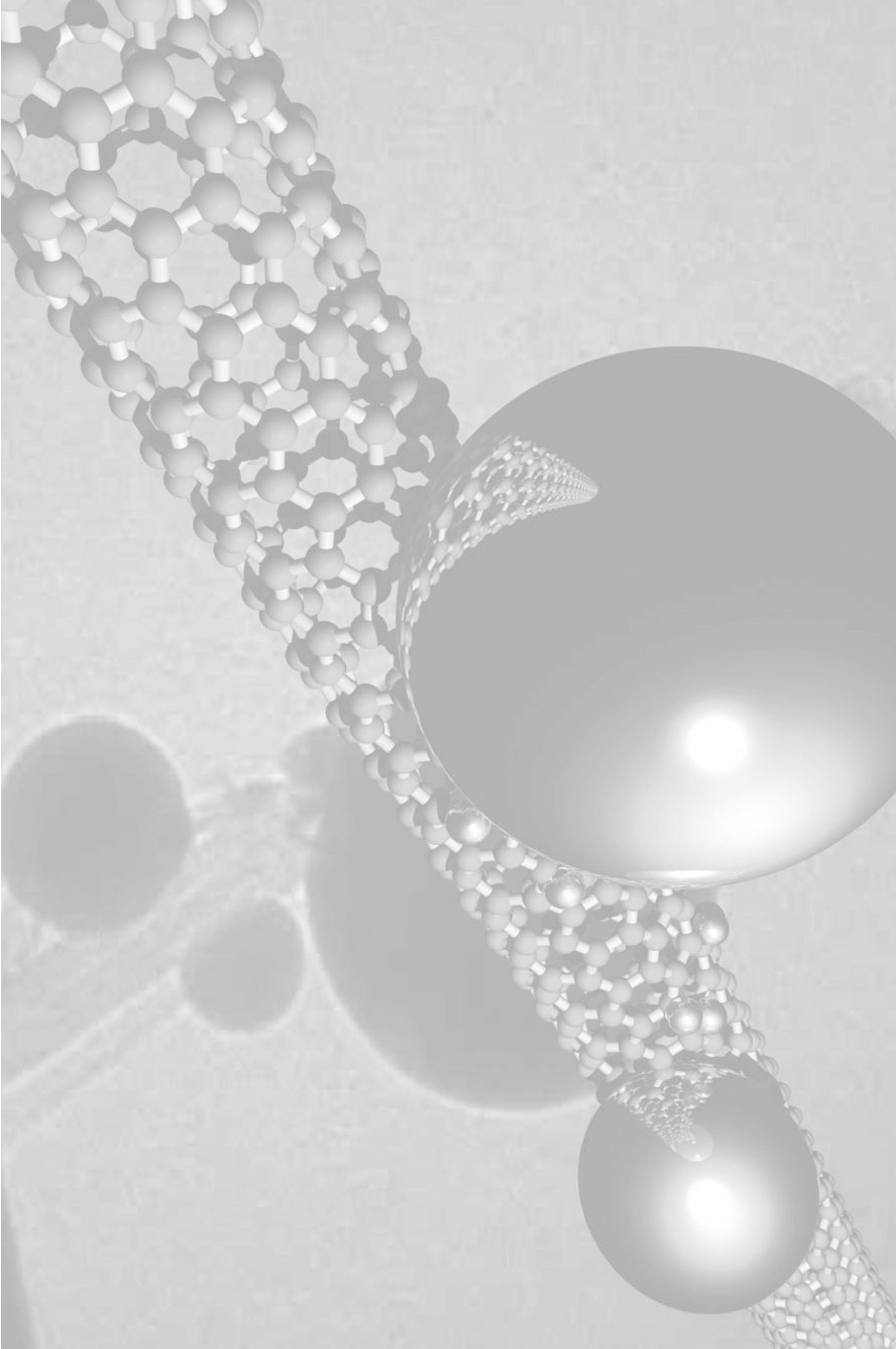

2

How Engineering Got Its Paradigm Shifted

The new era of engineering is being shaped by forces that have been building over several decades as well as by more recent events. This chapter looks at the trends that are reshaping and redefining engineering as we knew it.

