Management for Professionals

Sanford L. Moskowitz
Chris Erickson

Managing Technology from Laboratory to Marketplace

Cheating the Valley of Death

Springer

Management for Professionals

The Springer series "Management for Professionals" comprises high-level business and management books for executives, MBA students, and practice-oriented business researchers. The topics cover all themes relevant to businesses and the business ecosystem. The authors are experienced business professionals and renowned professors who combine scientific backgrounds, best practices, and entrepreneurial vision to provide powerful insights into achieving business excellence.

The Series is SCOPUS-indexed.

Sanford L. Moskowitz • Chris Erickson

Managing Technology from Laboratory to Marketplace

Cheating the Valley of Death

Springer

Sanford L. Moskowitz
Department of Global Business
College of St. Benedict & St. John's University
St. Joseph, MN, USA

Chris Erickson
Pangaea Ventures US Inc.
Phoenix, AZ, USA

ISSN 2192-8096 ISSN 2192-810X (electronic)
Management for Professionals
ISBN 978-3-031-51420-3 ISBN 978-3-031-51421-0 (eBook)
https://doi.org/10.1007/978-3-031-51421-0

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Paper in this product is recyclable.

Sanford Moskowitz dedication: To Becky and Leah – For their patience and inspiration.
Christian Erickson dedication: To my wife, Saleema Erickson, and my daughters Afton and Kate.

Preface

The technological landscape has changed a great deal over the past three decades. What has been known as information technology (IT) has in fact evolved into something very different. The 1980s and 1990s saw the rise of the personal computer as the central feature of the world of high tech. While computers remain an important part of the so-called Fourth Industrial Revolution (4IR), they are now only one aspect of the story of high tech today. Technology is now expanding beyond the rather flat, two-dimensional world of digital computing where machines – albeit very sophisticated ones at that – simply follow the instructions of programs fed into them. In the twenty-first century, the three-dimensional world itself is becoming digitalized. Products, components and systems that hardly existed a few decades ago – neural algorithms, microsensors, smart devices, clean energy – now link up with advanced personal computer technology to create systems that can perceive, digitalize and react to the world around us. Closely associated with this new perceptibility in technology is its ability to solve daily problems and ultimately to think independently. Combining its new powers of perception with its higher level of autonomy, twenty-first-century technology will not just do what humans ask it to do ever faster but will be enabled to point out new and previously unimaginable ways to tackle the world's most pressing problems including climate change, energy transition, food shortage, health care and disease, productivity decline and a host of other seemingly intractable problems of the modern era.

Those who still believe that IT "is the straw that stirs the drink" in the twenty-first century have seriously misread what this current era is all about. Solving the difficult problems that confront us in the age of 4IR is rapidly shifting attention from those downstream digital products based on computer technology that dominated the 1980s and 1990s, toward a new type of technological world controlled now by advanced materials and the devices, components and systems made directly from them. Sensors, robotics, big data, energy generation and storage, genetic engineering, climate control, autonomous technology all depend increasingly on the discovery, development and commercialization of radically new materials. Future material progress, economic growth and national competitiveness hinge on the ability of firms large and small, creating and injecting into the economy a new generation of nanomaterials, advanced alloys, complex polymers, diagnostic biochips, quantum circuits, superconductors, smart materials, liquid crystals and similar upstream technologies.

Given this tectonic shift in relevance from downstream and highly specific products (in the form of computers, peripherals and software) to upstream and generic materials and their devices and components, we run into the inconvenient problem that the earlier assumptions and beliefs surrounding what was then defined as "high tech" no longer apply. Thus, we can take exception to a statement made by the marketing guru of the 1990s Regis Mckenna in his Preface to Geoffrey Moore's highly influential book *Crossing the Chasm*:

> The chasm represents the gulf between two distinct marketplaces for technology products – the first, an early market dominated by early adopters…and the second a mainstream market representing 'the rest of us', people who want the benefits of new technology but who do not want to 'experience' it in all its gory details. *The transition between these two markets is anything but smooth*. (Moore, 1991, viii)

The italics in the last sentence is ours and is, frankly, an observation that we cannot confirm when dealing with the commercialization of advanced materials. In fact, we find quite the opposite to be true, i.e., the transition between early adopters and the mainstream *is* (more or less) smooth. That is to say, we find strong connections and common links between the two stages of R&D such that if one were to avoid taking what is learned in the early adopter stage and applying it to create the entrance strategy into the mainstream, one would be significantly reducing the chances for a successful outcome.

