Nanoinnovation: What Every Manager Needs to Know is the most comprehensive book written to-date on innovative technologies and applications in the field of nanotechnology. Author Michael Tomczyk conducted more than 150 interviews with nano-insiders to present the inside story of scientific discoveries, research breakthroughs, and commercial products and applications that are already changing our lives, thanks to the remarkable ability to manipulate atoms and molecules at the nanoscale.

Michael Tomczyk is one of the world’s leading authorities on nanoinnovation, and an expert on the impact of disruptive innovations on industries and markets. He became interested in nanotechnology while serving as Managing Director of the Emerging Technologies Program and the Mack Institute for Innovation Management at the Wharton School (University of Pennsylvania), where he provided managerial leadership for more than 18 years. He is a founding strategic advisor at the Nanotechnology Research Foundation, and served on the senior leadership of the IEEE/IEC committee that developed standards for the use of nanotechnology in electronics. As a technology pioneer, Michael is best known for his role in the development of the first home computers (at Commodore) in the 1980s. He holds master’s degrees in business (UCLA) and environmental studies (University of Pennsylvania) and a bachelor of arts in literature and journalism. Michael has written more than 150 articles. He retired from the University of Pennsylvania in June 2014 and is currently Innovator in Residence at Villanova University.
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Nanolinnovation

What Every Manager Needs to Know
This book is dedicated to

Fred Kavli (1927–2013)
Founder and Chairman, The Kavli Foundation

This book is dedicated to the late Fred Kavli. I was privileged to meet Fred in 2011 at the Wharton School when he was being presented with the Franklin Institute’s Bower Award for Business Leadership. He provided the following quotation for this book, although sadly he did not live to see it published:

“We cannot predict the future and foresee all the revolutionary developments that nanotechnology will bring us, but it gives us confidence that our rate of development and discovery will follow the logarithmic curve and maintain an ever-increasing rate of expansion and discovery to bring us a future that is so revolutionary that we cannot even imagine it today anymore that we could imagine the revolution that the transistor would bring when it was discovered in the 1940’s.”

Fred was a Norwegian (and naturalized American) entrepreneur, inventor, and philanthropist who used his wealth to fund the Kavli Foundation, Kavli Prize, and Kavli Institutes, including the Kavli Institute for Bionano Science and Technology at Harvard University. As you can see from this photo, the octogenarian retained his enthusiasm throughout his life and is a wonderful example of a world-class innovation champion.
# Contents

Preface \( \text{XI} \)  
Acknowledgement \( \text{XV} \)

## Part I What You Know (or Don’t Know) about Nanoinnovation \( \text{1} \)

1  **Quick – Name Something “Nano”** \( \text{3} \)  
   Your Nano I.Q \( \text{13} \)

2  **A Quick-Start Guide: 10 Things You Should Know About Nanoinnovation** \( \text{17} \)
   2.1  **10 Things You Should Know about Nanoinnovation** \( \text{17} \)
   2.1.1  **What is Nanoinnovation?** \( \text{18} \)
   2.1.2  **Five Categories of Nanoinnovation** \( \text{20} \)
   2.1.3  **Learning the Jargon of Nanoinnovation** \( \text{23} \)
   2.1.4  **How Small Is Nanoscale?** \( \text{26} \)
   2.1.5  **What Are the Unique (Quantum) Properties of Nanotechnology?** \( \text{28} \)
   2.1.6  **The Metrics of Nanoinnovation** \( \text{30} \)
   2.1.7  **The Need to Become Nanodextrous** \( \text{36} \)
   2.1.8  **Where Are We Now in the Evolution of Nanoinnovation?** \( \text{37} \)
   2.1.9  **A Short History of Modern – and Ancient – Nanoinnovation** \( \text{40} \)
   2.1.10  **Critical Issues for Nanoinnovation** \( \text{51} \)

References \( \text{52} \)

