et al., 1999). It provides a graphical interface to display large data set, clustering similar data together, as a 3D virtual landscape. This helps discover relationships between data elements and data sets. Knowledge mapping allows Sandia to decide where to most optimally invest its future R&D resources.

Prosperity Games, high-level interactive simulations, help Sandia make multi-dimensional assessment of strategic, political, social, and ethical issues for alternate product, process, and technology innovations. These games help test and explore the implications of different optional goals and strategies for all the relevant stakeholders for the next 5 years or longer. These are similar to seminar war games. They have a set of rules, multiple players, and strategic objectives. They help test the implications of competition and cooperation (Beck et al., 1999).

Sandia synergizes its technology roadmapping with knowledge mapping and Prosperity Games and provides pre-game and post-game interfaces with technology roadmapping.

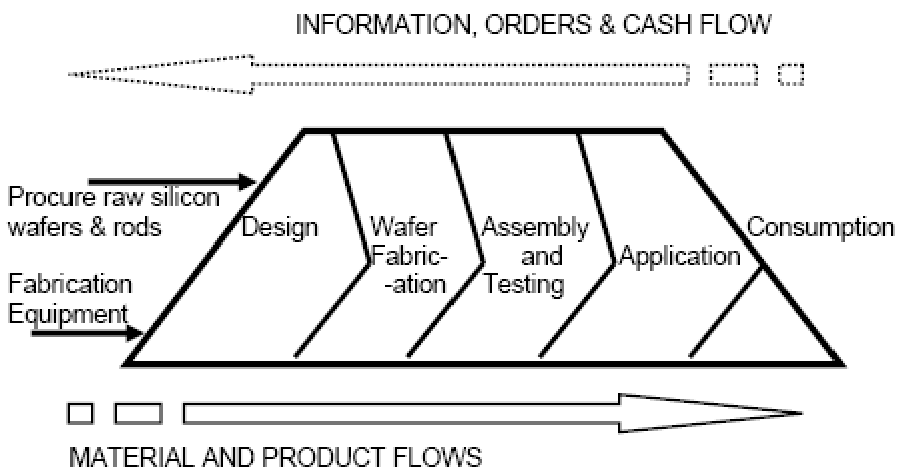
Case Study – C: SEMICONDUCTOR TECHNOLOGY ROADMAP

Since the early 1950s, when the transistor and integrated circuit (IC) chip (with many transistors interconnected) were invented, the rapidly evolving semiconductor technology has radically transformed many different segments of our life. By the early 1970s, Intel had developed a microprocessor by embedding complex solid-state circuits within a chip that provided high performance functionality. Within a short period of time, millions of individual circuits could be populated within one square centimeter. Miniaturization allowed embedding of electronic components into a huge variety of products, appliances, and equipments – transforming each.

The semiconductor products use highly complex circuits – to suit their different applications. Standard semiconductor devices are produced in mass quantities, whereas customized semiconductor devices are produced in smaller lot sizes. Some application specific IC (ASIC) devices have been migrated to mass production (Dicken, 2007).

The material flows and information flows in the production of a semiconductor product are shown in Figure -1. The overall semiconductor production is research- and capital intensive. The upfront design and wafer fabrication stages require highly skilled scientific and engineering talent working in a super-clean environment. Fabrication requires access to large amounts of pure water and disposal facilities for waste and noxious emission fumes. The downstream assembly activities for semiconductors require low-skilled workers, preferably females with nimble fingers, in very different production settings than the upstream activities. This part is, therefore, susceptible to migration from one low-cost outsourcing country to another lower-cost outsourcing country. As the semiconductor products and intermediates have a very high value per unit weight, the relative cost of their transportation across long distances is not that significant (Dicken, 2007).

Figure – 1: The production flow for a semiconductor product



Semiconductor technology based industry, because of the series of technological innovations and organizational transformations, is in a dynamic state of flux. With globalization of semiconductor production plants, the semiconductor industry has also seen huge geographic reconfiguration. The different value-adding capabilities for semiconductor production have been spatially redistributed. Collaborative innovation has emerged as a key strategic driver in this industry.

SEMATECH AND NATIONAL TECHNOLOGY ROADMAP

In 1987, SEMATECH was established by 14 founding firms because recovering the world leadership in semiconductor technology was not possible for any individual US firm (Barron, 1990). These US firms pooled their resources to recover from their Japanese rivals the US market share that was sliding from 85% to 20% in 1993 (SEMATECH, 1992). SEMATECH gradually emerged as an innovative leader and the model for industry wide collaboration (Harrell, 1996).

