MATERIAL VALUE

More Sustainable, Less Wasteful Manufacturing of Everything from Cell Phones to Cleaning Products

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Bebo Press

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First edition, Bebo Press, Redmond, WA

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Cover design and interior typesetting: Alan Barnett
Interior graphics: Janine Milstrey
Editing: Ariel Hansen
Proofreading: Elaine Duncan
Indexing: Judi Gibbs

ISBN: 978-0-9995956-1-9 (Paperback)
ISBN: 978-0-9995956-2-6 (Hardcover)
ISBN: 978-0-9995956-3-3 (eBook)

Library of Congress Cataloging-in-Publication (CIP) data is available upon request.
LCCN: 2019901489

TABLE OF CONTENTS

PART II The Materials We Use

PART III Rethinking Manufacturing

INTRODUCTION

Why this book, and why now

As the federal government in the US looks to dismantle many of the regulations around clean air, soil, and water that have been developed over the past few decades and businesses grapple with how to respond, we seem to be entering a new era. More and more, consumers want to know which chemicals and additives are in the products they buy and use, persuading various industries to become increasingly transparent about their products and their manufacturing methods. Manufacturing companies are taking a closer look at their operations. All types of businesses are considering more carefully where to buy the products they need, from coffee cups to furniture. Businesses of all sizes are reconsidering their materials usage, waste streams, and carbon footprints. However, some changes may be "feel-good" measures that do not make much of a difference.

This is the perfect time to publish a book looking at sustainability through a lens of materials extraction, processing, use, and disposal. My journey, however, started long before I began writing this book.

I first became fascinated by materials science—a field of engineering focused on materials selection, materials processing, and development of new materials—in college. I entered Harvey Mudd College in 1984 as a physics major. Second semester sophomore year I took a class called "Modern Physics" and realized that I didn't want to be a physics major. I wanted to study something more practical than quantum mechanics. I just wasn't driven to understand the world at that fundamental level.

Junior year, after switching my major to engineering, I took my first materials science course. Something about the idea of tailoring a material's physical properties by adding minute quantities of other materials or changing processing conditions fascinated me. And it didn't hurt that my professor, Joe King, was young and enthusiastic. He was brand new to teaching but had worked in industry for several years after earning his PhD. He brought that real-world experience to a failure analysis course he taught my senior year.

Professor King had served as an expert witness in product liability cases. His expertise in examining fracture surfaces to determine when and how a product had failed was considered extremely valuable to companies being sued. Many years later, I learned *just* how valuable such expertise can be when I did some research for a law firm on a patent infringement case and was paid what seemed to me to be an exorbitant hourly rate.

Back when I was in college, I didn't think much about the ethical implications of materials selection and designing new materials. This now strikes me as peculiar given the mission of Harvey Mudd College, which hasn't changed over the decades. As stated on its website, "Harvey Mudd College seeks to educate engineers, scientists, and mathematicians well versed in all of these areas and in the humanities and the social sciences so that they may assume leadership in their fields with a clear understanding of the impact of their work on society."

I did, however, attend college in the 1980s, a decade not known for emphasizing environmentalism or social responsibility. That was for the hippies. My generation graduated with engineering degrees and pursued available job opportunities, many of which involved military contracts and required security clearances. The ethical and moral implications of their work just weren't at the forefront of most of my peers' minds as they pursued their careers.

I did think about product liability, given my exposure to failure analysis, and even took a course called "Ethical Issues in Engineering" when I was working on my MS in materials science at Stanford, but the sustainability piece hadn't occurred to me. Over the years, my perspective has shifted. I now believe that sustainable materials management is crucial. It needs to be addressed throughout the supply chain, from raw materials extraction through the entire life cycle of a manufactured product.

My voyage into materials toxicity began with my PhD research. One of Professor Bill Morris's students at University of California, Berkeley, had been researching the effect of additions of small quantities of other metals on the properties of tin-lead solders. That student was graduating, so Professor Morris asked me to step in to continue the research, which I agreed to do.