## Part II The Science of Nanoinnovation \( \text{55} \)

3  **What Nanoscientists Are Working On** \( \text{57} \)
   3.1  **Using Nanoscience to Solve Puzzles and Unlock Innovations** \( \text{58} \)
   3.2  **Solid Smoke: Catching the Comet’s Tail** \( \text{60} \)
   3.3  **Turning DNA into Boxes, Lattices, and Pyramids** \( \text{62} \)
   3.4  **How Nanoinnovation Is Extending Moore’s Law** \( \text{67} \)
   3.5  **Invisibility Cloaks, Optical Tweezers, and Nanophotonics** \( \text{72} \)
3.6 Nanoscience Wild Cards: Will Tree Lights Replace Streetlights? 77
3.7 Science Genius versus Commercial Challenge 84
3.8 Nanoscience Pioneers Are Mapping the Future 87
References 89

4 Imaging the Unseen: Viewing Structures Smaller than Light Waves 91
4.1 What Nano Images Reveal 91
4.2 Using Electrons Instead of Light to View Nanoscale Structures 97
4.3 A Short History of Nanoscale Imaging 97
4.4 Different Types of Nanoscale Microscopes 99
4.5 Bringing Biological Nanostructures into Focus 102
4.6 Using Optical Imaging Systems to View Nanoscale Structures 104
4.7 Probing the Future 106
4.8 Nanoscopes on Mars 109
4.9 The Future of Nanoscale Imaging 111
References 112

5 Where Nanoscience Becomes Nanoart 113
5.1 Holistic Nano at the Convergence of Nanobliss, Nanoform, and Nanofunction 116
5.2 Innovating at the Convergence of Biomimetics, Nanoart, and Nanoscience 119
5.3 Using Art to Conceptualize the Future 123
Reference 125

Part III The Business of Nanoinnovation 127

6 Lessons from the First Wave of Nanoventures 129
6.1 The First Wave of Nanoventures 130
6.2 Zyvex: Divide and Conquer 131
6.3 Zyvex Piranha: The First Carbon Nanotube Boat 139
6.4 Nantero: Patent, Fabricate, Outsource 143
6.5 QuantumSphere: Competitive Catalysts 147
6.6 InsituTec: From Grad Students to Commercial Venture 153
6.7 Nanocomp: Taking Nanotubes to Jupiter and Beyond 155
6.8 Nanosys: Resurrection and Redemption 159
6.9 Graphene Frontiers: Commercializing Graphene 162
6.10 Carbon Nanotechnologies: Early Promise, Not Fulfilled 165
References 165

7 Implementing Your Nanoinnovation Strategy 167
7.1 A Sense-Making Framework for Nanoinnovators 167
7.2 10 Strategic Questions that Nanoinnovators Need to Ask 168
7.2.1 What’s the Value Proposition? 169
7.2.2 Where Do We Fit in the Supply Chain? 170
7.2.3 Can This Be Funded with "Patient Money?" 171
7.2.4 Can the "Lab Solution" Be Translated into a "Commercial Solution?" 172
7.2.5 Is the Intellectual Property Secured? 173
7.2.6 Do We Have the Right Partners? 174
7.2.7 Is This the Best Team for This Project? 174
7.2.8 Is Our Strategy Flexible? 176
7.2.9 What Are the Obstacles? 176
7.2.10 Is It Safe? 177
7.3 Where to Learn About Nanoinnovation 178
Reference 180

8 International Perspectives 181
8.1 The Critical Role of Nanoinnovation Ecosystems 183
8.2 Nanoinnovation in the Asia–Pacific Region 188
8.3 Nanoinnovation in Latin America 191
8.4 Nanoinnovation in the European Community 194
8.5 Insights from Selected Nanoinnovation Ecosystems 199
8.6 Critical Issues for International Nanoinnovation 206
8.7 Nanoinnovation for the Bottom of the Pyramid 210
References 212

Part IV Where Bio Meets Nano 215

9 Innovation at the Frontiers of Nanomedicine 217
9.1 Medical Miracles and the Nanomedicine Landscape 218
References 226

10 Areas Where Nanoinnovations Are Creating Medical Miracles 227
10.1 Smart Pills and Wearable Sensors = Digital Medicine 228
10.2 Organs-on-a-Chip 232
10.3 Growing Your Own Replacement Organs 236
10.4 Tumor-Seeking Nanoparticles 248
10.5 Nanosizing Drugs 257
10.6 Gene Therapy: The First Breakthroughs (At Last) 258
10.7 DRACO: Designing a "Kill Switch" for Viral Diseases 277
10.8 Nanoinnovation in the Decade of Diagnostics 286
10.9 In Search of the Star Trek Tricorder 290
10.10 Nanobacteria: The Smallest Life-Form? 292
References 294