In 1992, Gordon Moore, the co-founder of Intel, proposed a US-wide effort to develop a technology roadmap for semiconductor technology, and the need of the industry to look 15 years in future (Hack and DeTar, 1994).

The National Technology Roadmap for Semiconductors (NTRS) dealt with eight technology areas: (1) Design and Test; (2) Process Integration, Device, and Structures (PIDS); (3) Environmental Health and Safety; (4) Lithography; (5) Interconnect; (6) Materials and Bulk Processes; (7) Packaging; and (8) Factory Integration. By

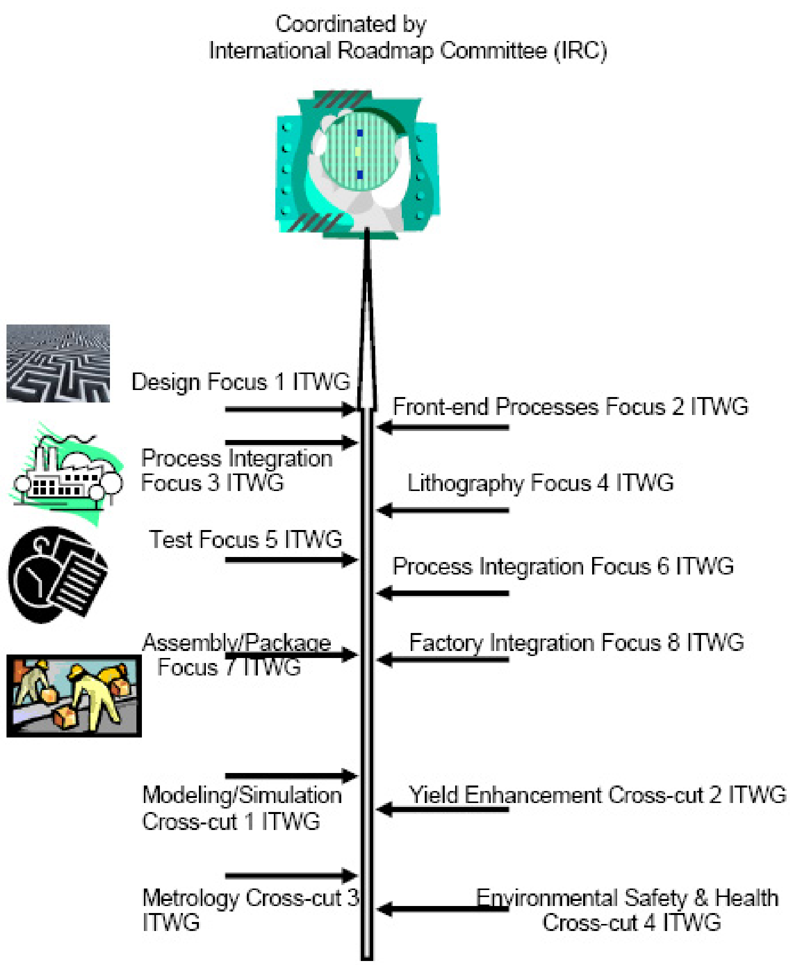
1994, when NTRS was in its second edition, the revenues for global semiconductor products exceeded US$100 billion, with equipment and materials accounting for US$25 billion, and lithography reaching $5 billion (American Electronics Association, 1994).

INTERNATIONAL TECHNOLOGY ROADMAP FOR SEMICONDUCTORS (ITRS)

The nation-wide US National Technology Roadmap evolved in 1998 to an International Technology Roadmap for Semiconductors (ITRS), with Semiconductor Industry Association from the US collaborating with their counterpart associations from Europe, Japan, Korea and Taiwan. ITRS included more than 800 experts, with representatives from other stakeholders such as semiconductors manufacturing and testing equipments manufacturers, materials suppliers, research institutions and their international consortia, and more.

An International Roadmap Committee (IRC) coordinates eight International Technical Working Groups (ITWG), each focusing on one key component of semiconductor technology, with four crosscut ITWGs (See Figure -2). The eight ITWGs focus on: (1) design; (2) test; (3) front-end processes; (4) interconnect; (5) lithography; (6) process integration; (7) assembly and packaging; and (8) factory integration. The four crosscut ITWGs work on (1) modeling and simulation; (2) metrology; (3) yield enhancement; and (4) environment safety & health issues.

Figure – 2: 12 International Technical Working Groups (ITWGs) for International Semiconductor Technology Roadmap (ISTR)



Source: Adapted from Arden (2002).

The overall ITRS mission was to define the near-term and long-term technology requirements for the global semiconductor industry, and describe the potential technical solutions to meet these needs. The ITRS was chartered to be edited every odd number year, with updates of the tables to be issued in the even numbered years.