Changes in the Nature of Engineering

Much of the transformation in engineering is being driven from the inside out. In this section, we'll explore changes in the scale of engineering, the increasing levels of collaboration among engineers, and the upward spiral of engineering influence on everything from products to corporate profits.

Engineering on a Whole New Scale

We're seeing radical changes in the scale of engineering on multiple fronts. First, the diversity and complexity of materials used in new products today are staggering, and some of the synthetic materials and chemical compounds we're using are creating issues we didn't anticipate and are still struggling to deal with: how to dispose of nonbiodegradable materials; how to prevent toxic and hazardous substances from leaching into our air, water, and soil; and how to reuse materials that were designed for very specific purposes.

Second, we now have the ability to produce things by the billions, the capacity to distribute them globally, and the markets to consume that kind of scale. Global markets, global fashions, and global consumer trends result in mass production of successful products—*and the repercussions of success can far exceed anything engineers originally envisioned.* The gizmo that's on your drawing board today could be on tens of thousands of store shelves in an incredibly short time. So, any unresolved environmental issue, design issue, or intellectual property (IP) issue gets proportionally amplified, often globally.

Simply put, the problem of scale can transform today's solution into tomorrow's problem. Did Henry Ford have any inkling that a hundred years after the introduction of the Model T we'd be trading streets full of manure for global climate change, due in part to the exhaust of more than a billion cars?

"When you scale things up, you change the fundamentals, and engineers are called upon to go back and innovate again and make the product or service sustainable," says Sun engineer Subodh Bapat. "We've seen this happen time and again—products that solved one problem and created another because of unforeseen scale issues: Teflon; DDT; more recently, CFLs [compact fluorescent lamps; see Figure 2–1] with their mercury content. I think today's Citizen Engineers will need to start thinking further ahead and consider the potential impact of success—from a sociological perspective. Our challenge will be to design products that can succeed in the marketplace without damaging our environment or our culture."

FIGURE 2–1 Examples of CFLs

That's no simple task, particularly given the accelerating pace of change in everything from technology to geopolitics. "Perhaps it is always hard to see the bigger impact while you are in the vortex of a change," wrote Sun cofounder Bill Joy in *Wired* magazine.[1] "Failing to understand the consequences of our inventions while we are in the rapture of discovery and innovation seems to be a common fault of scientists and technologists; we have long been driven by the overarching desire to know what is the nature of science's quest, not stopping to notice that the progress to newer and more powerful technologies can take on a life of its own."

While product volumes can scale to huge sizes, engineers are using building blocks of ever-smaller scale. We've gone from working with tons of raw materials to transistors, nanomachines, photons, and base pairs. Today we're working at an atomic scale to create new raw materials that can be used to create lighter-weight, sturdier autos and aircraft; we're manipulating subcellular structures such as recombinant DNA to create new biologics, pharmaceutical products, and potentially even new species; we're using microorganisms to develop everything from new breeds of biofuels to a new generation of fermented beverages. And as the size of our source material continues to shrink, the opportunity for building new and better products continues to grow.

Consider also the changing scale of our computational capabilities and how they have radically altered what it is possible for engineers to do. One eminent engineer at Sun put it this way: "What's different about today's era of engineering comes down to two things: mathematics and computers. Go back a hundred years or so: Thomas Edison tinkered stuff into existence. He tried thousands of filaments for his incandescent bulb—one by one. And he used direct current because when you're dealing with alternating current you have to work with complex numbers, and he simply didn't have the math to do it. Westinghouse, on the other hand, had Nikola Tesla and Charles Steinmetz, who could handle the math involved. Today, the ability to use high-powered computers to do mathematical modeling and simulations is absolutely vital and central to the nature of engineering. And as the scale of computing increases, so does the power and influence wielded by engineers."

