David Douglas and Greg Papadopoulos with John Boutelle

CITIZEN Engineer

A HANDBOOK FOR SOCIALLY RESPONSIBLE ENGINEERING

"Δῶς μοι πᾶ στῶ καὶ τὰν γᾶν κινάσω"

"Give Me a Place to Stand and I Will Move the Earth"

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Preface

This book is a fusion of ideas, information, advice, and opinions from the authors, their colleagues, and dozens of other sources, brought together to provide you with the tools and insights you'll need to maximize your success in a new era of socially responsible engineering.

The information in these pages will be most relevant to engineers who design and build "things"—engineers in fields such as electronic/computer engineering, software engineering, mechanical engineering, materials engineering, automotive engineering, and so forth—although we believe engineers in all disciplines, managers of engineers, and even consumers will find useful information in this book. We've divided the book into four parts.

- **Part I: Advent of the Citizen Engineer** defines "Citizen Engineer," describes the trends that have led us to this new era of socially responsible engineering, and discusses what it all means—to engineers, to businesses, and to our society.
- **Part II: Environmental Responsibility** provides practical "how-to" information and resources to help you minimize the environmental impact of the products and services you're designing. It gives you an overview of what you need to *know*, things you need to *consider*, and what you need to *do* as you create ecologically and economically sound products, including (to name just a few topics)
  - –Understanding and calculating the complete impact of a product or service
  - –Defining strategies for key impacts such as greenhouse gas (GHG) emissions and water usage

- –Trends in environmental regulations
- –Whether “carbon neutrality” is sufficient as a business goal

- **Part III: Intellectual Responsibility** includes basic information about patents, copyrights, trademarks, trade secrets, nondisclosure agreements, standards, and licenses—and offers practical advice about how to maximize the economic opportunities intellectual property (IP) law presents while avoiding the potential pitfalls. For example, we discuss
  - –The role of patents and when and how to file them
  - –How to encourage other engineers to adopt and amplify your ideas
  - –Pros and cons of various software licenses
  - –Whether our system of IP controls maximizes innovation fairly
  - –How to build communities to innovate and amplify your ideas
- **Part IV: Bringing It to Life** takes a look at some of the ways engineers—and engineering schools—are responding to the new realities and requirements of the new era, including
  - –The growing momentum behind broader curricula in engineering schools
  - –Advice for recent graduates and newly hired engineers
  - –Examples of interesting projects with which Citizen Engineers are involved worldwide

You’ll notice that the greatest emphasis falls on two broad topics that may not seem to be natural bedfellows: eco responsibility and intellectual property law. The reason is simple: These subjects have the greatest urgency to engineers today. They are redefining the way engineers do their jobs, yet most engineers are just beginning to understand the full impact each brings to bear on their work.

The book combines facts and viewpoints, and we’ve tried to be very clear about which is which. The subjects we discuss in each section can get enormously deep, so we’ve tried to give you enough basic understanding, along with pointers to further information, that you’ll be able to continue exploring each topic. We hope you’ll find the book useful in structuring your thinking and answering key questions.

Finally, a few notes about the book itself. Two of the key topics are environmental responsibility and intellectual property. Since the book will have physical manifestations and since it is, by definition, intellectual property, we’ve spent some time thinking about how this book lives up to the ideas it espouses.

First, let's look at the environmental impact of the book. If you're reading these words on a printed page, you're charmingly old-fashioned. This book is available in three forms, and only one of them is printed at all. We recognize the pleasures of reclining in a comfortable chair to read a book—but we also recognize the need to diminish the negative environmental impacts of traditional books. The publisher of this book, Pearson, has developed its own procedure to track wood back through the production process to the original forest, allowing the company to verify the sustainability of the papers it uses. Pearson also measures the carbon footprint relating to the shipping of its printed books around the world. The reuse/recycle rate for Pearson's unsold books and newspapers was 99% in 2007, in excess of the company's target of 95%. Pearson regularly reports on its progress to the United Nations as part of the company's commitment to the Global Compact.[1]

Our book is also available digitally. You can download it from a number of sources, and we hope you've taken the opportunity to acquaint yourself with the unique advantages of reading a book online: Digital versions are easy to scan; you can search for specific words or phrases; you can annotate and highlight electronically; and you can change the font size (those of us who are over age 40 appreciate this feature in particular).