In the ITRS definition phase, a hierarchy of requirements was established for the integrated circuits (see Table-1). First the power, cost, speed, and density requirements for ICs are established (Arden, 2002). Then the overall device requirements, such as transistor size, threshold voltage requirement, leakage and drive currents and supply voltage are established. This is followed by the device scaling and design requirements, including gate length and dielectric, junction depth, and channel engineering properties. Finally, the process integration requirements are developed, specifying overall process flow, thermal budget, and material properties.

Table – 1: ISTR Requirements and Choices Hierarchy for Integrated Circuits

1.Overall Chip Circuit Requirements and choices	Density, Speed, Cost, Power etc.
2.Overall Device Requirements and choices	Transistor size, Drive current, Leakage, etc.
3.Device scaling and design, Potential Solutions	Channel engineering, New structures, High K gate architecture etc.
4.Process Integration	Reliability, Material properties, Process Flow, Thermal Processing, Boron Penetration etc.

Based on intense interactions and collaborations between the different Technical Working Groups, the overall technology characteristics are established and projected for the next 15 years. As an illustration see Table-2 from the ITRS 2001. This Table defines the half-pitch values for Dynamic Random Access Memories (DRAMs) and Micro Processing Units (MPUs), and gate lengths for MPUs and ASICs. The DRAM features followed a 3-year cycle, using a scaling factor of 0.3 every three years. Until 2004, the feature size scaling for MPUs followed a 2-year cycle, and then it returned to a 3-year cycle. For MPU gate lengths, 2-year cycles were used until 2005, and then a 3-year cycle. ASIC geometries lag MPUs by two years, to facilitate better control of system power consumption and device leakage currents (Arden, 2002).

Table - 2: Product Generations and Chip Size Model Technology Nodes in ITRS for 15 Years

Production Year:		Near Term Years 2001	2003	2005	2007	Long-Term Years 2010	2013	2016
DRAM½ pitch	nm	130	100	80	65	45	32	22
MPU/ASIC ½ pitch	nm	150	107	80	65	45	32	22
MPU Printed Gate length	nm	90	65	45	35	25	18	13
MPU Physical Gate length	nm	65	45	32	25	18	13	9
ASIC/Low Power Printed Gate Length	nm	130	90	65	45	32	22	16
ASIC/Low Power Physical Gate Length	nm	90	65	45	32	22	16	11

Notes: DRAM: Dynamic Random Access Memory; MPU: Micro-Processor Unit.

Subsequent editions of ITRS noted the need for new technology generations, with exponentially increasing requirement for packing density and device speed at significantly decreasing cost per function (Arden, 2006). The packing density has been doubling every three years, and microprocessor performance has been doubling every 2-3 years. Cost per function has been decreasing by 29% per year. In the former years, 30% scaling factor in 3 year cycle was used, speeding to 2-year cycle after 1998. For future projections, ITRS was considering the implications of using both the 2-year cycle and the 3-year cycle. Whereas DRAMs are driving for the minimum feature sizes, the microprocessors are requiring higher device performance and very short gate lengths (Arden, 2006).

Case study – D: NANOTECHNOLOGY ROADMAP

The recent innovations in nanomaterial technology are radically transforming a number of different industries, just like the way semiconductor technology transformed many industries in the 1970s and 1980s (Hood, 2004). Nanomaterials have at least one dimension of nano or 10^{-9} meters (or about 10 atom long). These materials behave according to the Einsteinonian quantum mechanics rather than according to the Newtonian mechanics. Compared to conventional materials, nanomaterials have a large proportion of surface atoms and high surface area where reactive activity takes place. This gives the nano products, depending on the specific nano particles involved, extraordinary characteristics, such as mechanical strength, optical sensitivity, magnetism, reactivity, conductivity, and much more properties commonly not seen in the Newtonian materials.

The National Nanotechnology Initiative (NNI), is a US consortium of 19 federal agencies including the National Science Foundation (NSF), the National Institute for Health (NIH), the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), and others. It overseas and funds close to US$1 billion on widespread efforts to develop nanotechnology in the US. NNI estimates that Nanotechnology based industry in 2015 (or sooner) would be worth more than US$1 trillion, and a significant part of the world economy (Chemical Industry Vision 2020; Hood, 2004). This consortium meets monthly to exchange knowledge, identify goals and research gaps, and coordinate efforts.

The NIH Roadmap for Medical Research, that guides speedy development and commercialization of new technologies and knowledge for diagnostics, treatment, and prevention of diseases, contains a significant nanomedicine initiative. This started in September 2005 with the development of a few multidisciplinary Nanomedicine Development Centers to develop and commercialize Nanotechnologies in less than 10 years. NIN projected that by 2015 about 50% of all drug discovery and delivery technology would be based on Nanotechnology (Hood, 2004).