One of the main problems with this marketing-oriented approach favored by McKenna and Moore is that in the realm of advanced materials, pre-marketing activities play a (even *the*) major role in effecting a successful journey across the Valley of Death. Thus, we cannot side with Moore when he writes that ultimate success in whole product R&D "…is driven not by the laboratory but by the marketplace. It begins not with creative technology but with creative market segmentation. It penetrates not into protons and processes but rather into habits and behaviors (Moore, 1991, 212)."

While we understand the point Moore is making, we also must insist that when it comes to materials research (MR) and its role in driving 4IR, the laboratory and its ability to "penetrate…into protons" must indeed be the starting point. One cannot appreciate how and why an innovative concept got to the point where it becomes a working (if imperfect) technology suitable for the early adopter market nor the dynamics through which this early market segment advances into the larger, mainstream market arena without a full understanding of how a technology evolves through its entire lifecycle, from laboratory idea to a fully formed system diffusing within and impacting the social and economic fabric of a nation.

This book then aims at revealing how new ideas in the realm of advanced materials and allied fields come to successfully negotiate the Valley of Death and enter into and influence twenty-first-century economies. In doing so, we need to revise generally held beliefs on what constitutes "high tech" in this century and how it finds its way across the dreaded "Chasm." In our telling, the new technology centers on the advanced materials industry that is embedded within and is the major driver of the Fourth Industrial Revolution. Further, the chasm is no longer just the single large gap existing between the risk-taking early adopters and the risk-averse mainstream segment but the entire sequence of events from laboratory experiment to first creation and early adoption and through to expansion into and acceptance by the mainstream customer. In this sense, we can think of the chasm or Valley of Death in toto as a sequence of tightly bound and closely interacting regions which bleed into and help nurture one another with the ultimate aim of propelling a new technology into the mainstream economy. In this scenario, we assume that innovations that fail to achieve this eventually fall into the chasm to their deaths; those that succeed stand an excellent chance of advancing the competitive position of the firms that created them and the nations within which these firms operate. From this perspective, we hope this book will be employed by managers, entrepreneurs, high-tech investors and governments as a guide as to what factors to look for when prioritizing projects vying for their attention, time and money.

The authors completed this book with the kind help of many people and organizations both directly and indirectly. A work such as this has been driven and informed by literally hundreds of discussions, many of an informal nature, and interviews held with entrepreneurs, scientists, managers investors, government officials and educators held over the years in corporate meetings, at high-tech conferences and symposia, and over the phone and through teleconferencing facilities.

We do want to acknowledge the contribution of certain individuals and organizations. We want to thank Elicia Maine, the W.J. VanDusen Professor of Innovation & Entrepreneurship, at the Beedie School of Business at Simon Fraser University. While she did not directly take part in this study, her pioneering work in the field of advanced materials innovation proved to be an important source for this book. The book also benefitted greatly from input provided in an extensive interview conducted by the authors with the former president and cofounder of the energy startup ESS, Inc., Craig Evans. His responses provided important insights useful to this study across a number of chapters. We appreciate as well the support given by the College of St. Benedict/St. John's University in Collegeville, Minnesota which provided one of the authors (Sanford Moskowitz) with a Sabbatical from teaching to pursue the line of research that greatly helped in the completion of this book project. We are grateful to the Science History Institute (formerly the Chemical Heritage Foundation) and its Oral History Program in Philadelphia, Pennsylvania as well for allowing us access to their archive of oral histories of persons and themes relevant to this study. We also thank the SIH for allowing us access to their holdings related to the life and work of nanotechnologist and Nobel Laureate Richard Smalley. The project also benefitted significantly from discussions we had with Steve Rodgers, Founder and CTO of EmergenTek LLC. His insights on nanotechnology in particular added to the thinking that went into this book.

Finally, we would like to thank Pangaea Ventures Ltd. for allowing us access to their pool of on-going advanced material firms and for supplying their current assessment of each of them. We also are grateful for their help in putting together the statistical tables that appear in the book.