Next, let's talk about the intellectual property that this book entails. By writing the book in the United States, we automatically get the privileges of copyright. In addition to the copyright, we have decided to license the content under a Creative Commons license, namely the Attribution-Noncommercial-Share Alike 3.0.[2] This means you are free to *share* this book (copy it, distribute it) and *remix* it to make derivative works under the conditions that your copies or remixes are for *noncommercial* purposes, that you provide proper *attribution,* and that you *share alike* any changes you make under the same (or a similar) license.

Finally, we have made every effort to properly recognize the works of others that we have leveraged in the writing of this book. If we've borrowed a line or a paragraph from someone's article or book, we've cited the source and referred you to the complete text. If we've used a resource such as Wikipedia to help us define a term or provide statistics that support our point, we have attempted to verify the accuracy of the content and cite the original source of the information.

One additional form of the book is interesting as it embodies both eco responsibility and intellectual property: We're making the book available as part of a living Web site (www.citizenengineer.org). We want you to do more than read the book; we want you to contribute to it. Add your thoughts about the new era of socially and environmentally responsible engineering. Insert your advice and lessons learned. Give the community tips for developing an environmental impact study. Got a better way to measure the carbon footprint of a new device? Have some new information about an energy regulation? Let everyone know. This is a community effort; we welcome your participation.

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Beyond the Black Cloud: Looking at Lifecycles

When you're behind a bus that's belching black clouds of exhaust, you can't help but think about the consequences of environmentally insensitive design. It's easy to be disgusted by what the bus is doing to air quality. It's also easy to miss the fact that the billowing fumes represent only a tiny fraction of the environmental impact of the bus. It's harder still to remember that the bus may also have major environmental benefits, despite its obvious eco shortcomings.

Let's start with the total impact. Think about the individual parts that comprise the bus. Thousands of them, globally sourced from a hundred different manufacturers and suppliers around the world, were brought together to a central location for assembly.

Think of the energy expended and the waste created in the process of obtaining the basic materials and manufacturing each of those parts. Consider the greenhouse gas (GHG) emissions of the cargo planes and freighters and delivery trucks that brought the parts through the supply chain and ultimately to the assembly plant.

Think of the fossil fuels burned by workers commuting to and from that final assembly plant—and all of the other assembly plants where the subcomponents were built.

Consider the fact that some of those parts may have used toxic and carcinogenic substances either in the manufacturing process or within the parts themselves, and that those substances will eventually be heading to our landfills. Consider the waste materials left over after the bus has served its useful life: the massive tires with their polyester belts and steel cords, the petrochemical-based seat upholstery, the batteries with their lead oxide plates and rich assortments of acids (all of them with the potential to leach toxins into our soil and water).

And don't forget that the emissions and contaminants and waste of the bus are only one form of its environmental impact—there's also the noise pollution, the damage done to roadways, the visual pollution of the ads and graffiti on the sides of the bus, and so on.

The bus example helps to illustrate two of our engineering challenges. First, the environmental impact of any one product or service is multifaceted and dependent on many factors, and when you're designing something to be "eco-friendly," you need to take all of those factors into consideration. Second, much of the impact of a product may lie outside any single company. If you're the owner of the bus, or even the company that did the final assembly, understanding the manufacturing process or waste issues is challenging at best.

We have no agenda against buses. In fact, they provide a great example of how something that has its own set of environmental impacts can also have a very positive effect: getting cars off the road. If we need to get 40 people from one place to another, a bus is far more environmentally friendly than 40 cars, even after the full accounting of the aforementioned impacts. This illustrates another of our challenges: Even eco-friendly programs, such as mass transit in this case, have an impact that can't be ignored. When justifying a decision based on environmental impact, it is important to consider the full lifecycles of the proposed solution and the alternatives.

