Information Accelerated Radical Innovation From Principles to an Operational Methodology

John P. Dismukes
Chemical and Environmental Engineering Department
Manufacturing Value Chain Innovation Center
The University of Toledo
Toledo, Ohio 43606

ABSTRACT

Recognition since the mid 20th Century that scientific technology is the key driver of economic development and job growth, has sparked increasing collaboration of government, industry and academia in commercial areas outside the historical focus areas of defense, public health and transportation. Notwithstanding, theories and tools to anticipate innovation with certainty are limited primarily to those instances of incremental innovation, for which historical project analysis provides a sound basis for planning. The capability for real time computation and telecommunication makes rapid development and commercialization of breakthrough innovations imperative for competitive success in the globally connected 21st Century environment.

This paper assesses the course of technology from its empirical base in antiquity through the initial scientific technology stage of the 19th and 20th Centuries, to the 21st Century environment governed increasingly by technologies of thinking. It examines the need for and benefits from a new information technology enabled paradigm of Accelerated Radical Innovation (ARI). By combining advanced information and telecommunications technology tools and innovation management techniques in a real-time decision-making environment, the ARI paradigm has the potential to overcome technological, organizational and societal challenges and hurdles, thereby achieving a factor of 10X improvement in radical innovation effectiveness.

Further development of this proposed new paradigm is envisioned through a collaborative multi-university program of research and teaching, in collaboration with selected industrial partners to identify methodology variants appropriate for diverse companies and industries. Successful implementation will contribute significantly to the proposed activities required for a 21st Century innovation ecology, envisioned by the National Innovation Initiative report, “Innovate America”.

Key Words:
Accelerated Radical Innovation, Paradigm, Challenges, Hurdles, Information Technology

Background and Introduction

From antiquity tacit knowledge and empirical discovery provided the basis for major technology advances, and subsequent incremental improvements associated with the maturing of these technologies and their geographical and temporal propagation (Merrifield 1999). The 19th Century marked the boundary between the ancient world and the modern world (Betz 2003) characterized increasingly by the disciplinary influence of science and the research university in defining the underlying principles for a rapidly growing science and technology infrastructure that enables technological innovation based on ***scientific technology***. The rise of large industrial organizations in the late 19th Century played a significant role through the formation of major, central research and development laboratories seeking competitive advantage based on proprietary technology (Fusfeld 1994). During the 20th Century the size and scope of industrial research grew both geographically and virtually due to the increasing capability of transportation, communication and computing technologies (Gerybadze 1999).

Recognition since the mid 20th Century that technology is the key driver of innovation (Schumpeter 1939, Mensch 1982), has stimulated multidisciplinary management of technology (MOT) research dedicated to better understanding and improving industrial innovation through collaborative industry-university-government initiatives (Kelly 1978). National Research Council workshops (NRC 1987, NRC 1991) have further stimulated systematic study of the innovation process leading to the recognition of many diverse individual and organizational roles important for success (Fusfeld 1994, Roberts 1987 and 1988, von Hippel 1986 and 1988). Nevertheless, the complexities inherent to innovation have hindered the development of qualitative and quantitative models for forecasting and prediction (Age 1995). High performance execution of innovation projects to plan are limited to incremental innovation projects for which documented, historical procedures provide a basis for repeated success (Senhar 1995). Due to the unavailability of a sound, general theory for improving radical innovation effectiveness, practical guidelines for breakthrough innovation are still based primarily on historical best practices from case study research (Leifer 2000 and 2001, O'Connor 2001 and 2005, Christensen 1995).

Recently a consensus has emerged (NII 2004) that a more rapid and effective approach to radical innovation is needed for future industrial and societal competitiveness. Existing innovation strategies for cost reduction and continuous improvement over the past 25 years are inadequate, and may prove counterproductive in creating the high growth rate industries and sustained economic development and job creation required for success in the globally connected 21st Century world.

In May 2004, a group of fifty leading scholars and industrial practitioners of radical innovation from around the world (Dismukes 2004, Bers 2004) established the vision for a dramatically improved, global, accelerated radical innovation methodology that could significantly improve the arduous, meandering, often decades-long process of radical innovation, thereby achieving a factor of 2X-10X improvement in innovation effectiveness, as measured by reduced risk, reduced time and reduced cost. To realize this vision, they proposed a mission to develop sound theory and validate practical open-innovation approaches (Chesbrough 2003) that would integrate academic and business innovation professionals and knowledge workers in a collaborative environment enhanced by computer science and telecommunication tools.

In today's geographically and virtually connected society, the widespread availability of education and knowledge, and access to exponentially increasing power of information technology for real time interaction makes possible the development of a practical breakthrough innovation process with a sound theoretical basis. This paper briefly reviews the course of technology revolutions, assesses the structure and practice of incremental and radical innovation, and further develops the vision and mission recently proposed (Dismukes 2004; Bers 2004) for the new paradigm of Accelerated Radical Innovation (ARI). The result is a strategic roadmap and plan for its implementation through iterative university-industry collaboration funded by government and foundations, to validate and teach the methodology.

Current Status and Future Directions of Technological Innovation

The Phenomenon of Industrial or Technology Revolutions

From antiquity technology has played an important role in innovations that determined the economic status of individuals and societies, and their geographical and temporal propagation. Various eras are often historically linked to specific technologies that played a key role at that time and place (Merrifield 1999). Hence the stone age, copper age, bronze age and iron age, for example, are associated with technologies based on tacit knowledge and empirical discovery, before the advent of modern science. The impact of technology on individuals and society changed irreversibly (Betz 2003) from the ancient world to the modern world based on the rise and adoption of the paradigm of ***scientific technology*** in the late 1700's. This new paradigm emphasizes the rationality of nature and the possibility for human beings to successfully investigate, understand and develop technological applications based on the scientific laws and principles governing the physical world, e.g. chemistry, physics, biology, and the various engineering disciplines.

The industrial revolution model (Perez 2002) views technological and economic growth over the last 230 years in the empirical context of five technology revolutions (Table 1) each of approximately 50-60 years duration. Perez associates each revolution with a specific period or age, a core geographical region of origin, a nominal "big bang" or launch event, and a time of maturity of the core technologies. Each technological revolution comprises sequential, experimentally measured periods of discovery and commercialization, followed by diffusion and eventual maturation of the technologies. Although the basis is empirical, not theoretical, the rate of historical growth and diffusion of particular technology applications can be mathematically retrofit (Hirooka 2003) to substitution type plots (Fischer 1971) based on demographic saturation of end application usage.

A significant and as yet unexplained feature of this model, warranting further research, is that even though scientific knowledge and the number of worldwide scientific investigators has been exponentially increasing, the nominal duration of these innovation cycles appears to have remained approximately constant at 50-60 years.

Theory and Practice of Technological Innovation in the 20th Century

Prior to 1930 the influence of technology on innovation and economic growth was largely ignored, in favor of classical economic theory in which technological change is viewed outside the scope of economics, and prices of products and services move to reach an equilibrium equating supply and demand required by Adam Smith's theory of the "invisible hand". The published work of the early pioneers in this field (Kondratiev 1926, Schumpeter 1939) provided clear evidence that new technology exerts a "creative destruction" effect, whereby new products, processes and markets are created and existing ones become mature or obsolete. Technology is thus a powerful and often dominant driver of economic growth, even more significant than labor and capital. Indeed, studies by the National Science Foundation have confirmed that technology contributed approximately 50% of economic growth in the United States over the last 50 years of the 20th Century.