In June 2004, NNI coordinated leaders of Nanotechnology in 25 countries into The International Dialog on Responsible Research and Development of Nanotechnology. Their objective was to develop a global vision of developing and commercializing nanotechnology appropriately. This group proposed the establishment of a preparatory ongoing international organization dedicated to global coordination, responsible research and development, and commercialization of nanotechnology (Hood, 2004).

ROADMAPPING AND COMMERCIALIZING TECHNOLOGICAL INNOVATION

In this section, we illustrate the benefits of using roadmapping for commercializing technology innovations.

Consider Niagara Nanopolymer (a composite of real companies) investing $120 million and seven years for developing an innovative silicon-based *Nanotoughner* additive product to reinforce synthetic elastomers. This product innovation has potential for multiple market applications in tires and engineering belts. This new product was likely to revolutionize the industry by replacing carbon black as a reinforcement in tires.

The strategic leaders at Niagara Nanopolymer were intensely aware of their rapidly emerging rivals in China and Japan, ready to imitate or pirate its technological advantage by reverse-engineering Nanotoughner. These strategic leaders, therefore, focused their enormous time, efforts, and financial resources to build a strong intellectual property fence by patenting the product and trade-marking its brands. The product launch was highly successful and a large number of potential tire manufacturers rapidly accepted the new product, demanding for large quantities of deliveries.

In their rush to develop Nanotoughner, and to protect its intellectual property, the strategic leaders at Niagara Nanopolymer did not find it necessary to roadmap their nanotechnology. They failed to allocate adequate resources to develop the production process innovations with higher yield. To rush to market, the Nanotoughner product innovation was developed at the expense of developing appropriate process innovations with higher productivity yields. As the purchase orders started pouring in, Niagara Nanopolymer was forced to invest large capital investments on its inefficient production process with low yield. Their cash flow suffered, and Niagara Nanopolymer was heading rapidly towards bankruptcy.

Niagara Nanopolymer had a long-time Japanese rival in Nippon Nanopolymer. While Niagara Nanopolymer was developing its Nanotoughner, Nippon Nanopolymer was known to be developing a competing Nanoflex product innovation. The strategic leaders at Nippon Nanopolymer believed in using technology roadmapping process. They closely coordinated their product innovations, production process innovations, quality promise innovations, and other related value-adding capabilities (Gehani, 1998). While developing its innovative product Nanoflex, the strategic leaders at Nippon Nanopolymer allocated adequate capital resources to innovate and improve yield of the production process for Nanoflex. At the same time, the strategic leaders at Nippon Nanopolymer also started collaborating with their suppliers so that they were able to supply the most economical raw materials, and were able to scale up rapidly to the high volumes their customers needed.

As the global market demand grew for Nanotoughner and Nanoflex, Niagara Nanopolymer was unable to ramp-up but Nippon Nanopolymer was able to scale up its production process rapidly, and penetrate the global markets with fast diffusion of Nanoflex.

This case study clearly indicates the strategic significance that technology roadmapping can make for commercializing product, process, and technology innovations. In the next section, we briefly discuss the five-stage technology roadmapping process.