This point was driven home by syndicated columnist George Will, who argued in a 2007 opinion column that a Hummer is more environmentally efficient than a Toyota Prius hybrid.[1] He even went so far as to say that "perhaps it is environmentally responsible to buy [a Hummer] and squash a Prius with it." It's a claim that sounds patently ridiculous—until you take a closer look at the concept of "lifecycle analysis."

Yes, the Prius is fuel-efficient by today's standards, but when you factor in the environmental costs of mining and smelting the zinc required for the battery-powered second motor, the production processes for turning the zinc into the component that goes to a battery factory in Japan, and the expected life of a Prius (109,000 miles) versus the expected life of a Hummer (207,000 miles), the environmental benefit of the Prius becomes fuzzier.*

Although some of the numbers behind Will's analysis are suspect—and the Sierra Club's attitudinal advice columnist "Mr. Green" has issued a detailed

* There is also a subtler argument that even if today's hybrid lifecycle isn't as favorable as we might expect, future ones are apt to be better. Why? Because the market for hybrids today fuels the R&D dollars for future engineering of what, at a fundamental level, is an innovation in engine efficiency.

rebuttal[2]—the point is well taken: The environmental impact of any product must be measured over its full lifecycle, not just at a moment in time in its useful life.

As we noted earlier, trying to compare the relative impacts of two products or approaches can often be difficult, especially when the impacts aren't directly comparable. For example:

- **Cloth versus disposable diapers:** It's easy to point to the 20-year degradation time frame of plastic diapers and argue for cloth, but when you factor in the environmental cost of producing, distributing, washing and drying, using pick-up and delivery services, and ultimately disposing of cloth diapers, the debate is much less clear. What value do we place on long-term waste versus short-term energy and fresh-water usage?

- **Paper versus plastic:** Consumers have now been conditioned to have a knee-jerk reaction against all things plastic, but when you begin to consider the energy that's used to create a paper bag—cutting the timber, manufacturing the paper, processing the various glues and resins needed to transform the paper into a bag, distributing it to stores, and so forth—plastic may not look so bad.

Sometimes the best answer comes from simply looking at the problem differently. Rather than analyze all of the variables involved with the paper versus plastic discussion, some stores are now promoting a whole new option: asking shoppers to bring a couple of recyclable bags with them to the store. Or consider what Netflix did for the traditional video rental model. Rather than try to find new ways to make the old model more efficient, the company radically changed the whole distribution system and cut the carbon footprint of video rental by orders of magnitude (no more deliveries of new releases to thousands of video stores, no more back-and-forth trips by consumers to rent and return discs).

Because of all of these challenges, we need a framework for thinking through the impacts and tradeoffs of more responsible design. Since we have neither the time nor the data to measure and model everything, this framework must rely on strategies for estimation, prioritization, and focused measuring and modeling within constrained situations. But before we dive in, it's important that we take a step back and ask ourselves what our true goal is here, and make sure that we're not missing the proverbial (and eco-friendly!) forest for the trees.

The "Cradle to Cradle" Vision

So far we've talked about the scale of our environmental challenge and the complexities involved in getting our arms around the problem. But now we need to ask ourselves an important question:

What is the ultimate objective? From an environmental perspective, what are we trying to accomplish?

One common answer: The goal is to minimize the environmental impact caused by this product or service. Fine. *But then we've implicitly said that some amount of damage is acceptable*. There's a presumption that everything that is produced will inevitably create some quantity of waste, and the best we can do for Mother Nature is to reduce the volume of that waste and take greater care in disposing of it.

But the potential exists to get beyond an approach that simply minimizes damage. In their remarkable book *Cradle to Cradle*[3] William McDonough and Michael Braungart have laid out a compelling vision that does just that.