A final aspect of scale to consider is the temporal impact of the products and services we design. "The scale of our impact on the environment now has effects on time scales much longer than those of typical human time horizons," wrote Kirk R. Smith, professor of Global Environmental Health at the University of California, Berkeley, in an editorial about climate change.[2] "The archetypal example is perhaps global pollution leading to global climate change. We are now well into a planetary experiment on the effect of injecting a bolus of warming pollutants, three to four times natural levels, during an instant of geological time. Nothing much happens at first, but analysts say that much more is set to happen unless we mend our ways soon."

Simply put, Citizen Engineers will need to consider the long-term issues of what they produce—air pollution, climate-changing emissions, potential public health issues, and so on—at the same time they're addressing today's problems.

In summary, we can now design things that are more complex, can last longer, have more impact, and can be replicated more times than anything that came before it. This gives tremendous power to engineers, but also tremendous responsibility.

Pervasive Collaboration

The Internet also broadens the scale of engineering collaboration. We now have instant access to the thoughts, insights, and feedback of other engineers, community members, partners, suppliers, and customers, all the time. The result is a surge in the sheer volume of new ideas (because more ideas from more sources are instantly accessible); constant growth in the size of engineering teams; and the demise of the mythical "lone-wolf inventor" as an icon of engineering.

"People had this image of a mad scientist working alone in a lab, and you slide a pizza under the door every once in a while until they emerge with this ingenious new thing," says Sun's Bapat. "And it's so laughable. Engineering success today is about teamwork; teamwork is about communication skills and collaboration tools; and the network is the ultimate collaboration tool."

"Individuals have more tools and more power as engineers than ever before to both receive information and communicate with others," says Sun engineer Mike Shapiro. "And the individuals who work most effectively are the ones who seek out information and input from their colleagues."

For individual engineers, the Internet means instant access to the knowledge and research of colleagues around the globe, an incredibly powerful tool. For groups of engineers, it means collaboration can take whole new forms. For example, development work on Sun's Solaris operating system is now perpetual: Software engineers in the United States work all day on new features, enhancements, and bug fixes, then transfer their work over the network to another team in Asia, which works all day and then transfers its work to another team in Europe—so that 24 hours a day, someone somewhere is working on Solaris.

The Internet has also enabled competition among engineering teams—even teams from the same company working in different parts of the world. At GM, for example, two design teams more than 6,000 miles apart—one in Detroit and one in China—competed for the right to reengineer the Buick LaCrosse for the Chinese market.[3] After an intense internal competition, the Chinese team won complete authority over the interior design, while the exterior was handled in the United States, but with a great deal of input from China. Eventually the two teams collaborated, harnessing the network to share ideas and design concepts.

The network also makes it possible for ad hoc communities of engineers to spring up overnight to work on specific technologies or technical issues. Some projects spring up as communities of like-minded individuals. In other cases, software projects initiated by corporations are virtually taken over by these communities—to the benefit of the corporation, the community, and consumers alike. We could write a separate book on that topic. At Sun alone we've seen more than a hundred communities form to build on our core technologies, from performance tuning Open Solaris to improving Java security to translating products and documentation to additional languages.

Broader Influence for Engineers

As the scale of engineering increases, so does the influence wielded by engineers. You see the evidence all around you—literally. You're surrounded by things engineers created, and chances are you're using more "things" than ever before.

You've probably also noticed the increasing clout of the engineering department within the corporation and the growing number of engineers in the executive suite. You personally may be benefiting from the premium salaries paid to top engineering talent and the fierce recruitment battles for the best and brightest from our universities (not too different from the competition for running backs and defensive ends in pro football). But there are other dimensions to this widening sphere of influence.