St. Joseph, MN, USA Sanford L. Moskowitz
Phoenix, AZ, USA Chris Erickson

Reference

Moore, G. (1991). *Crossing the chasm: Marketing and selling high-tech products to mainstream customers*. HarperBusiness.

Contents

1 Introduction

Abstract

This chapter ("Introduction") introduces the concept of the Valley of Death and the importance of high-tech innovations to successfully negotiate their way through the Valley and enter into the mainstream economy. It discusses the central role of advanced materials and allied technologies in the ability of firms and nations achieving competitive advantage, particularly within the context of the rise of the Fourth Industrial Revolution. Various models of technological change as possible approaches to understanding advanced materials innovation are introduced and critiqued. Particular attention is paid to the product-centered model, which focuses on marketing as the primary strategic tool used for conquering the Valley of Death. The gap between early and later adopters posited by this model is questioned and an alternative evolutionary scheme proposed as more appropriate for twenty-first-century innovation. The structure of the book, designed to further develop these ideas and underscore the role of advanced materials in the growth of high-tech today, is outlined.

This book is about how to take great ideas from the laboratory to become successful, mainstream technologies that solve significant problems in the world. It is a story of survival and growth of vital technologies in a time of great change and uncertainty when society is transitioning from the known and relatively restricted world of information technology to the new and more challenging, and seemingly unbounded, age of energy transition, genetic engineering, and artificial intelligence (AI). This story of the death and survival of ideas and technologies is also one that demands a shift in focus from the finished, downstream products that defined the computer age of the 1980s to those upstream materials, components, and processes that today feed the so-called Fourth Industrial Revolution. The forces that propel these technologies across the Valley of Death are fundamentally different than those

S. L. Moskowitz, C. Erickson, *Managing Technology from Laboratory to Marketplace*, Management for Professionals,
https://doi.org/10.1007/978-3-031-51421-0_1

that underlay the success of those earlier products and systems pivotal to the IT revolution of a few decades ago. Those actors who plan to invest time and money in future high-tech ventures need to understand this new landscape of technology creation, as do nations that wish to be competitive in the modern world. This book then delves into, uncovers, and follows the implications of these new laws of survival that apply to those foundational technologies that together drive competitive advantage and economic growth in the twenty-first century.

Crossing the Chasm in the New Technological Age

Attaining competitive advantage in the twenty-first century depends to an increasing extent on firms and nations capturing and controlling advanced technology. The growing number of high-tech initiatives taking place today in universities, government labs, and corporate R&D departments testifies to the importance placed by society on retaining the country's technological leadership. Whether, to take one current example, the US maintains its position as a technological leader in the burgeoning field of artificial intelligence (AI) may well hinge on whether its companies—both startups and established corporations—can create the technological system that enables robots and autonomous machines to distinguish and find the relation between "cause and effect" in the physical world, something they cannot do at present (Savage, 2023). It is of course one thing for a firm to spend a lot of money on all sorts of projects that sound interesting and relevant, it is quite another to show wisdom and discrimination—and economic efficiency—in separating those most likely to succeed and actually enter into and significantly influence the greater economy. The fact is too many R&D projects never make it from the laboratory to the marketplace and thus never turn a profit or impact a society in any material way. These failed efforts are then said to have fallen into the "Valley of Death." For instance, despite the attention given to university research and its role in a nation's economic growth, in fact very little practical technology comes out of academia. By its last measure, only 2% of patents granted in the United States came out of university laboratories (Marcus, 2020).

The reasons given by scholars and executives for these failures are many and familiar, including lack of resources, poor internal communication, the dominance of short-term vision (and thus lack of patience for R&D's long road to success), strong (and deadening) influence of a firm's current customer base, and so on.[1] Whatever the cause, the failure of so many projects to enter into the commercial space is a financial and intellectual drain on a firm and on a country.[2]

Two questions immediately come to mind if one wants a greater percentage of R&D efforts to make it across that dreaded R&D chasm and actually impact the

[1] See, for example, Vinsel and Russell (2021).