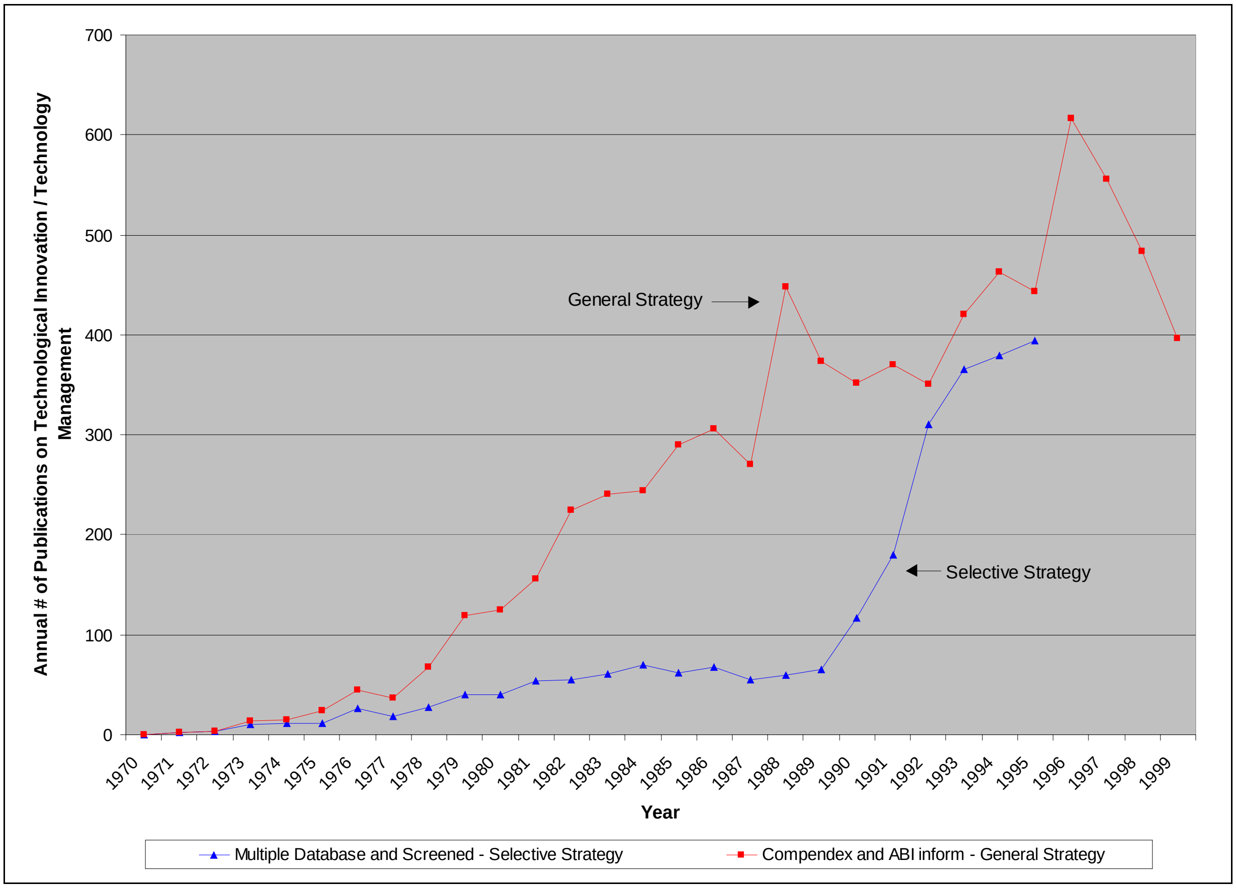
Published research studies of the innovation process began in the 1950s with investigation of the phenomenon of spatial and temporal technology and product diffusion (Rogers 1962, Grubler 1997, Baptista 2001). Progressively, physical and

Table 1. Summary of Scientific Technology Revolutions Since the Late 1700s, Representing Each as a Constant 50-60 Year Cycle

Scientific Technology Revolution	Period or Age	Core Region of Launch	Big Bang Event (feasibility)	Launch	Maturity (approximate)
1st	Industrial Revolution	Britain	Arkwight Textile Mill	1771	1829
2nd	Steam and Railways	Britain (Europe & USA)	Rocket Steam Engine	1829	1873
3rd	Steel, Electricity, Heavy Engineering	USA & Germany (Britain)	Bessemer Steel Plant	1875	1918
4th	Oil, Automobile, Mass Production	USA (Germany & Europe)	1st Ford Model T	1908	1974
5th (Perez (2002) Hirooka (2003)	Information, Telecommunications, Biotechnology, Nanotechnology	USA (Europe & Asia)	1st Intel Microprocessor	1971	2045

social scientists and business professionals took up the study of innovation, with initial focus on identifying the important factors influencing the success of technological innovation (Kelly 1978, Myers 1976). Recognition of the competitive threat to US manufacturing by the Japanese during 1970s also stimulated increased study of the innovation process, as reflected by the exponential increase in the number of papers on innovation, Figure 1, appearing in peer reviewed journals between 1970 and 2000. During this period two industry-university-government workshops sponsored by the National Research Council (NRC 1987, NRC 1991) recommended launching new multidisciplinary Management of Technology (MOT) programs within universities. The following are representative of the many published studies assessing diverse individual, organizational, geographical and societal factors important for initiation, propagation and renewal of innovation (Abernathy, 1974 and 1977, Carlsson 2002, Chesbrough, 2003, Collins, 1994 and 2001, Drucker 1993 and 1999 and 2002, Eidt 1995, Kocaoglu 1994, Kodama 1995, Leifer 2000 and 2001, Mansfield 1968, McElvey 1985, Moore 1999 and 2002, Porter 1990, Roberts 1987 and 1988, Rouse 1992, Smits 2002, Utterback 1974 and 1993, and von Hippel 1986 and 1988).

Figure 1. Exponential Increase from 1970-2000 of Published Papers Dealing with the Technological Innovation Process



As a result of these studies it also has become clear that interactive engineering-business-social science approaches to technological innovation are required for development of a robust theory and model of innovation (Aje 1995).