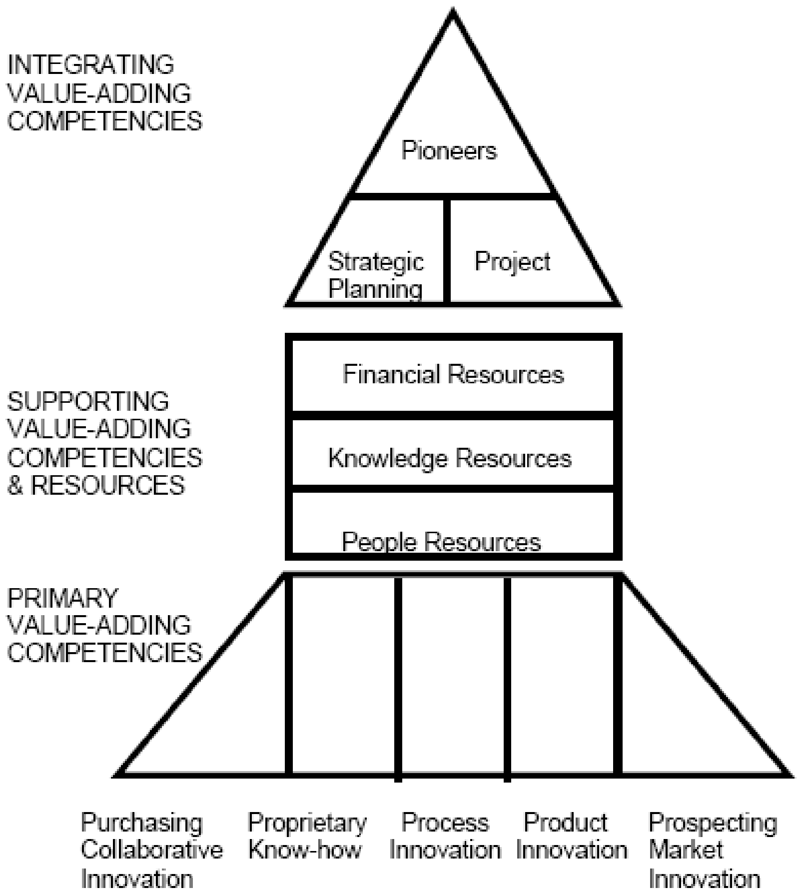
TECHNOLOGY ROADMAPPING PROCESS

In this section we review how an innovative enterprise can effectively align and integrate its strategic vision and intent with its organizational capabilities and resources, and commercialize its strategic innovations to gain sustainable competitive advantage.

VALUE-ADDING CAPABILITIES

Technology-intensive enterprises can innovate by networking their value-adding capabilities clustered in three layers: primary transformational, supporting secondary, and tertiary value integrating capabilities (Gehani, 1998). The primary value-adding capabilities deal with the primary business of the enterprise, transforming its lower value raw materials into higher value finished goods. The supporting value-adding capabilities appropriately allocate the people and their skills, knowledge and information, and financial resources raised internally or acquired from outside. And, finally, the tertiary value-adding capabilities involve integrating primary and secondary value-adding capabilities listed earlier, and develop the strategic intent or vision of the firm. This alignment can be often done in a variety of ways discussed next.

Figure – 3: Value-Adding Net (VAN) of Competencies for Strategic Innovation



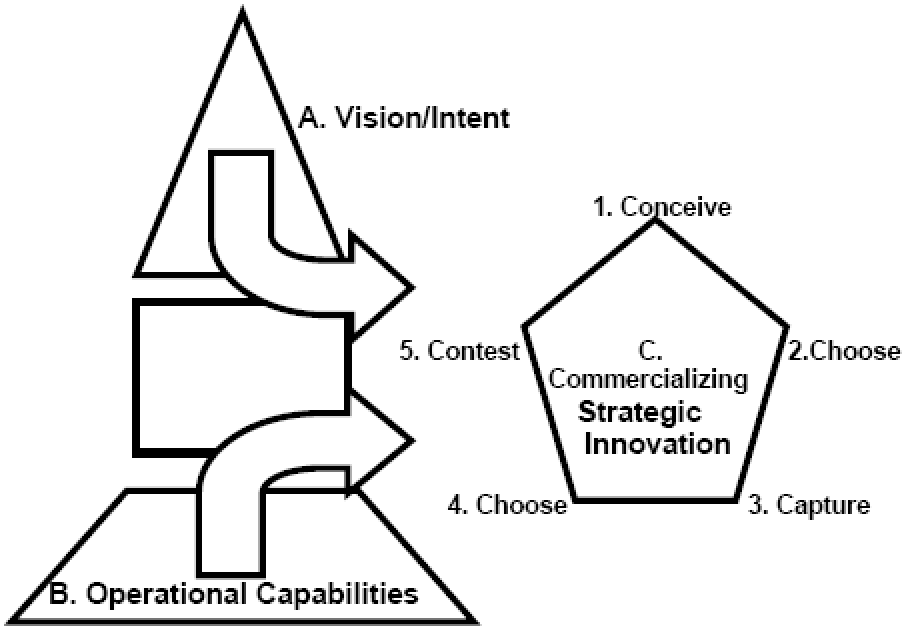
Source: Adapted from Gehani, R. Ray. 1998. Management of Technology and Operations, New York: John Wiley & Sons.

According to the top-down planning paradigm, the process begins with an organization's vision and strategic intent – usually conceived by the strategic leaders in the upper echelons (Gehani, 1994. QP). The strategic alternatives are then implemented through operational capabilities to achieve above market-average returns. One might expect that such an organized and controlled top-down approach to innovating would consistently produce a series of superior innovations. Empirical research studies in strategic management (Bresser and Bishop, 1983), however, do not provide conclusive evidence that strategic planning consistently produces superior corporate performance. The top-down strategic planners are often obsessed primarily with financial resources and profit performance. This is generally done at the expense of neglecting other key resources, such as the human capital and their creativity.