[2] The congressional Budget Office, for example, has recently pointed out the problems for society that result from the failure of research money in the pharmaceutical industry to result in commercial drugs. See Congressional Budget Office (2021).

competitive position of firms and the countries in which they operate: (1) out of the barrage of proposals that come across the desks of R&D managers, venture capitalists, and corporate investors, which ones ought to be tagged as the most promising and earmarked for future support? and (2) how can investors and innovating firms guide these most promising projects to a successful transition from the laboratory to the market? But these questions force another and very important one: which sort of technology ought to be given precedence to begin with? Each period of history, of course, is associated with certain types of technology. A method to make better horseshoes would no doubt have meant something to eighteenth-century business, but not so much today. Steam engine technology in the nineteenth century, electrification in the early twentieth century, and the automotive revolution after World War I are obvious examples of technological movements occurring at specific periods over the last two centuries. The rise of Silicon Valley and its IT revolution in the last half of the twentieth century shifted attention to computers and the components and software that went into them.

However, in some cases, the identification of a technological movement with a particular historical period is not so clear-cut. While remaining in the background of the historical narratives of the better known innovations, some innovations in fact generate much of the technological input needed that allows the star attraction to thrive on the historical stage. Advanced materials technology is a prime example of this sort of background player. It produced iron and steel for steam power, glass and filaments for electric lamps, fuel and metal (and later plastics and composites) for automobiles, and silicon and material fabrication processes (ion implantation, photolithography, chemical vapor deposition) for the chips used in computers and smart phones. Considering advanced materials as only a background player in the story of innovation not only fails to tell the full story of these high-tech revolutions and how they evolved, but has obscured the great advanced material technologies that occurred at the same time as, and often independent of, the more famous innovations. Indeed, the importance of materials research (MR) to society and its economy has become particularly evident since the 1990s, as advanced materials research has brought into the commercial market such technologies as super alloys, advanced fibers, polymer composites, and nano- and biomaterials (National Academies of Sciences, Engineering, and Medicine, 2019: 1–6). These technologies have entered into and transformed a wide range of products, components, and systems and, as a result, reinvigorated those critical industrial sectors that drive national economic growth. The last two decades of the last century witnessed a number of revolutionary, high-impact advanced materials innovations. The company Nucor, for example, bolstered America's steel industry, in large part, due to a new and radical process that makes flat-rolled steel continuously using thin-slab technology (Preston, 1991). For its part, the chemical industry developed a revolutionary new way to make new types of polymer plastics that has become the dominant technology in this field, a development that has had significant economic impact across numerous market sectors. This was a time as well when IBM employed nanomaterial technology to create the first "alloyed" chips for the wireless communications industry and advanced the field of spintronics to greatly expand the capacity of computer hard drives, an important achievement in bringing PC technology into the twenty-first century and in ushering in the era of big data (Mearian, 2012).[3] Important as well was the rise of the startup Nanosys and its success in finding commercial markets for one of the major nanomaterials—specifically, the use of quantum dots in flat-panel television displays—and the introduction by the company Applied Materials of a new plasma-enhanced process for performing chemical vapor deposition operations for the semiconductor industry (Arizona State University n.d.).

If such technologies—those products, processes, and materials that flow into and help shape final products and systems—have historically been cast in the shadows of other technological revolutions—their importance has been noted more recently by those who are charged with monitoring and forecasting the technological profile and economic competitiveness of nations. The National Academies of Sciences, Engineering, and Medicine undertook a comprehensive study of the current status and probable future course of advanced materials research in the United States and globally. One of the tasks the National Academies took on was to assess the role of materials research (MR) in generating economic growth and national competitiveness. The report, which came out in 2019, concluded that MR plays a critical role throughout national economies, an insight that will have even greater relevance in the coming years:

> Materials research is a critical underpinning to economic growth as well as national competitiveness, wealth and trade, health and well-being, and national defense. The impact that materials research has had on emerging technologies, national needs, and science has been important to date, and it is expected to become even more so as the United States… faces current and future global challenges. Many of the world's larger nations and economies have recognized this relationship, and recent trends show that today many nations have developed and articulated national investment strategies to ensure robust progress in materials research for national competitiveness (National Academies of Sciences, Engineering and Medicine, 2019: 12).