Observed Innovation Patterns Based on Incremental and Radical Innovation

Literature studies have proposed classification of innovations in a number of types, including basic, radical, disruptive, discontinuous, next generation, incremental, imitative, new to the company, new to the world, and others (Mueser 1985, Shenhar 1995, Garcia and Calantone 2002, Betz 2003). Due to the complexity of the phenomenon, no universally accepted typology exists. For simplification and clarity of focus, in this paper innovations are classified fundamentally in two categories, as either ***incremental*** (continuous) or ***radical*** (discontinuous), with additional descriptors providing insight into the nuances of the innovation process as indicated in Table 2. An incremental innovation represents a relatively small and

Table 2. Innovation Categories Based on Level of Innovation Uncertainty Combined With Other Differentiating Innovation Characteristics

Differentiating Innovation Characteristics	Incremental Innovation		Radical Innovation	
	Low-Tech	Medium-Tech	High-Tech	Super-High-Tech
Technology	No new technology	Some new technology	Integration of new, existing technology	Development and integration of new technology and system
Scope of Product or Service	Existing material, component, subsystem, system, array	Some newness of scope	Major newness of scope	Broad newness of scope
Time (months, years, decades)	Months, estimated with high accuracy	Months to several years, estimated with fair accuracy	Several to many years, estimated with uncertainty	Many years to decades, estimated with extreme uncertainty due to numerous re-do loops
Company or Organization Size	Small, medium or large	Small, medium or large	Venture, small, medium, large	Venture, small, medium, large
Industry	Various product, process, and service providers	Various product, process, and service providers	Various product, process, and service providers	Various product, process, and service providers
Supply Chain or Value Chain	Regional, national or global	Regional, national or global	Regional, national or global	Regional, national or global
Market	Known market and customer	Known market and customer	Anticipated customer	Anticipated product or service need
Company Structure and Culture	Age, Core Values, Vision	Age, Core Values, Vision	Age, Core Values, Vision	Age, Core Values, Vision

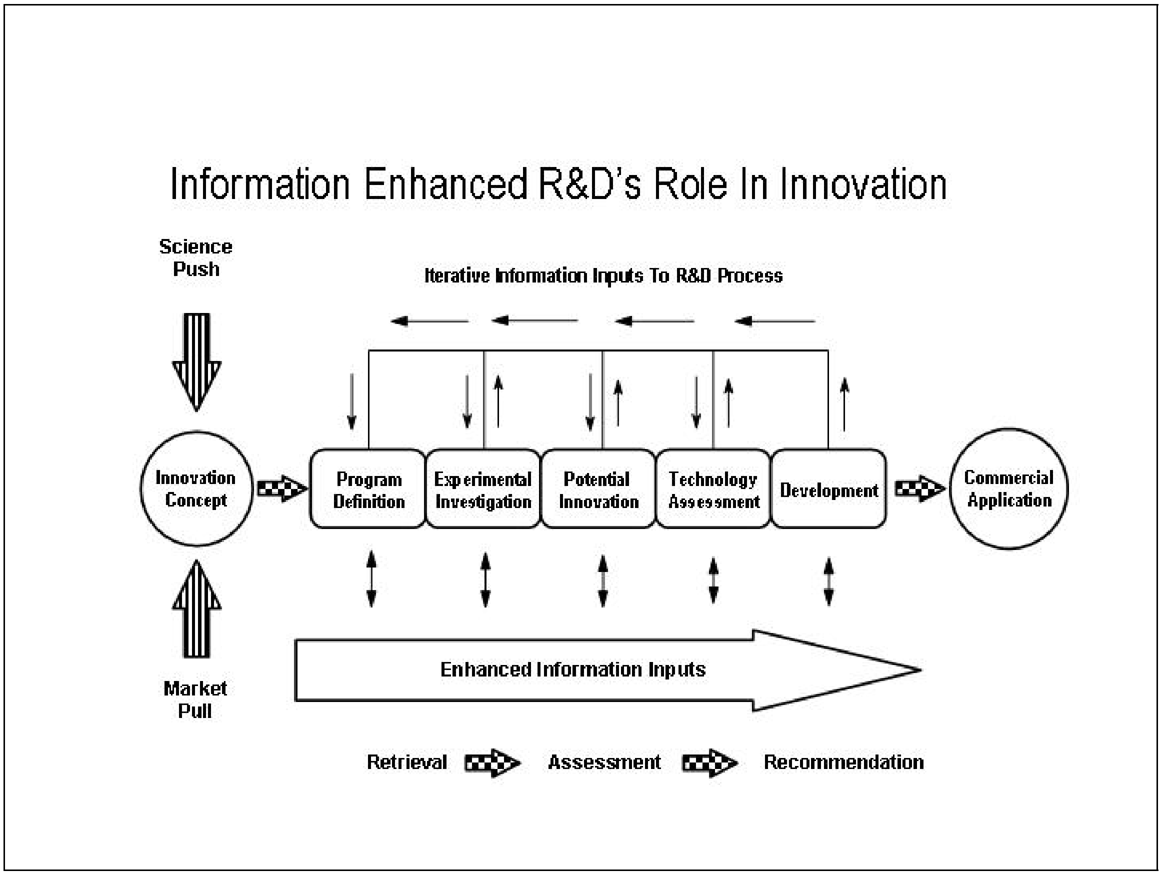
continuing improvement to an existing technology, so that the cumulative impact of incremental innovations can be quite large as represented by an S-curve of progress. However, these improvements typically approach diminishing returns based on reaching some fundamental limit imposed by the physical nature of the core technology (Foster, 1986). In contrast, a radical innovation represents a dramatic, major, improvement based on a discontinuity in the type of core technology and magnitude of application performance achieved (Leifer 2000). Most often, radical innovations have no clearly defined performance specification or market as first conceived. Thus an iterative process of technology push and market pull is typically involved during which product specifications and cost are examined and debated by supplier and customer, and finally concurrently defined leading to eventual market acceptance.

The classification in Table 2 follows the phenomenology of an earlier analysis (Shenhar 1995) proposing that that innovations first be grouped into columns representing four levels of technological uncertainty: 1) low-tech, 2) medium-tech, 3) high-tech and 4) super-high-tech. Low tech innovations involve no new technology, and the company addressing them has a successful track record and ample history of successful innovation projects of this type. Medium tech innovations are similar to low tech innovations, but require incorporation of some new technology that appears well defined. Both low tech and medium tech innovations can be considered as ***incremental innovations***. High tech innovations require the integration of new, but known technologies into new, first of a kind product, process or service. Super high tech innovations require the design and integration of new, key technologies into a new family of product, process or service representing a quantum leap in performance and cost effectiveness for the user. Both high tech and super high tech innovations can be considered as ***radical innovations***.

Even a brief inspection of Table 2 suggests why a quantitative or even qualitative general theory of innovation is so elusive (Age 1995). Any defining theory of innovation must deal with at least the eight innovation characteristics indicated as rows: 1) technology, 2) scope of product, process or service, 3) time, 4) size of company or organization, 5) industry, 6) supply chain or value chain, 7) market and customers, 8) organizational structure and culture. The complexity of this tabular representation of innovation perhaps provides a clue why a constant period of 50-60 years has been repeatedly assigned to the industrial or technology revolutions discussed in Section 2.1. This simple analysis also suggests that any significant advance in methodologies and tools for improvement of innovation effectiveness must deal with this complexity.