In a fast-shifting "Flat" world market, the assumptions needed for top-down strategic planning are frequently disrupted. Bhide (1986) proposed that successful innovative enterprises do not pursue strategic planning, but develop hustle as a strategy, characterized by action-oriented fast decisions with a focus on operating details. Hayes (1985) suggested that for fast-shifting dynamic markets, the enterprises must first carefully assess the available resources and capabilities to determine the domain of feasible actions and the bottom-up strategies that they can afford.

For the fast-shifting "flat" global markets, the best features of the two alternate approaches, visionary top-down planned innovation and the bottom-up resource based strategic innovations, can be fused together to commercialize the strategic innovations in the most effective and efficient way (Gehani, 1994, QP). This process shown in Figure –2, can be done in five stages.

Figure - 4 Integrating Strategic Intent and Operations for Strategic Innovation



Stage - 1. Conceive a strategic intent or vision for future technological innovations.

Monitor the drivers of the market environment, such as flattening of the world and globalization of former closed markets. Consider the fragmenting customer preferences and shortening of product life cycles (including other drivers discussed in the earlier section). Before choosing strategic intent or vision, audit the internal capabilities and resources to identify the emerging technological innovations that might drive global competition in the near-term and the long-term. Consider how product innovations are becoming increasingly complex, and the product life cycles are shrinking.

Stage - 2. Capture the available technologies and capabilities in-house and choose those needed technologies not available in-house that you have resources to acquire.

Many technological capabilities may be scattered in the "attics" and the "basements" of the innovative enterprise. A careful audit of the available portfolio of product, process, and technological innovations may identify some strategic gaps that must be filled. Beware of the Not-Invented-Here (NIH) syndrome and the pitfalls of underestimating the potential utility of product, process, and technology innovations developed elsewhere. Collaborate with carefully selected partners to share the risk of developing technologies for complex products.

Stage - 3. Choose from the alternate strategic innovations.

Before selecting the strategic innovations that an enterprise proposes to pursue in the future, it must carefully assemble the key criteria for choosing the desirability and feasibility of the selected strategic innovations. Many US enterprises are impatient in seeking out as high profitability from their "star" and "question-mark" product and process innovations as they have been extracting from their "cash-cow" businesses (Gehani, 1998). Japanese rivals, on the other hand, value market penetration and market share more than profit margins. Whereas incremental improvements reduce the risks, these also offer lower barriers to new entrants, and thereby lower the potential profit margins.

Stage - 4. Commercialize the selected strategic innovations.

Strategic innovations are embedded into new products that customers value, high yielding productive processes, and/or innovative platforms of technologies that disrupt or create new segments of sustainable opportunities. Commercialization must take into account the diffusion time it takes from getting early adopters to a rampant growth (Gehani, 1998). Rate of potential returns invariably correlates with the extent of risk a firm is willing to take in commercializing its incremental or radical innovations.