Then, a chance comment from another student at a weekly research group meeting changed the course of my research and my career. She mentioned that the US Congress was considering a ban on tin-lead solders in electronics, with the goal of eliminating lead, a toxic element. I decided almost on the spot that I needed to research lead-free solders. Would these alloys exhibit the same microscopic changes that tin-lead solders experienced when deformed at high temperature? I was curious.

The title of my PhD thesis, published in 1993, was "Microstructural Development and Mechanical Behavior of Eutectic Bismuth-Tin and Eutectic Indium-Tin in Response to High Temperature Deformation." In some ways, I was ahead of my time—it would take more than a decade before the Restriction of Hazardous Substances Directive, known as RoHS, was adopted in the European Union (EU). RoHS restricts the use of six hazardous materials in electronics, including lead. In other ways, my research was completely irrelevant, as is the case for many PhD research projects. Neither of the alloys I studied is a suitable replacement for tin-lead solder. Their melting points are too low.

Regardless of the significance of my research, my involvement in the early days of RoHS shaped my perspective. As an engineer, and later a journalist, in the field of semiconductor packaging, I became acutely aware of the struggles of the semiconductor industry to find a replacement that worked as well as tin-lead solder. I also became aware of the absurdity of the whole effort when put in a wider context. The amount of lead in solder joints is minuscule compared to the quantity of lead in lead-acid batteries, for example.

Throughout my career, I have been especially drawn to stories about new materials or better ways to use existing materials. In my freelance commercial writing business, I like to highlight ways in which my clients are reducing waste, saving energy, and creating manufacturing processes that are less toxic and more sustainable. I do this even when it is not part of the official agenda. When I'm interviewing engineers for a blog post covering some chemical compound or processing method, I ask questions about water use or how their company is managing toxic waste. Are they making sure toxins do not enter the local water supply, or are they working on finding ways to avoid using toxic compounds in the first place?

My clients' response to such questions influences my interest in pursuing further projects with them. Stories about companies that are apparently poisoning waterways without a second thought get my attention, and my instinct is to avoid those companies. But the story is not always as clear cut as it may seem. There are certainly examples where corporations appear to be acting with profit as the only goal despite harm to workers, the local communities, and the environment. In other cases, manufacturers may be negligent but not willfully so, and need guidance to better consider the consequences of their production methods or supply chain.

Materials and processing methods are usually chosen with performance as the key metric. Why has our society embraced plastics? Because they work. In most cases, they are lighter, easier to manufacture, and less expensive than the metal, wood, or stone they have replaced. Why do industrial manufacturers use toxic chemicals? Because they are effective. They efficiently clean surfaces or help create durable coatings. But the unintended consequences may be severe.

By learning how metals and plastics are made and what happens when various materials are recycled, readers will better understand the value of materials and the challenges that manufacturers face when trying to make their facilities and products less toxic and less wasteful. This is a huge subject, and I cannot possibly convey the whole story—entire books have been written about each of the topics in my chapters.

I've chosen instead to provide enough background that even readers who have forgotten everything they learned in high school chemistry can understand the concepts. Stories from my experience and that of the inspiring individuals I interviewed bring a personal touch to my narrative. I hope to awaken in my readers a new sense of the importance of materials selection, development, and processing.

As companies struggle to find replacements for materials, either to reduce real or suspected toxins or to reduce the amount of material wasted to manufacture a product, it can be hard to keep a proper perspective. Which efforts really matter, and which ones are a waste of time and effort? Which should be prioritized? I certainly don't have all the answers, but I hope that I can shed light on the problem and guide you, my readers, toward solutions that make a positive difference.

How this book is organized

This book is divided into four main parts, each broken into several chapters. Part I, "Setting the Stage," serves as an introduction to the parts that follow. The remaining chapters fill in the details: Part II covers materials, Part III focuses on manufacturing, and Part IV discusses the role of regulations and certifications and suggests strategies for readers wanting to incorporate a greater focus on sustainability in their lives.