Salaries for engineers are rising—and rising faster than those of other professions. According to recent data from The Engineering Income & Salary Survey, median salaries for engineers are up more than 10% from 2006, and up more than 19% from 2005. The average starting salary for an engineer with a bachelor's (four- to five-year) degree ranges from $36,000 to $50,000—significantly higher than salaries for graduates with bachelor's degrees in many other fields. In comparison, lawyers starting out after at least seven years of school average just $45,000.

Higher economic impact and higher salaries translate directly to greater influence within the organization. One interesting piece of evidence: The most common undergraduate degree for CEOs of Fortune 500 companies is not marketing, sales, or finance—it's engineering, with 20% of all CEOs holding engineering degrees.[4]

But it isn't just their growing economic impact that has increased engineers' influence. Once again the network plays a crucial role. Sun engineer Mike Shapiro provides an excellent example: "When I was in college I wrote a program for the Macintosh—a little utility, which I gave to friends and put on an FTP site. With it I included a message: something to the effect of 'this is free, but if you like it, send me a postcard.' The utility became very popular, and I literally started getting pounds of mail from around the world. People sent me everything from a ten-lira note to pictures of their children—even recipes. That's when I realized how much influence I can have as an engineer, and how much reach my ideas can have. And the fact that you can have that level of influence that quickly—it's very powerful and revolutionary."

As this example shows, engineers are now often getting closer to their users, using the network to stay in touch with them over time. Millions of engineers blog and "tweet," including thousands at Sun. Many software companies urge their engineers to be active on the company's online forums, interacting directly with customers on their issues and ideas. And in almost every case we've seen, engineers have accepted the responsibilities that come with this unfettered access to the "real world." As a result, companies are pushing engineers to the edge of the company, not burying them inside for fear of what they may say.

Another aspect of engineering influence is subtler but equally important: the ability to change the way people think. And you don't have to work for a large organization or an economic powerhouse to do that.

Consider the example of Tesla Motors, the Silicon Valley start-up company that's building the first high-performance, consumer-oriented electric cars. The company's first production car, the Tesla Roadster, has a range of 221 miles (394 km), accelerates from 0 to 60 mph (100 km/h) in less than 4 seconds, and has power costs of only about 2 cents per mile. It emits no exhaust. Simply put, it's the car that proves that an eco-effective yet practical vehicle is technologically within our grasp. The company's financial future, however, is in question. Despite having raised more than $100 million, it remains to be seen whether Tesla's business model proves viable.

The point is, whether or not Tesla Motors survives, it has already won a huge victory in terms of influence. "I would argue that Tesla has already changed the world," says Craig Carlson, lead software engineer at Tesla Motors. "If we have to close our doors tomorrow, we will still have had a major impact, because people have seen that it is possible to build a very impressive electric vehicle now, and that wasn't clear a few years ago. So, I'd argue that we've been very influential even if the road isn't full of Tesla vehicles."

Combined with the disintermediation we've described, this ability to change minds and alter purchase decisions is evident in many forms today: blogs from engineers offering tips on minimizing power consumption in new devices; YouTube videos showing new ways to use photovoltaic cells. Increasingly, engineers have both an important message and the medium to deliver that message.

When you combine the increased economic impact engineers have; the increasing speed, power, reach, and capabilities of the network; and the growing ability of engineers to shape attitudes and purchasing decisions, the result is an enormous expansion of influence for engineering.

Externally Driven Changes in Engineering

We've said that the emergence of the Citizen Engineer is partly the result of trends within engineering itself and partly due to new pressures from society. Let's take a look at a few of the society-driven changes.

The Green Explosion

Flip through any newspaper or magazine and you'll see that as a society we've become obsessed with eco-friendliness. The News section will have articles about the opening of a local recycling center or a new battle between the EPA and the state of California over the jurisdiction of eco legislation. The Sports section will include articles about new eco-friendly packaging for hydration products and more energy-efficient lighting at stadiums. The Style section will discuss the latest green fashions featuring clothing made from bamboo or hemp. The Home section will provide pointers about cutting the power consumption of appliances or making the move to geothermal heat-transfer systems. And the Business section will be filled with articles about new corporate environmental initiatives, the latest take-back legislation, or sales projections for the Smart Car.