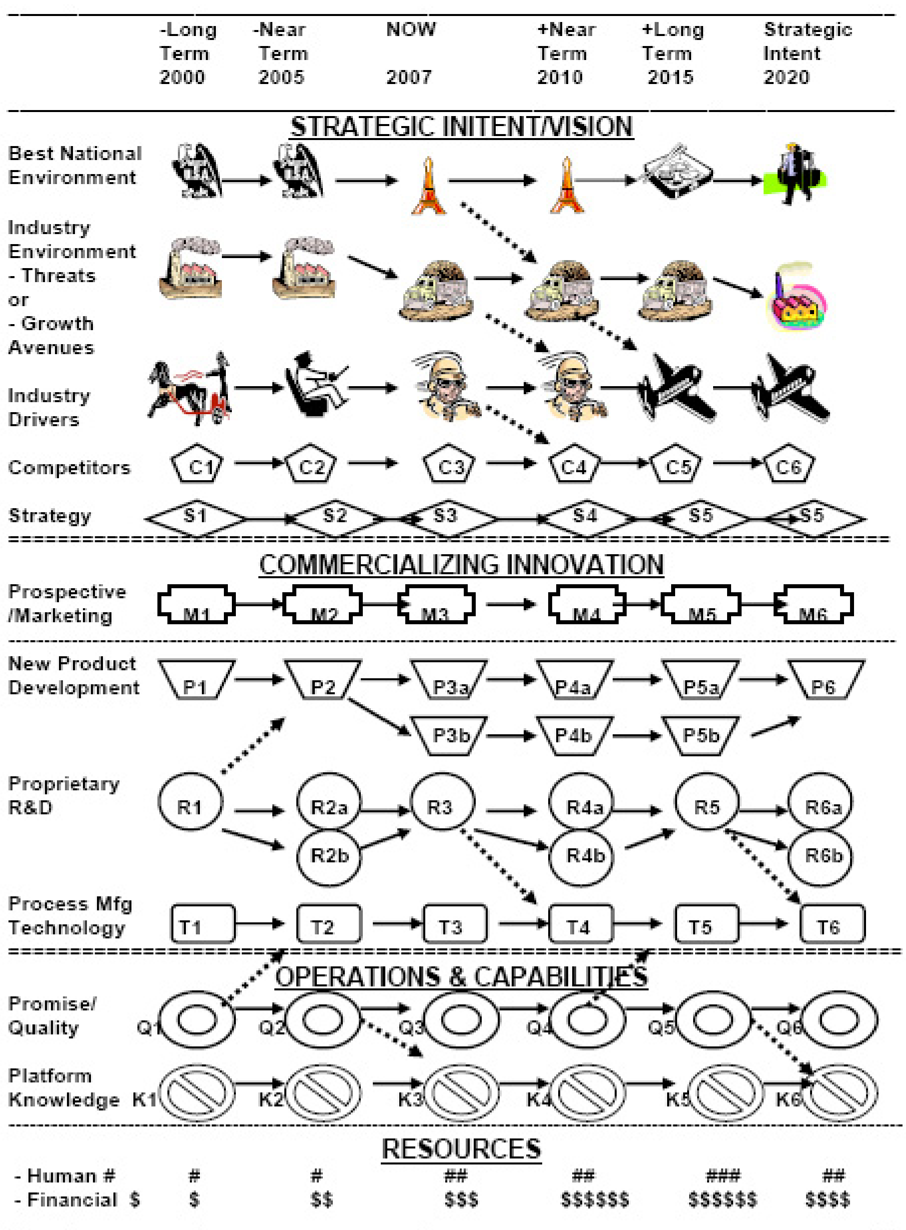
5. Contest the intellectual property in your strategic innovations.

The process of strategic innovation does not end with commercializing new products and/or platforms of innovative process technologies. If the intellectual property thus created and embedded in products and processes is left inappropriately protected, it is likely to be appropriated by rivals or pirates.

Innovative companies integrate their strategic business plans with their technology roadmaps. The technology roadmap identifies how the relevant product, process, and technological innovations would meet over time the business objectives according to its strategic vision/intent (see Table –3 for the composition of a comprehensive technology roadmap). This is a living document that must be re-clarified, altered, and updated from time to time.

ISSN: 0718-2724. (http://www.jotmi.org)

Table – 3: Technology Roadmap Composition



Stage-1 of the technology roadmapping process helps develop the uppermost layer of the Technology Roadmap. A careful assessment of the different national environments would help identify the most appropriate macro-economic national environment for your technological innovations. This may have been the USA in the past, but it may switch to France or Japan in the near-term future, and China in the long-term future. In a similar manner, the micro-industry environment may switch from adverse now to favorable in the distant future. The market drivers in this industry may have been slow in the past, but with complimentary innovations, these may have gradually galloped to a jet-age pace of change. Similar changes are recorded for competition and business strategies (See Table-3).

Stage-2 of the process provides information for the bottom-layer of operational capabilities and resources.

Note down how the quality expectations are shifting, and how the knowledge platform will grow over time.

Stage-3 and stage-4 help develop the middle layer in your technology roadmap. This layer takes into account that the product innovations are expected to become more complex, while their life cycles would steadily shrink. The production process innovations may become exceedingly expensive over the years, as in the case of semiconductor fabrication plants. Finally, stage-5 helps maintain the competitiveness of the firm by protecting and contesting the intellectual property created with product, process, and technology innovations.

MANAGERIAL IMPLICATIONS AND FUTURE RESEARCH

Technology Roadmapping has found many supporters, considering the widespread and multi-year participation of more than 800 experts in the International Technology Roadmap for Semiconductors (ITRS) since its start in 1998. The strategic leaders at Motorola continue to be committed to their use of Technology Roadmapping for mobile telecommunication technology. National Nanotechnology Initiative (NNI) is helping a large number of policy makers and innovative entrepreneurs to make sense from this emerging technology.

Planning technology may be straight-forward in those technologies where an enterprise has a long history of well-established capabilities and knowledge expertise. Such an enterprise is well-prepared for their customers' current and potential future needs. Their competitors' current and potential future threats are clear and well understood. On the other hand, in the case of fast-changing and frequently disrupting technologies it is much harder to assess the current status of an enterprise, relative to its rivals, with respect to the strategic technologies. It is also harder to pinpoint where it needs to be in future and how it will get there, and by when.