11 Nanomimicry: Cool Things We Can Do with Nanobiology 297
11.1 Turning DNA into Nanocomputers 298
11.2 Turning DNA into “Walking” Nanorobots 299
11.3 Nanomimicry: Learning from Nature at the Nanoscale 300
11.4 Mimicking Geckos to Create Glue 300
11.5 Biomimicking the Waterproofing Properties of Butterfly Wings 306
References 309

12 Nanotechnology: Is It Safe? 311
12.1 Early Experience with Nano Safety 313
12.2 What We Know about Nanoparticle Risks 316
12.3 The Regulatory Climate and Safety Knowledge Gaps 321
12.4 Perspectives of Nano-Insiders 326
References 328

13 Prologue to the Future What’s Next?: Predictions and Possibilities 329
13.1 Keeping Nanoinnovation on Your Radar Screen 340
References 340

Appendix A: Answers to the Nano I.Q. Quiz 341

Appendix B: Carbon Nanotubes: Company List 349

Appendix C: University Nanotechnology Research and Educational Centers 353

Index 359
Preface

In 2000, I was giving a series of presentations to industry and academic groups on radical innovations that have the potential to reshape the future, and one of these innovations was nanotechnology. At the time, there was a lot of hype around “nano,” but I had the sense that most people didn’t really understand what was really going on in the field. So I began asking my audiences, “Who can name one product that uses nanotechnology?”

To my amazement, most people couldn’t name a single product. This happened year after year. In the fourth year, one hand went up and someone said, “carbon nanotubes.” At the time, I knew there were already more than a thousand products that used nanotechnology. Obviously, the business community needed to know more about nanoinnovation. At the same time, many of my colleagues in business were expressing frustration over the media hype and constant flow of “breakthrough” announcements that were causing a lot of confusion and misinformation. Finally, I decided to write a book that tells what’s “really happening” in nanoinnovation – the book you’re reading now.

I started by interviewing nano-insiders in business, government, science, and academia. Thanks to contacts shared by friends like Michael Terlaak and others and by using LinkedIn and other networking resources, I was able to interview more than 150 nano-insiders. Over time, I got to know many of the most prominent nano pioneers. I invited them to provide updates on their research at an annual event I hosted at the Wharton School called the Emerging Technologies Update Day.

Virtually everyone I contacted was eager to participate and to help convey the “real story” of nano. In addition, people in many countries worked behind the scenes to answer questions, provide details, and secure permission for nanoscale images. Some laboratory technicians took nanoscale photos especially for this book. Others provided me with background summaries of nanotech projects and details that are not yet public.

One of my most important challenges was to make this a dynamic publication. When I began this project, I noticed that a lot of nanotechnology books offered snapshots of innovations that quickly grew out-of-date, so I tried to take a slightly different approach. My goals were to make this a starting point, not an endpoint or snapshot. So I tried to design this as a dynamic living document that
you the reader can use as a basis to continue your own investigations. Most of the nanoinnovations you’ll learn about here will continue to evolve over time, and you can easily track their progress on the Internet and in science and business media.

Another goal of this book is to give credit to some truly impressive pioneers, and tell their stories in their own words where possible – because many of the most significant breakthroughs are the result of extraordinary personal effort. It’s fascinating to learn, for example, how Ned Seeman gleaned a breakthrough idea from a woodcut on the wall of a pub while enjoying a beer, or how Tony Atala redesigned inkjet printers to “print” human organs. I also invited business entrepreneurs to discuss how they developed their ventures – including failures as well as successes.