This wave of green isn't just a passing fad. Legitimate concerns over climate change driven by increased production of greenhouse gases (GHGs), shortages of fresh water, and issues with disposal of complex chemicals are just the tip of the proverbial iceberg (oh yeah, those might be disappearing also). In addition, the increasing scarcity of energy sources and critical natural resources will have growing economic impacts. Jeffrey Immelt, CEO of GE, says "Green is green," recognizing the tight coupling of our ability to produce sustainable products and services, and our ability to have a growing economy.

In response, the new generation of green products and gizmos has arrived in full force. On display recently at the Consumer Electronics Show in Las Vegas:

- Solar-powered backpacks that can do everything from charging your cell phone to heating water for an outdoor shower
- A laptop with a plastic case made from corn rather than petroleum products
- Smart power adapters that don't waste as much electricity
- New silver-zinc batteries that could replace the highly toxic lithium-ion batteries that power most cell phones and laptops today
- Home automation systems that can be set to make intelligent decisions about when to turn themselves off

What it all means to Citizen Engineers is that the market for eco-effective products is here; consumer demand for eco-effective products is real; and efforts that ignore standard practices for eco-effective design will be punished by the marketplace.

Corporate Social Responsibility

Corporations have a major environmental impact, but they can have a huge effect on society as well. Companies touch the lives of their employees in some way almost every day, and they impact everyone they do business with as both a buyer and a seller of goods and services.

In recognition of this, the practice of Corporate Social Responsibility (CSR) is exploding. Shareholders are asking whether the companies they invest in are exposed to unnecessary risks or legal liabilities. Companies are checking into the ethical behavior of their major suppliers. Watchdog organizations are keeping tabs on every direct and indirect impact of corporate behavior. And consumers are reacting with a vengeance when bad news comes in any form.

For engineers, this means a new set of things to pay attention to. Selecting a part that is made by only one company of questionable background is probably not a good idea. Outsourcing to factories with bad pollution records will be noticed. And the discovery of a competitor's files on your company's computers can be expensive on many different levels.

Security and Privacy Concerns

Virtually everyone has a creepy story involving an online scam, identity theft, or fraudulent use of sensitive information. Maybe you returned home from a vacation and your credit card statement included the purchase of a new plasma TV that you don't recall buying. Maybe you got a couple hundred bounce-back emails one day because your computer or email address has been usurped by some kind of "zombie" or "bot" to send spam. Or maybe you responded to an email about a recent purchase on eBay and noticed that the Web site you were directed to was a fraudulent subdomain (ebay.cbay.com or www.paypai.com; see Figure 2–2).

FIGURE 2–2 Examples of Authentic-Looking Brand Marks Designed to Entice Users to Fraudulent Web Sites

We all know that malware, viruses, phishing scams, man-in-the-middle attacks, worms, logic bombs, and various other exploits have been with us for many years and will probably always be part of the online landscape. But few of us realize just how serious this problem is becoming.

In 2007, the losses from phishing attacks in the United States alone reached the multibillion-dollar level worldwide, according to the Anti-Phishing Working Group (APWG). And recent exploits underscore the growing sophistication and creativity of hackers. It's not just the naïve who are victimized.

In 2007, for example, a wave of "pump-and-dump" scams on stocks trading on NASDAQ victimized seven online firms, earning the perpetrators $732,941 in illegal profits.[5] The attackers used phishing techniques to break into the accounts of innocent brokerage customers. They sold off holdings and used the money to purchase penny stocks, then used email promotions to artificially inflate the price of those stocks and sold them at a profit. Another example: An engineer from Virginia (an engineer!) thought hackers who broke into his computer stole only his bank account information; but a hidden virus continued to record his every keystroke, and hackers soon got his new account information and passwords too.