Paradigm Shift From Scientific Technology to Accelerated Radical Innovation Figure 2, adapted from a

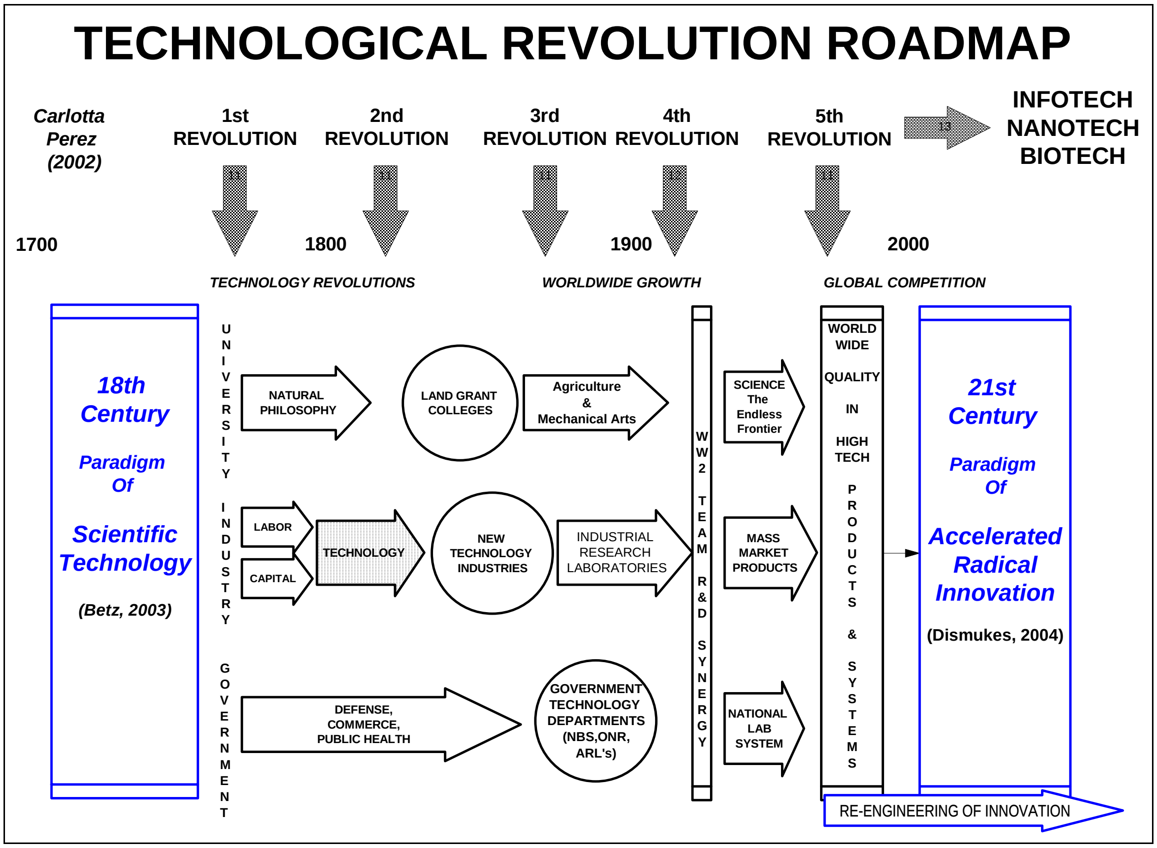
Figure 2. Schematic Representation of the R&D Process Sequence From Concept to Commercialization.



published paper (Walton 1989) reveals early recognition of the significant impact of information in enhancing the progress of R&D towards commercialization. This effort, undertaken by the author and co-workers at Exxon Research and Engineering in the late 1980s to investigate the effect of information retrieval and analysis on materials science R&D, is one of the first published studies documenting the importance of information assessment for enhancing the effectiveness of research. These

results motivated further research leading to the recent development of a technological revolution roadmap, schematically shown in Figure 3, depicting a fundamental postulate as a guide to further advance the theory and practice of radical innovation. Specifically, Figure 3 proposes that a paradigm shift has been in progress since the beginning of the 5th technological revolution (ca. 1971), whereby the world is in transition from a period (ca. 1771- 1971) dominated primarily by ***scientific technologies of power*** to a 21st Century world that will be increasingly dominated by ***scientific technologies of thinking*** (Betz 1997).

Figure 3. Paradigm Shift from Economic Progress Driven by Technologies of Power During The First Four Technology Revolutions, to Economic Progress in the Fifth Technology Revolution Driven By Technologies of Thinking.



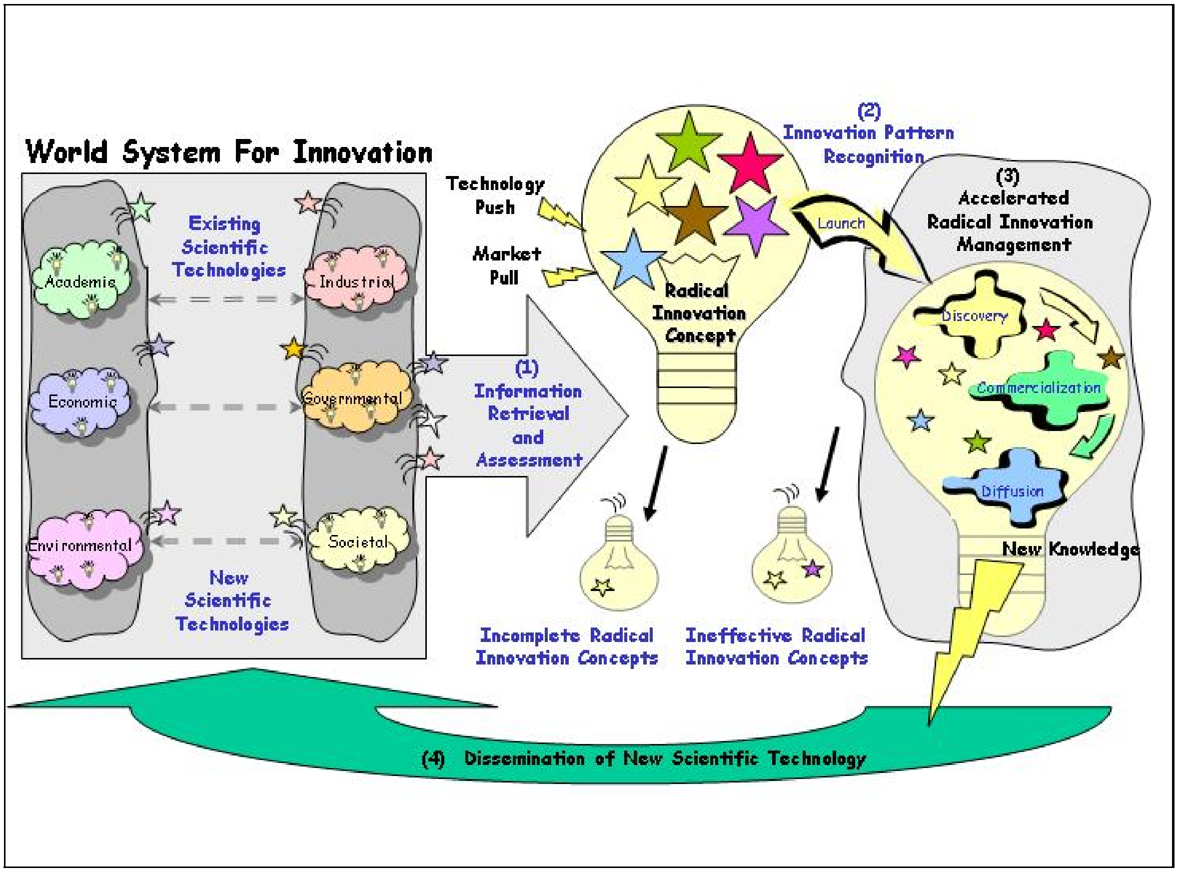
Source: Betz (1997)