This is not just a book about what’s happening in nanotechnology – this is also a book about what you can make happen. You don’t have to be a scientist to be a nanoinnovator, or to champion nanotechnology. I know this, because early in my career I was fortunate to play a role in developing and launching the world’s first home computer (the Commodore VIC-20). I was not an engineer. I went to college in Oshkosh, Wisconsin and studied literature and journalism. After military service as a US Army officer, I earned an MBA from UCLA, fell in love with home computers, and played a lead role in developing and launching the first home computers at Commodore. My love affair with emerging technologies helped me to become a pioneer in home computing and kept me involved in innovation throughout my career, including 18 years at the Wharton School as Managing Director of the Emerging Technologies Management Research Program, the Mack Center for Technological Innovation, and the Mack Institute for Innovation Management. As my own story confirms, there are many paths that allow you to get involved in innovation.

Most of the nanotech pioneers you’ll meet in this book did not start out specializing in nanotechnology. They come from physics, chemistry, biology, engineering, business, environmental technology, and other fields. Most are self-taught. For many researchers, nanotechnology was so new and different that it forced them to think in new and different ways. Their stories are fascinating.

One of the things we learn from their stories is that anyone can be a nanoinnovation champion. If you’re in a company, you can support and cultivate an innovation culture that includes the manipulation of atoms and molecules in the R&D toolkit. If you’re in marketing, think about how nanoinnovations will compete with existing technologies and change your industry. If you’re managing a business, think about how nanotechnology will affect your organization, your industry, and your competitive markets. If you’re a parent, encourage your children to study science and technology – especially nanotechnology. If you’re a teacher, push to integrate nanotechnology in your school curriculum. Learn about nanotechnology and scan the horizon for emerging technologies and applications. If you’re in a country that is out of the nanoinnovation mainstream, find ways to educate students and seed the nanoinnovation process. Focus on
how nanotechnology can solve problems in your country, especially problems for which there are no other solutions.

As you read this book, keep thinking about how nanoinnovation will change your world. Will a new material made from carbon nanotubes or graphene replace plastic, steel, or aluminum? Will nanosensors create a “sensor revolution” where almost anything can be detected? Will nanomedicine cure diseases that have been stubbornly resistant to cures for decades or centuries? Will we be growing our own hearts and livers to replace failing, damaged, or even aging organs? Will we wrap buildings in nanoskins to regulate environmental conditions? Will we change the structure of materials by mimicking innovations created by Nature, such as creating a new type of dry adhesive by imitating the footpads of a lizard, or engineering a material based on the nanostructure of a butterfly’s wing?

The answer is, these wondrous things are already happening. The revolution in nanotechnology is changing our lives, wherever we live on the planet. Many of these nanoinnovations are happening out of sight and are hidden from view in research laboratories. Some innovations are discussed only in specialized science, engineering, or medical journals. This book throws light on hidden corners of science and technology, just as nanoimaging systems reveal nanoscale objects that are smaller than visible light waves. It also gives you a portfolio of ideas and themes that belong on your radar screen, if you want to keep current on what will be happening in the coming decades, in nanotechnology and other areas.

These are exciting times to be involved in science, technology, and business. There have never been so many innovations poised to change our lives, from robots that walk and fly to genetic solutions that will save and prolong our lives. Everything is changing, from how we use mobile social media to communicate, to how we process and package food, to how we use energy. Most of these innovations are visible, but the science and technology that drives them is invisible, and that’s why we need to know more about nanoinnovation.

I invite you to join me and millions of others who are helping to drive progress through nanoinnovation. Together, we can make the future happen faster.
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Several university colleagues at the Wharton School and University of Pennsylvania played an important role in my “academic development.” I want to thank Jerry Wind, Saikat Chaudhuri, and the Mack Institute’s Core Group for giving me an informed vantage point on a wide array of emerging technologies during my more than 18 years at the Wharton School. I joined Wharton in 1995 to help launch the Emerging Technologies Management Program, which in 2001 became the Mack Center for Technological Innovation and in 2013 became the Mack Institute for Innovation Management. Throughout these changes I was privileged to provide managerial leadership as Managing Director, which kept me thinking constantly about radical innovations including nanotechnology.