There is even a thriving underground economy for stolen personal information. A complete identity—a package of a person's name, date of birth, Social Security number, and credit card and bank account numbers—sells for about $14 to $18, according to Alfred Huger, vice president of Symantec Security Response.[6] Huger says a verified PayPal account sells for $50 to $500, depending on the available balance in the account. And there is a large and growing market for malware, the software that hackers use for phishing and other exploits. For subscriptions starting at about $20 per month, organized hacking gangs sell fully managed exploit engines that spyware distributors and spammers can use to infiltrate systems worldwide.[7]

And the threat to our security and privacy doesn't come only from malicious exploits. Many legitimate companies collect massive amounts of data about us: the time, date, and particulars about our past purchases; the frequency of our visits to their stores or branches or Web sites; and the tendencies, tastes, and preferences we've displayed about everything from reading materials to frozen foods. We trust them to protect our privacy, but we have no real assurance that they will, beyond the "privacy protection policy" that we scroll by on our way to the Checkout button. Nor are we even aware, necessarily, when companies breach our trust and sell or exploit our private information.

Some of the most obvious and egregious problems with privacy protection are now so commonplace that we barely notice them. Even today, when you log onto Amazon.com, for example, you'll be greeted with a message such as "Hello, Greg Papadopoulos. We have recommendations for you." Right next to that you'll see a link that says "Not Greg?" It might as well say "Not Greg but want to use Greg's account anyway?" or "Not Greg but interested in Greg's personal information?" Identity management has a long way to go.

What all this means to engineers is that there will be increasing pressure—and incentive—to design products and services that ensure data security and protect consumer privacy while still allowing companies to use data to improve customer service. And beyond this, a Citizen Engineer needs to be active across the entire dialog of product and service design and planning—to be informed and to reason through social consequences. It is, after all, systems designed by engineers that have at once created the opportunities and the potential for misuse. We can't enjoy the benefits without also assuming the responsibilities.

Rise of Digital Goods

Our notion of a "product" as a physical entity has been challenged by the rise of digital downloads. Huge numbers of consumers now have the tools to create, market, sell, and collect money for movies, photography, music, games, and more.

Perhaps not surprisingly, the environmental pluses and minuses of digital goods create some difficult questions for engineers. How will you encourage people to purchase digital goods and make it more convenient for them to do so while protecting the rights of the people who created the digital content? What is the environmental impact of digital products and how will you measure it? Which IP laws apply to digital goods and how will you stay abreast of fast-changing IP laws relating to digital content?

Digital rights management (DRM) systems are available to help control the distribution of protected content, but these systems raise additional questions. Does DRM quash creativity and freedom of expression? After all, in both science and art, innovators build on each other's work. And is tighter control of digital goods a good thing for business in the long run? Won't consumers find workarounds, as they did with Napster, and create a perpetual game of cat-and-mouse with businesses and content owners?

It's up to all of us who see ourselves as Citizen Engineers to advocate policies and to design technologies that respect the legitimate needs and current rights of honest users.

New Laws, Tighter Controls

Engineers who were once preoccupied by Moore's law are now dealing with more laws—an ever-increasing set of regulations and controls governing their work. The world is increasingly a patchwork of laws that regulate everything from chemical content to noise levels to recycling to safety labels.

In addition to laws, engineers often face tighter controls and processes within their own companies. These often come in the form of formalized quality assurance methodologies. Six Sigma, Statistical Process Control (SPC), Total Quality Management (TQM), the Shewhart Cycle (a.k.a. Plan-Do-Check-Act or PDCA), Top Quality Control (TQC), Zero Defects, and Software Quality Assurance (SQA) are just a few examples.

Engineers understand that process and constraints are important, but they almost always make engineering more complex. In addition, there's a very fine line between a well-designed process that adds value with limited overhead and a poorly designed process that inhibits engineering and provides little or no value add.