The "recent trends" noted by the report refer to the importance of MR to the rise of what is known as the Fourth Industrial Revolution (4IR). The term Fourth Industrial Revolution first gained prominence in 2015 when the executive chairman of the World Economic Forum introduced it in a 2015 article published by the journal *Foreign Affairs* (Schwab, 2015). The annual meeting of the WEF in Switzerland the next year followed up on this article with its theme "Mastering the Fourth Industrial Revolution (World Economic Forum, 2016)" If the first industrial revolution harnessed the power of water and steam, the second brought electrification to manufacturing and third centered on computers and software technology, the fourth has evolved beyond this to become a separate and distinct technical movement, a totally new technological era that will have (and is already having) a profound impact on manufacturing and the global industrial landscape. According to the United Nations Industrial Development Organization's (UNIDO) Industrial Analytics Platform, the power of the Fourth Industrial Revolution resides in the fact

[3] See also, Phys. Org. (August 5, 2005)

that it blurs the boundaries that traditionally have existed between the biological, physical, and digital realms (Lavopa & Delera, 2021).

Commentators and researchers in business, government, and academia have focused on the Fourth Industrial Revolution and the unprecedented rate of innovation resulting from its closely knit family of previously separate technological realms as the most impactful development of our time. In 2018, a contributor to Forbes maintains that this development "describes the exponential changes in the way we live, work and relate to one another…The Fourth Industrial Revolution is disrupting almost every industry in every country and creating massive change in a non-linear way at unprecedented speed (Marr, 2018)." *The MIT Technology Review* claims. "It's a technological shift that will ultimately have worldwide implications." *The Economist* agrees maintaining that it is rapidly seeping into every space, nook, and corner of our lives: "In almost every aspect of society, the Fourth Industrial Revolution is changing how we live, work, and communicate. It's reshaping government, education, healthcare, and commerce. In the future, it can also change the things we value and the way we value them. It can change our relationships, our opportunities, and our identities as it changes the physical and virtual worlds we inhabit (Economist Intelligence Unit, 2018)." Given the rapid development of this technological revolution in industry and society, it is natural that influential outlets, such as the *Harvard Business Review*, should delve into the readiness of corporate America to deal with this new industrial force. HBR's "How Leaders Are Navigating the Fourth Industrial Revolution (Harvard Business Review, 2019)," one of the more prominent contributions to the discussion, estimates a revolution close to generating $4 trillion in value creation. The slew of other similar articles that have recently emerged from prominent sources thus serves as a potent indicator of how quickly this revolution is gaining momentum and taking control of the developed world's technological landscape (MIT Technology Review Insights, 2020).

This revolution is pushing the integration into a single cohesive system what has formerly been five separate disruptive technologies. The following table shows the five technological areas that comprise the Fourth Industrial Revolution along with their major technical sub-fields (Table 1.1).

This historic technological convergence then opens the way for solving difficult problems and extending the technical envelop in ways that were not possible before. Thus, for example, the component "biotechnology" converges with "analytics and

Table 1.1 The composition of 4IR: fields and their subfields

The five major technological components of 4IR	The major corresponding Sub-Fields
Information Technology and Connectivity	The Internet, Wireless Technology, The Cloud
Analytics and Intelligence	Data Analytics, Artificial Intelligence (AI)
Human-Machine Interaction	Virtual Reality, Robotics, Autonomous Machines
Advanced Engineering	Additive Manufacturing, Smart Design, Nanotechnology, Renewable Energy
Biotechnology	Genetic Engineering, Drug Platforms CRISPR

Intelligence" in the new field of computational biology, which is the application of data analytics and computational simulations as tools to develop new types of drugs and gene therapies. Similarly, "information technology and connectivity" merge with "advanced engineering" and the field of nanotechnology creating new (non-silicon-based) materials and processes that enable the semiconductor industry to build faster and more powerful chips in the face of a declining Moore's Law. Then too, artificial intelligence ("analytics and intelligence") and smart technology ("advanced engineering") join forces with the Internet of things ("human–machine interaction") to create smart cities. A multitude of such interactions between two or more of these technological components plays the defining role in the emergence and evolution of the Fourth Industrial Revolution.