I started writing this book while studying for my master’s degree in environmental studies at the University of Pennsylvania. The research methodologies I learned during my graduate studies were immensely valuable. Yvette Bordeaux, who chaired the Master of Environmental Studies (MES) program at the University of Pennsylvania, helped me tailor my graduate studies to include nanotechnology in my curriculum, including a superb course on nanotechnology taught by Dr. Jody Roberts from the Chemical Heritage Society. My graduate advisor Stan Laskowski was extremely helpful and supportive.
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Having started my career as a journalist, I greatly appreciated the availability of Google, Google Scholar, LinkedIn, Gmail, and other tools that gave me instant access to emerging innovations and allowed me to contact virtually any nano-insider I wanted to interview, including some of the world’s leading scientists and business leaders.

My mega-thanks and gratitude go to the more than 150 nanotechnology insiders who participated in interviews and provided information, insights, and images, graciously sharing their experiences to help make this book accurate, relevant, and “real.” Many of these pioneers and champions have already made tremendous contributions to the field of nanotechnology, and continue to help drive nanoinnovation forward. Others are toiling 24/7 in laboratories and offices to turn possibilities into solutions. Their enthusiastic participation in this book project allowed me to include observations and opinions that can only come from insiders who truly know what’s really happening in nanoinnovation. I also want to thank those who provided or facilitated the use of the images and diagrams included in this book.

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– Michael S. Tomczyk
Part I
What You Know (or Don’t Know) about Nanoinnovation
Quick – Name Something “Nano”

Quick – name something “nano.”

Name something that occurs at the nanoscale – a structure or process that we measure in nanometers. One nanometer is a billionth of a meter. Nanoscale refers to 100 nm or less. So name something under 100 nm.

As a manager, you should be able to name at least one or two things that are nanoscale. Can you do it? How quickly?

Are you still thinking? Do you have it? Are you sure that’s a nanoscale example? Okay. Let’s make it easy. Name something nano that occurs naturally in the human body.


A human hair is 50 000–80 000 nm thick. A red blood cell is about 2000–5000 nm. A white blood cell is about 10 000 nm in diameter. The period at the end of this sentence may contain 1 000 000 nm of ink.

Think smaller. Much smaller.

Can you name one commercial product that uses nanotechnology? This could be something that contains nanosized particles or nanomaterials. Here’s a hint: You can find a nanotechnology product in almost any gift shop on the beaches of Cancun, Florida, California, or the French Riviera.

What about man-made nanostructures (Figure 1.1)? Almost any nanotechnology article talks about carbon nanotubes, the popular building blocks of nanotechnology. Can you name one product that uses carbon nanotubes?

Here’s one example – most automobiles use carbon nanotubes in engine coatings because their semiconducting properties make nanotubes ideal for controlling static electricity or sparks that might cause a fire or explosion. Nanotubes are also mixed with polymers in seat covers so that you don’t get a shock when you slide behind the wheel on a cold winter day. Carbon nanotube fibers are so incredibly strong and durable that they are used to strengthen military body armor.

Nanotechnology is used in an incredible variety of products, processes, and applications. Your tablet computer and smartphone use nanoscale circuits. Your flat screen TV is thin and lightweight, thanks to nanomaterials. Nanoskins protect antique buildings. Edible nanoskins protect apples and other fruits, and
allow the last drop of ketchup to slide out of the bottle – although most food manufacturers are being highly secretive about their use of nanomaterials, having been spooked by the industry’s experience with genetically modified foods.

Nanomaterials protect your pants against stains, liquids, mildew, and wrinkles. A nanofiber pocket in your shirt or jacket can screen the radiation from your cell phone. Athletes can buy no-smell socks infused with nanosilver particles that eliminate odor-causing bacteria. Other applications include clothing that changes color in response to light or body heat.

Many clothing items use technology developed by NanoTex, a US-based company that uses nanotechnology to develop “intelligent fabrics.”

Figure 1.1 Carbon nanotubes that are 1 or 2 nm in diameter can be grown on a substrate as a tangled “forest” (a), made to grow in tight clusters (b) and formed into complex shapes and patterns, using photolithography and catalyst patterning (c). Shown here is the first nanoscale image of a world leader – President Barack Obama. Each Obama face contains 150 million nanotubes (images by Anastasios John Hart, University of Michigan).