From an engineering perspective, not a lot can be done. It is important to educate our legislators and corporate process wonks on what will be effective and what will be just plain expensive. But it's also important to invest the time to understand the laws and processes that do exist, in order to build them into your designs and activities so that you can stay legal both inside and outside your company.

Perspectives on an Engineering Transformation

In the course of writing this book, we've had an opportunity to speak with many of our colleagues about the emerging era of socially responsible engineering, and the different perspectives we've heard are fascinating and illuminating. We'll end this part of the book with a few viewpoints that lend additional contour.

First, as several of our colleagues have pointed out, what's "new" about this era is not the focus on responsibility; engineers have always taken their civic and moral responsibilities very seriously. What's new is the groundswell of interest among engineers in extending that same conscientiousness to new areas: to the environment, to the proper use of intellectual property, and to public policy, for example.

Nor is it new that engineers now have to "juggle many balls" and broaden their knowledge beyond the field of engineering. But our colleagues sense that what we're seeing today is a growing recognition of the importance of "breadth" in the face of steadily mounting pressure to narrow one's focus.

It's a very interesting phenomenon. Today, as Sun's cofounder and chairman, Scott McNealy, once said, "Technology has the half-life of a banana." As technologies and fields of engineering continue to grow more specialized, more and more time and effort are required to master any engineering specialty and stay abreast of developments. Yet the new generation of Citizen Engineers has recognized that if you only know your stuff, you'll eventually limit your role, your professional options, and your influence. And in ever-growing numbers, they're looking to broaden their formal education and extend their skill sets beyond traditional fields of engineering.

Several engineers have voiced the opinion that engineering itself isn't changing at all—economics are. "Society keeps changing, so the economics of meeting society's needs keep changing," one of Sun's most distinguished engineers commented. "Engineering hasn't changed; it is still the art of making something useful that's also economic. And if you argue that social responsibility boils down to economics, then what we're seeing today certainly isn't anything new."

There are plenty of examples of how social responsibility drives economics and how that in turn drives innovation. However, we think social responsibility is about more than economics, and that being a Citizen Engineer is about more than filling market needs. Engineers do not merely cater to the tastes and demands of consumers; they also influence and guide the attitudes and preferences of a society and create new capabilities. When Alexander

Graham Bell demonstrated the telephone to President Rutherford B. Hayes in the White House in 1876, there was no consumer demand for a new communication device. In fact, President Hayes remarked, "That's an amazing invention, but who would ever want to use one of them?" The telephone was a breakthrough innovation that created a new market and changed society.

Finally, a number of people have pointed out that while there is indeed a shift toward more socially responsible engineering, it's actually part of a broader trend that's gaining momentum in relatively affluent countries.

"There is a growing realization that we can afford to be eco-responsible and use our influence and wealth not only to do good for ourselves, but also to help the developing world," says Steven Eppinger, deputy dean at the MIT Sloan School of Management. "It's within our ability and it is part of our shared duty. I've seen a tremendous amount of enthusiasm and activism around that idea—not just at the engineering school here at MIT, but on campuses across the country."

We're glad to see it happening, and we hope this book will be a catalyst for even greater momentum behind the movement toward environmental and techno responsibility.

Part I Summary, and What's Next

This part of the book has discussed the nature of the change in engineering and what it means to engineers; now let's turn our attention to the core topics that comprise the "handbook" portion of the book: how to make products and services that are more environmentally responsible, and how to use ideas—your own and those of others—more responsibly as you create the new generation of products and services.

While this part of the book took a philosophical bent, the next parts get much more prescriptive, helping you sort through the complexities of assessing environmental impact and dealing with IP law. We'll give you advice based on our experience, the input of our colleagues, and expertise from many other sources, and we'll give you pointers to additional information you may find useful.

We hope this part of the book has given you some context for understanding the era of the Citizen Engineer and the new requirements you'll face. Now let's roll up our sleeves.