As a further development of this line of thinking, Figure 4 provides the first schematic representation of the ***Accelerated Radical Innovation*** paradigm presented in a poster session paper at the 1st ECI Conference on Accelerating the Radical Innovation Process, Charleston, SC, USA, May 2004 (Dismukes 2004). Figure 4 further pictures radical innovation as an information driven, closed loop process involving a number of complex phases:

1) information retrieval and assessment of existing scientific and technological knowledge from the "world system for innovation",

2) application of technology push, market pull and pattern recognition criteria for identification of a highly promising radical innovation concept,

Figure 4. A Schematic Illustration of a Closed Loop Paradigm for Accelerated Radical Innovation, Driven by Information Technology



3) a disciplined process of innovation management through the stages of discovery, commercialization and diffusion, and

4) the dissemination of new knowledge as scientific technology back to the "world system for innovation".

Clearly this is a selective process as indicated by the rejection of radical innovation concepts as incomplete for further consideration during Phase 1 or Phase 2, or as inadequate for commercialization based on results from various steps in Phase 3.

This plausible process description includes all of the steps involved in an actual process for commercialization of a successful radical innovation. Considerable assessment and analysis is typically conducted during the initial evaluation of a radical innovation concept, leading to its classification as a "discovery". Numerous recent publications have treated this portion as the "fuzzy front end" of the innovation process (Koen 2002). The "commercialization" portion of the innovation, typically an extended and often iterative investigation lasting from years to decades depending on technical, market, management and societal acceptance factors, may be represented as a sequence of decision "gates" and development "stages" popularized by Robert Cooper (Cooper 2001 and 2002A and 2002B) as the Stage-Gate-System approach. Sustained profitable commercialization of the innovation by one company typically marks the end of the "commercialization" portion of the innovation. Propagation of the innovation geographically and temporally to other commercial companies comprises the "diffusion" portion of the innovation, that can be considered to approach completion at demographic market saturation. The diffusion portion might also be designated the "fuzzy back end" of the innovation cycle.

The time from Discovery through Commercialization through Diffusion will obviously differ considerably depending upon the differentiating factors identified in Table 2. Classically this might be identified with a fraction (e.g. 0.2-0.9) of the typical time of 50-60 years for a technology revolution (Table 1) to which the radical innovation might be classified.

An Improved Approach to a 21st Century Innovation Ecology

The initial descriptions of the principles and vision of the paradigm of Accelerated Radical Innovation (ARI) for speeding up and improving the radical innovation process, were developed and published (Dismukes, 2004, Bers, 2004) subsequent to the 1st ECI Conference on Accelerating the Radical Innovation Process, Charleston, SC, USA, May 2004. This section of the paper extends these initial descriptions and proposes an information enabled methodology for accelerating the sequential innovation phases of discovery, commercialization and diffusion that addresses many requirements for a new innovation ecology proposed by the National Innovation Initiative Report, "Innovate America" (NII 2004).

Recommendations of the National Innovation Initiative

The recent task force report, "Innovate America", drafted by top industrial and academic leaders based on a 15 month study, has identified the need for a new 21st Century innovation economy focused on talent, the capacity to take risks, and the continuous renewal of an innovative infrastructure. Reports by the National Academy of Engineering and the Task Force for the Future of Innovation have reached similar conclusions. Significant characteristics that must be addressed for industrial and societal competitiveness include that 1) the bar for innovation is rising, 2) innovation is diffusing at ever-increasing rates, 3) innovation is becoming increasingly multidisciplinary and complex, 4) innovation is becoming more collaborative requiring cooperation and communication among scientists and engineers and between creators and users, 5) workers and consumers are demanding higher levels of creativity, and 6) innovation is becoming global in scope with mutual demands from centers of excellence and from consumers.

The report further concludes that the innovation economy differs fundamentally from the industrial or even the information economy, and that it will require a new relationship among companies, government, educators and workers to assure creation of an effective innovation ecosystem that can successfully adapt and compete in the global economy. As during the 1970s and 1980s, when the United States faced a similar challenge in manufacturing from Japan, new innovation methodologies and management tools are now required to catalyze the transition from a nationally oriented to a globally oriented economy.

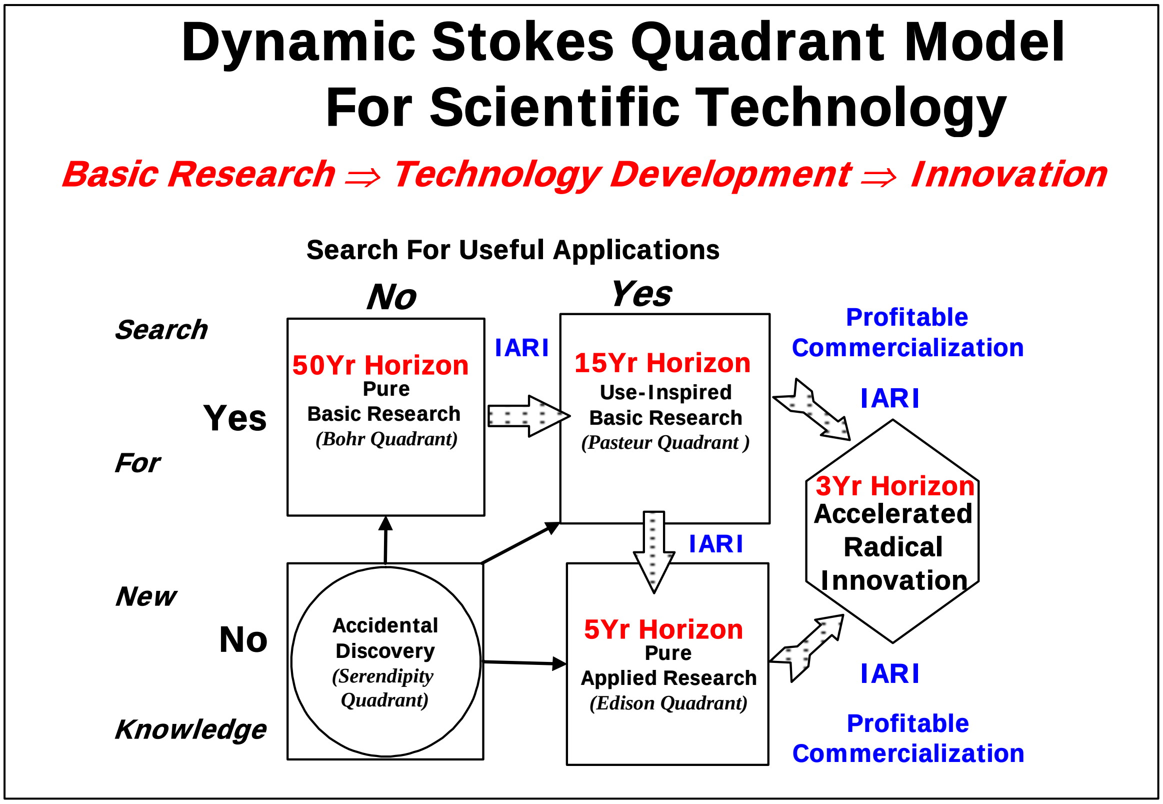
The next section describes a dual conceptual framework required as a basis for building an effective operational roadmap for an information driven innovation ecology. The first is a unifying description of the relation between scientific discovery, useful technology development, and commercialization. The second is a generic representation of the grand challenges and hurdles that must be overcome to achieve Accelerated Radical Innovation.