The book begins with the premise that the processes we have today for designing and building things are linear and one-way—a cradle-to-grave approach. Our companies make what consumers want and get it to them as quickly as possible, while waste is assumed, and disposal of waste is simply part of the process.

McDonough and Braungart contend that making this model more efficient—focusing on reducing, reusing, and recycling—is not sufficient, that it perpetuates a deeply flawed model and merely delays the inevitable: immense damage to the environment and depletion of vital natural resources. In other words, being less bad is not good enough.

> *Eco-efficiency is an outwardly admirable, even noble, concept, but it is not a strategy for success over the long term, because it does not reach deep enough. It works within the same system that caused the problem in the first place, merely slowing it down with moral prescriptions and punitive measures. It presents little more than an illusion of change. Relying on eco-efficiency to save the environment will in fact achieve the opposite; it will let industry finish off everything, quietly, persistently, and completely.*

The book challenges engineers to focus not on eco-efficiency but on "eco-effectiveness," or designing products in a way that actually replenishes and nourishes the environment rather than simply using up natural resources. One example of eco-effective design would be a new kind of roofing. As opposed to the traditional layer of asphalt shingles or wood shakes, an eco-effective roof would be a light layer of soil covered with plants. Its "growing grid" would maintain a stable temperature, provide cooling in hot weather and insulation in cold weather, and last longer because it would shield underlying building materials from the sun. In addition, it would produce and sequester carbon; it would also absorb storm water.

The vision articulated in *Cradle to Cradle* is compelling and inspiring. But is it practical? Do we, as engineers, have the creativity, the resolve, and the resources required to make the leap from the cradle-to-grave approach to this new model?

Some of you may be thinking that it would take a catastrophic event—the submersion of Manhattan or Silicon Valley due to polar ice-cap melting, for example—to get people to make such fundamental changes. Others believe profound cultural change requires a unity of purpose that's no longer possible given the diversity of our society. Still others are thinking it's already too late and our collective doom is inevitable.

We don't think the cradle-to-cradle vision is an all-or-nothing proposition. Our advice is to use it as a guiding principle. Look for opportunities to fundamentally rethink product and service design in a way that conforms to the vision of eco-effectiveness. We believe that as you attempt to put this vision into practice you will find more and more ways to bring it to reality. However, we also have to be realistic and understand that we sometimes don't have the time, technology, or know-how to apply this vision to every situation. In these cases, we need to make sure that we still practice eco responsibility, reducing impacts as much as we can along the way.

The key is to allow yourself to be more creative in how you approach product design. As we've said, sometimes the most eco-effective alternative comes to light only when you look at an engineering problem from a completely different angle. Consider the example of Interface Carpet. Several years ago, engineers at the company were trying to find an eco-friendly adhesive for a popular new line of modular carpet tiles and carpet squares. For almost two years they experimented with many different compounds, looking for one that provided the right level of adhesion, protected the carpet against molds, didn't wreck the underlying floorboards, and didn't use toxic chemicals. In the end, their solution was not to use an adhesive at all. Instead, they used gravity and rubber, a renewable natural resource that met all the design criteria with minimal environmental impact.

Another example from our own experience is the development of "chip multithreading" (CMT) processors. The obvious way to get higher performance from a processor is to make the "clock" go faster, and for the past few decades that's been the standard approach. Sun engineers, however, found a way to improve overall performance by enabling a single processor to execute more "threads" or tasks in a given period of time. That way, the processing power per thread could actually be reduced—resulting in lower total power consumption—while overall performance increased substantially.

So, we'll conclude this chapter with this thought: Eco-effective engineering is not simply "visionary," and it is not outside the scope of pragmatic engineers. The vision articulated in *Cradle to Cradle* can become reality when there's an intersection of will, creativity, and the right opportunity. But can we count on a true cradle-to-cradle breakthrough on every project? Can we hit a home run on every trip to the plate? Unfortunately, no. So, for the remainder of this part of the book we're going to focus on what to do with the impacts that you're left with after you've tried your best to reach the ideal.

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