The Fourth Industrial Revolution and Advanced Materials Research

Advanced materials, processes, and devices drive the Fourth Industrial Revolution. The importance of a parallel revolution in energy emphasizes this linkage. The technological convergences noted above—and which fuel the revolution's momentum—cannot take place without a fundamental shift in the energy economy. This current era of energy transition involves the replacement of carbon intensive energies such as oil, coal, natural gas, and conventional hydrogen by renewable energies such as solar, wind, tidal, and green hydrogen. Renewable energies are helping to drive the world economy toward more electrification, whether it is the cars we drive or the energy that powers industry. Energy transition is also necessary to reduce carbon dioxide emissions and the threat of climate change. Advanced materials are critical to all facets of the energy transition. For example, conventional hydrogen is made from steam methane reforming and emits about 10 tons of carbon dioxide for every ton of hydrogen produced. When powered by solar or wind, hydrogen electrolyzers emit no carbon dioxide. An October 2022 McKinsey Report states that by 2050, hydrogen could contribute more than 20% of annual global emissions reduction. The same report states that the demand for green hydrogen could grow to approximately 660 million metric tons (MMT) annually by 2050, with total planned production for green and blue hydrogen through 2030 having reached more than 26MMT annually (Heid, 2022). However, this won't happen without significant advances in advanced materials. The drive to low-cost green hydrogen requires improvements in materials' efficiency and durability. Similarly, the drive to make wind and solar the main source of energy for electrification and the nation's grid requires large-scale energy storage systems. In Chap. 7, the story of ESS and its iron flow battery is discussed in detail.

Advanced materials technology plays a seminal role as well in the evolution of another significant component of 4IR, namely Artificial Intelligence (AI). AI systems absorb from The Cloud the vast amounts of data collected by advanced sensors. Powered by deep-learning technology, they identify and analyze salient patterns that allow them to come up with novel ways to solve problems for, and perform functions needed in, different fields of activity such as estimating when equipment failure will occur in an automotive plant, building robots to serve as waiters in a restaurant, predicting the occurrence of breast cancer for a patient, and teaching a self-driving car to identify and avoid pedestrians in a crosswalk. These advances also depend on MR and the advanced materials and processes that emerge from it. Further advance in robotics, for example, requires new types of polymers with flexibility and strength. The relationship between MR and self-driving cars is particularly compelling. For instance, they communicate with one another through a system of laser and radar sensors located on the vehicles. This requirement is forcing a revolution in advanced coatings and plastics that are radar and laser compatible. Companies like BASF are developing radically new automotive paints that increase reflectivity and can be used to make autonomous vehicles (AVs) detectable to laser and radar systems so that they can communicate with one another in real time (BASF, 2018). Self-driving cars also must communicate with the road itself. New types of smart materials are being developed to be incorporated into roads and highways to improve safety, increase energy efficiency, and advance traffic management. These advanced sensors and Wi-Fi transmitters monitor and report changing road conditions and provide broadband services to vehicles, homes, and businesses. They communicate with traffic lights and signals to optimize traffic flow. Smart pavement can also charge electric cars as they drive. All of these innovations require new ways of constructing roads and producing and assembling cars.

At the center of the 4IR and AI revolutions is the chip itself. The basic components of 4IR—sensors, actuators, and smartphones—require their own microchip technology with specific design and materials specifications. The sensor field alone must create a wide variety of chips for different types of sensors—biosensors, accelerometers, temperature sensors, piezoelectric sensors, optical sensors. The challenge for MR in meeting the performance demands of 4IR is to create new materials exhibiting ultra-sensitivity while enabling devices to operate with high energy efficiency.

Furthermore, 4IR demands that data storage and microprocessors enable computers to handle the unprecedented amount of data that must be collected, stored, and processed in an increasingly connected world. The fields of AI, data analytics, and genetic engineering are all data-hungry and cannot advance without this capability. But as the history of the microprocessor tells us, for the logic chip to increase its power, it must follow the dictates of Moore's Law. And here today, in 2024, this is the rub, for the number of transistors on a chip reaches tens of billions and the individual transistor approaches atomic dimensions, Moore's Law appears to be losing steam with many observers predicting its immanent failure. The business and technical press warns of this impending disaster. *The Economist* considers this reality and its impact on the semiconductor industry: "The twilight of Moore's law, then, will bring change, disorder and plenty of creative destruction. An industry that used to rely on steady improvements in a handful of devices will splinter. Software firms may begin to dabble in hardware (The Economist, 2016)." Possible solutions to this dilemma invariably turn to either novel transistor designs, the use of advanced materials and processes or both. They include developing radically new