A Conceptual Roadmap For Building a 21st Century Innovation Ecology

Stokes recently published an enlightened science policy assessment of role of research funding at the research university on the development of new knowledge in science and technology (Stokes 1997). In his monograph, “Pasteur’s Quadrant”, Stokes for the first time provided a generic, rational distinction between applied research and basic research, and further categorized basic research depending upon motivation for new knowledge or upon search for useful applications. Figure 5 presents an expanded version of Stokes’ four-quadrant model in a format that enables clear visualization of the dynamic, operational relations of these four research quadrants to the innovation cycle comprising scientific discovery, technology commercialization, and diffusion of technology and new knowledge.

This expanded model enables both academic researchers and industry technology and business managers to visualize a collaborative innovation ecology, in which academic researchers will no longer be threatened by the fact that basic research can lead to useful applications, and in which business managers will recognize that basic research can play a dual role in providing useful applications as well as new knowledge. This model is the first portion of the required dual conceptual framework required for building an effective roadmap.

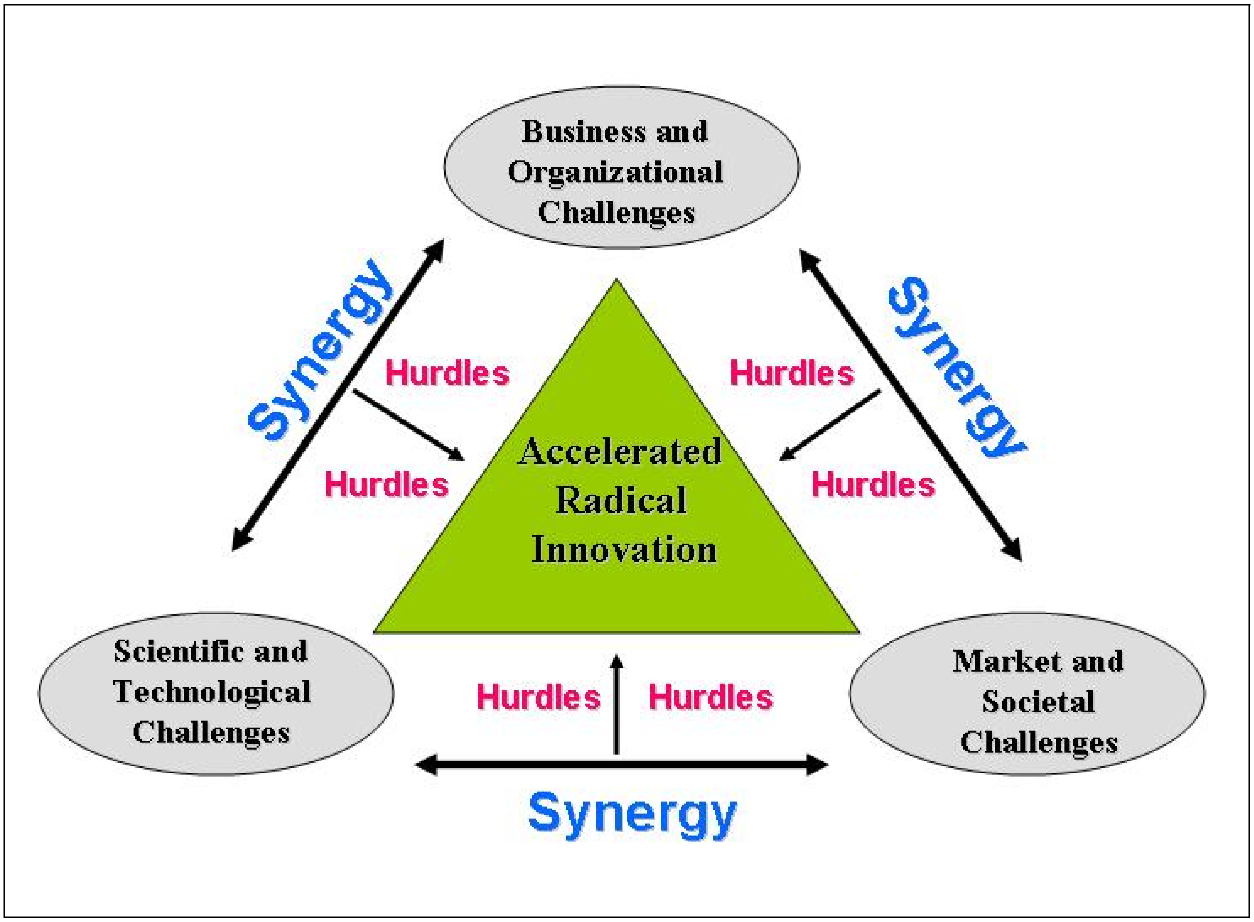
Figure 5. A Dynamic Stokes Quadrant Model of Scientific Research Connecting Basic Research With Technology Development Leading To Accelerated Radical Innovation



The problematic characteristics of the 21st Century Innovation Ecology discussed in Section 3.1 constitute a synergistically related set of grand challenges and operational hurdles that must be envisioned, addressed, and overcome by any truly effective, operational roadmap to Accelerated Radical Innovation. For simplicity, Figure 6 groups these inter-related grand challenges into three categories: I) Scientific and Technological Challenges, II) Business and Organizational Challenges, III) Market and Societal Challenges. Various hurdles will be encountered depending upon the interaction of the many complex factors listed in Table II that govern the dynamics of innovation, including: 1) technology, 2) scope of product, process or service, 3) time, 4) size or company or organization, 5) industry, 6) supply chain or value chain, 7) market and customers, 8) organizational structure and culture.

This complexity suggests that any effective roadmap to an innovation ecology must combine a generic framework with an approach tailored to the particular innovation. Since at present no "Ohm's Law" is envisioned that will simplistically describe all

Figure 6. The synergistic interaction of the grand challenges and associated hurdles that must be overcome to achieve Accelerated Radical Innovation. The three linked grand challenges are: I) Scientific and Technological Challenges, II) Business and Organizational Challenges, III) Market and Societal Challenges.



innovations in the 21st Century innovation ecology, development of a comprehensive theory and model must be the subject of further research.