Whereas, successive iterations of ITRS have upgraded and revised their assumptions from one edition to the next, some semiconductor experts have questioned the basis for such assumptions (Braun, 2003). Some companies accelerated the speed at which they introduced new technology nodes, from a 3-year cycle to a 2-year cycle in the late 1990s. The 2005 ITRS removed the assumption of technology node as the main pace setter for the IC industry (Singer, 2006). Braun (2003) proposed that it was time to develop a more comprehensive systems roadmap.

Dr. George M. C. Fisher (1991), President and CEO of Motorola in the late 1980s, suggested that the United States must develop a roadmap to technological leadership. Fisher urged that,

> "*…this roadmap should include a national intent to be the world's leader in developing and commercializing technologies that improve our standard of living, quality of life, international competitiveness, and national security. It should also include national strategy to ensure that resources are available and committed to this effort.*"

Finally, the case studies of four different technology roadmaps discussed here, indicate that usually the upper strategic part of a technology roadmaps is paid much less attention than its lower operational capabilities part. More research is recommended to better integrate the strategic drivers in future technology roadmaps.

REFERENCES:

American Electronics Association, 1994. *World Economic Outlook*

Arden, W. M. 2002. The International Technology Roadmap for Semiconductors – Perspectives and challenges for the next 15 years. *Current Opinion in Solid State and Materials Science*, 6, pp. 371-377.

Arden, W. 2006. Future semiconductor material requirements and innovations as projected in the ITRS 2005 roadmap. *Materials Science and Engineering B*, 134, pp. 104-108.

Barron, J. J. 1990. Consortia: High-tech co-ops. *Byte*, 15 (June), p. 269.

Beck, D.F., Boyack, K.W., and Siemens, W.D. 1999. *Bringing the Fuzzy Front End into Focus*. Sandia National Lab. Document SAND99-0532J.

Bhide, A. 1986. Hustle as strategy, *Harvard Business Review*, September-October, pp. 59-65.

Braun, A. 2003. Time for a systems roadmap? *Semiconductor International*, April, p. 17.

Bresser, R. K. and Bishop, 1983. Dysfunctional effect of formal planning. *Academy of Management Review*. 8, pp. 588-599.

Chemical Industry Vision 2020 Technology Partnership, http://www.chemicaldivision2020.org/pdfs/nano-roadmap.pdf

Dicken, P. 2007. *Global Shifts: Mapping the Changing Contours of the World Economy*. 5th edition. New York: Guilford Press.

Fisher, G. M. C. 1991. American companies can compete anywhere. *Machine Design*, June 17, p. 160.

Friedman, T. 2005. *The World is Flat: A Brief-History of the Twenty-First Century*. New York: Farrar, Straus, Giraux.

Galvin, R. R. 1998. Science Roadmaps. *Science*, May 8, p. 803. American Association for the Advancement of Sciences.

Gehani, R. R. 1992. Concurrent Product Development for Fast-Track Corporation, *Long Range Planning*, December, pp. 40-46.

Gehani, R. R. 1994. The Tortoise versus The Hare. *Quality Progress*, May, p. 99-103.

Gehani, R. R. 1998. *Management of Technology and Operations*. New York: John Wiley & Sons.

Hack, D. and DeTar, J. 1994. SEMATECH vows future fiscal Independence, *Electronic News*, 40, Oct. 10, p. 2035.

Harrell, S. 1996. The National Technology Roadmap for semiconductors and SEMATECH future directions. *Microelectronics Engineering*, 30, pp. 11-15.

Hayes, R. 1985. Strategic Planning – Forward in Reverse? *Harvard Business Review*, November-December, pp. 111-119.

Hood, E. 2004. Nanotechnology: Looking as we leap. *Environmental Health Perspectives*, 112(13, Sep.), pp. A740-749.

Northern Ohio Live, 2000. 20 in 2000. January, pp. 10-19.

Phaal, R., Farrukh, C. and Probert, D. 2004. Customizing Roadmapping. *Research Technology Management*, March-April, pp. 26-37.

Richey, J. M. and Grinnell, M. 2004. Evolution of Roadmapping at Motorola. *Research Technology Management*, March-April, pp. 37-41.

SEMATECH, 1992, Annual Report, Austin, TX: USA.

Singer, P. 2006. No more technology nodes in new ITRS. *Semiconductor International*, January, pp. 13-14.

Willyard, C. and McClees, C. 1987. Motorola's technology roadmap process. *Research – Technology Management*, 30 (5, Sep-Oct), pp. 13-19.