An Operational Methodology For a 21st Century Innovation Ecology

The historical assessment and current status of the field of technological innovation supports the need for a new operational methodology based on the technologies of thinking (Betz 1997) as an important component of a 21st Century innovation ecology (NII, 2004). Due to the complexity of the innovation process (Age 1995), numerous models proposed for the innovation cycle have proved inadequate. A decade after this assessment, the situation still remains the same, that successive models proposed as generally applicable to the innovation process still have limitations (Porter 2005).

This is particularly true of the "linear model" that originated after World War II based on Vannevar Bush's paradigm of "science the endless frontier" (Bush 1946). That model assumes a successful sequence of activities such as those made popular as a Stage-Gate System (Cooper 2001 and 2002 A and 2002 B). The best current guideline for radical innovation, based on the extraction of best practices from historical case studies (Leifer 2000), however, does not provide a predictive model.

The new methodology proposed in this paper adopts three guiding principles:

1) identification, creation and application of the best possible management techniques for accelerating radical innovation in a real world industrial environment

2) adaptive real-time integration of the best information technology software tools for pursuit of accelerated radical innovation,

3) continuous adaptive improvement of management techniques to address the acceleration of each sub-step of the innovation process .

This model incorporates a world view (Figure 7) of the innovation cycle (discovery, commercialization, diffusion) that envisions the use of four key information and telecommunications tool suites (e.g. Boer 2002, Cios 1998, Kostoff 1999 and 2004, Porter 1985, Porter 2005, Price 1984, Probert 1999, Quinn 1996 and 1997, Stratton 2003, Wymbs 2004, Willyard 1987) that can be applied by an innovation team at various milestone points in the innovation. These are:

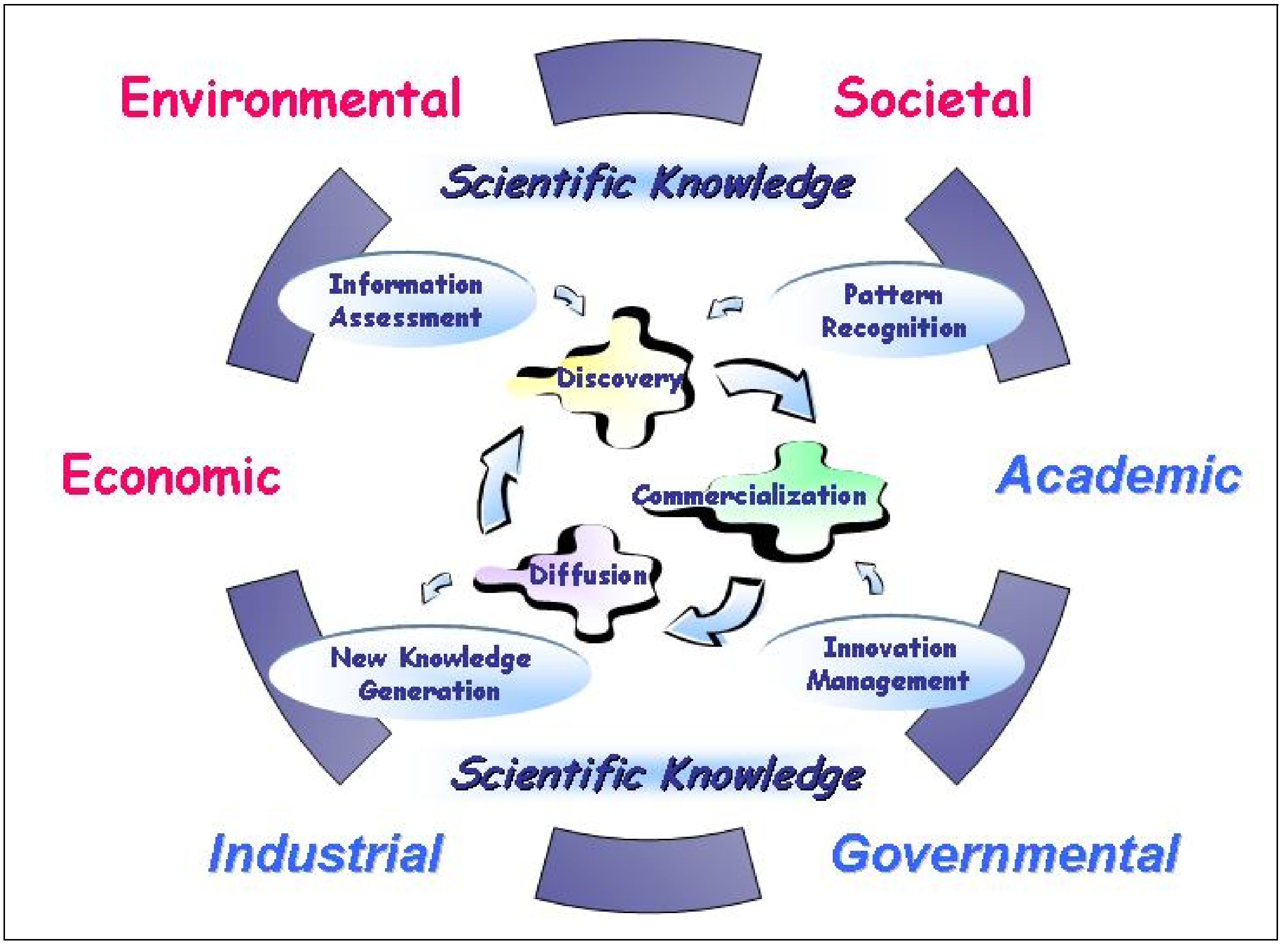
- Information Assessment,
- Pattern Recognition,
- Innovation Management, and
- New Knowledge Generation.

As indicated in the outer "influence circle" in Figure 7, environmental, societal, and economic factors exert both long term and near term guidance on innovation strategy and operations, reflecting up to date real time consumer viewpoints. Industry driven research, development and innovation activities in the cycle of discovery, commercialization, and diffusion, aided by academic research and governmental policy inputs, provide the engine of the overall innovation system.

Based on experience in the electronics and petrochemical industry over a 30-year period, the author proposes an adaptive innovation template, Figure 8, that can be applied at any individual step or sequentially at each step of the overall innovation cycle, Figure 7.

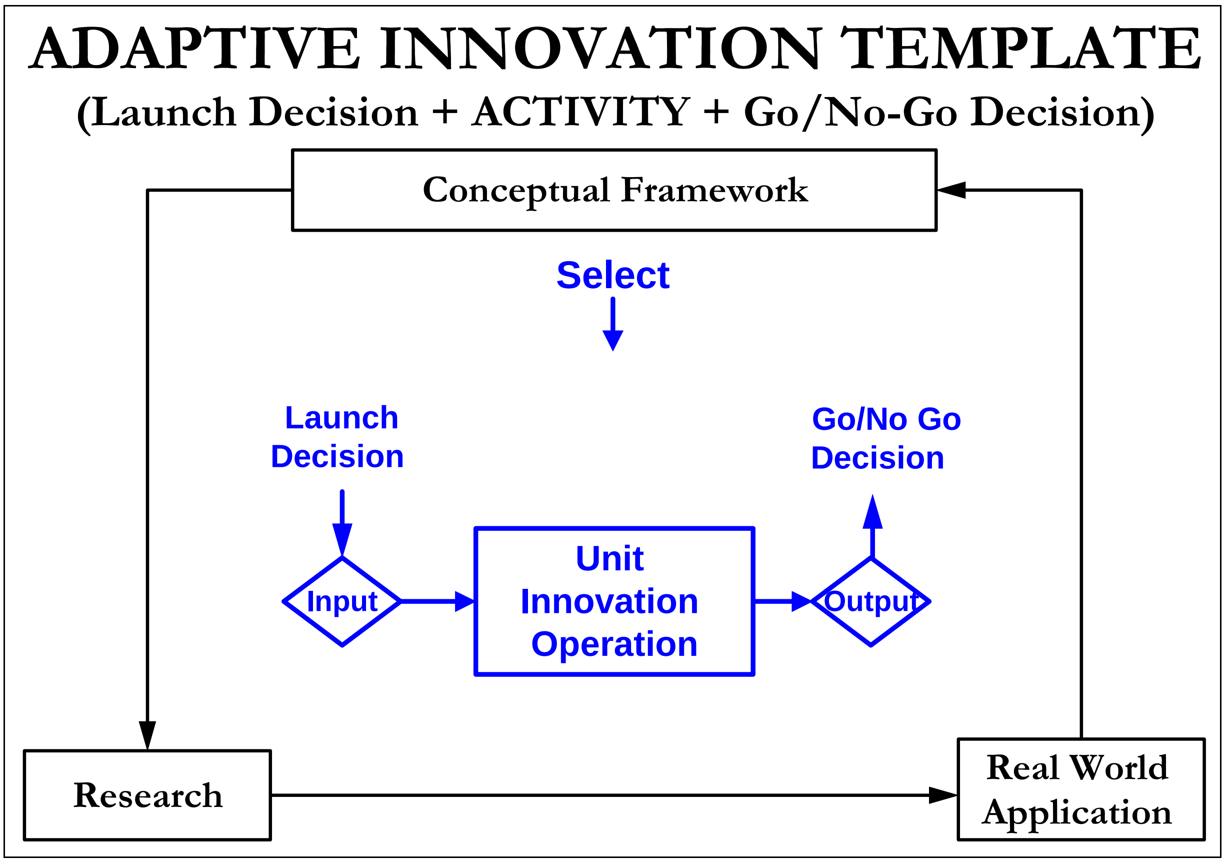
In spite of the frequent criticism of the linear Stage-Gate-System model that it is linear and unrealistic, a number of studies (Walton 1989, Cohen 1998) have recognized that this type of model comprises an iterative sequence of independent operations (i.e. launch decision + unit innovation operation + go/no-go

Figure 7. A conceptual "adaptive and self-renewing radical innovation system model" driven by "technologies of thinking". In this model, industrial activities supported by academic research and governmental policy and funding inputs, provide the operational driver of the overall innovation system comprising the sequential phases of discovery, commercialization and diffusion. Societal, economic and environmental requirements exert a strong influence on the selection and success of specific industrial innovation activities. In this operational model, strategic application of computer science and telecommunication tools is the catalyst resulting in dramatic improvement in the effectiveness of each phase of the overall innovation cycle. The key assessment methodologies include: a) Information Assessment, b) Pattern Recognition, c) Innovation Management, and d) "New Knowledge Generation".



decision) with periodic interruptions or termination possible. Although superficially similar to the Stage-Gate-System models (Cooper 2001) simplistically laid out in a linear array sequence, the iterative model proposed here truly envisions real time input and assessment, and recording of activities, information

Figure 8. Conceptual description of the key adaptive building block process for an operational innovation methodology involving pursuit of an innovation goal involving iterative conduct of innovation phases punctuated by milestone decision points.



and decisions in a data mining system (Cios 1998) retained for future instant retrieval and review. Therefore the innovation activities of the iterative model may be considered as a commercial or industrial equivalent of the military special forces operations involving a focused team of specialists in real-time communication, dedicated to a specific well defined task. Hence the iterative model should be capable of improved 10X performance compared to baseline activities using conventional techniques. Referring to the dynamic stokes quadrant model in Figure 5, this chart

illustrates the possibility based on Accelerated Radical Innovation to reduce the time for profitable commercialization from 50 years ⇒ 15 years ⇒ 5 years ⇒ 3 years. Such an achievement, if experimentally verified, would bring the particular radical innovation into view on the typical radar screen of business executives faced with quarterly and yearly profitability demands of stockholders and the investment community.

As a final justification in this proposal for information Accelerated Radical Innovation (ARI) as the operational model required for a 21st Century innovation ecology, the issues of risk, cost and acceptable success rate of profitable commercialization need to be considered. Two strategies are proposed to address these obvious requirements for a dramatically improved and effective operational methodology. The first strategy begins with is a rigorous initial assessment of discoveries and their potential (Walton 1989) as innovations, and a systematic screening and selection at the start of the innovation cycle, rather than at the end of the innovation cycle, as conducted in the classical funnel model (Chesbrough, 2003). Reduced overall operating costs of a company's R&D operation achieved by focusing on fewer, higher potential value innovations should more than offset the costs of a higher intensity, information enhanced, real-time approach to the highest priority projects. Reduced time and higher success rate should also be obtained by focusing on the highest value potential innovations.

The second strategy proposed in launching information Accelerated Radical Innovation as the operational model for a 21st Century innovation ecology involves adoption of a methodology successfully employed for total reorientation of R&D focus by a major petrochemical company during the early 1990s (Eidt 1995). This approach, here given the name ***Activity Based Roadmapping***, is in effect the development of a long range business model based on an interactive assessment and prioritization of:

- long range business opportunities and associated grand challenges (Figure 6)
- technologies needed as core technologies for success

- technological hurdles that must be overcome for success
- scientific and engineering research required to overcome the hurdles
- a flexible, interdisciplinary and cross functional plan with predetermined goals

Though superficially similar to the classical case-study based radical innovation methodology, in reality it is radically different, since it involves a generic system approach to a business model incorporating a sequential assessment and targeting of core technologies, without regard to a specific organizational structure or business hub (Leifer 2000). The new methodology can be applied at any step of the innovation process, including new venture activities, new attempts at an overall radical innovation, and new attempts at getting an existing radical innovation process back on target.

Conclusion

This paper first reviews the course of technology from its empirical base in antiquity through the initial scientific technology era of the 19th and 20th Centuries, to the 21st Century environment of Accelerated Radical Innovation governed by technologies of thinking. It then assesses the need for and benefits from a new information technology enabled paradigm of Accelerated Radical Innovation (ARI). By combining advanced information technology tools and innovation management techniques in a real-time decision-making environment, the ARI paradigm has the potential to overcome technological, organizational and societal challenges and hurdles, thereby achieving a factor of 10X improvement in radical innovation effectiveness.

Further development and validation of this proposed new paradigm is envisioned through a collaborative multi-university program of research and teaching, in collaboration with selected industrial partners to identify specific methodologies appropriate for specific company structure and industry goals. Successful implementation will contribute significantly to the proposed activities required for a 21st Century innovation ecology, envisioned by the National Innovation Initiative report, "Innovate America".

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