Part I: Setting the stage, posing the problem

It is both extremely challenging and vitally important to get rid of environmental toxins. The first chapter puts the concepts of chemicals and chemistry into perspective. Not all toxins are created equal, and sometimes the consequences of removing a toxic material are counterintuitive or unexpected. Removing a toxin is not helpful if you only introduce a bigger problem in its place.

In the past decade, more and more companies have jumped on the "sustainability" bandwagon. Sometimes their efforts reflect an honest desire to reduce the environmental impact of their operations, but in other cases it still looks like greenwashing. Putting plans in place to deal with real and perceived dangers to employees, customers, and local communities is no longer optional, and corporate executives understand the need to say that sustainability matters.

The scope of sustainability covers a wide range of concerns, and corporate sustainability programs don't all look alike. Transparency is tricky, especially when combined with the concern about keeping proprietary information away from competitors. Chapter 2 discusses the importance of transparency and gives examples where things have gone horribly wrong, but also where companies have taken a better route by openly admitting failures and explaining the steps they have taken to improve their products and processes.

The Four Systems Conditions provides an excellent framework for considering the importance of not making existing environmental problems worse. The fewer natural resources manufacturing requires, the less chance there is for excess waste, toxic or not, to pollute the Earth. That's the premise behind Chapter 3, which also addresses lean manufacturing practices.

Part II: The materials we use

Every physical object or substance on the planet is formed from some combination of elements in the periodic table. Natural materials like rocks and minerals, created deep in the Earth millions of years ago, predate human history. People have been using materials in creative ways since prehistoric times, but civilization has come a long way since our ancient ancestors used wood and stone to create tools.

All the items we use in our daily lives are made from materials. Some are created from natural materials, changed very little from how they appear in nature. But most of the objects that humans interact with are made from engineered materials. These materials have been transformed through manufacturing processes, in many cases designed to serve specific purposes. Plastics are an obvious example of a highly processed material that looks and feels nothing like its original source. But glass and metal, while created from naturally occurring minerals, undergo extensive manufacturing processes before they become raw materials for creating useful objects.

Part II of this book focuses on two primary classes of engineered materials: plastics and metals, with a chapter devoted to each. Many of the chemicals that cause health problems are those that are added, intentionally or unintentionally, to metals and plastics during processing. Certain metals, lead in particular but many others as well, are toxic on their own. Whether present as unwanted contaminants or additives designed to improve performance, there is a reason to be concerned about toxic substances.

Plastics and metals are the primary building blocks for many everyday objects. For example, a smartphone contains dozens of different metals, in quantities ranging from substantial to minuscule, and several plastics. Automobiles are made of many metal and plastic parts. Manufacturing of all sorts of products necessarily involves equipment made from these two classes of materials.

There are certainly other types of materials that are important in our society. The construction industry, for example, couldn't have developed as it has without concrete and glass. Ceramics are used in applications ranging from cookware to packaging for computer chips. Computer chips rely on the semiconductor silicon for their computing power. And although our society is well into the information age and supposedly weaning ourselves off physical documents, we remain attached to paper and continue to use a great deal of it. This book does touch on these materials briefly, but they are not my primary focus.

Part III: Rethinking manufacturing and recycling

The environmental impact of the products we use lies not only in their ingredients but in how the products are manufactured and how they are handled at the end of their useful life. No discussion of efficient manufacturing would be complete without addressing recycling. Part III opens with two chapters on recycling, looking at both why and how.

Chapter 6 dives into the details of the recycling process, with extensive discussion on the challenges involved in recycling various materials. Plastics, for example, are especially troublesome to recycle efficiently.

The topic of electronic waste (e-waste) is deeply entwined in both reducing waste and handling hazardous materials and deserves a separate chapter. While e-waste is a huge global problem, there are excellent solutions on the horizon, which is encouraging. Chapter 7 highlights the problems with existing e-waste infrastructure and points to ways in which it can be improved.

Chapter 8 focuses on industrial manufacturing and examines ways to reduce waste. Many conventional manufacturing processes are subtractive—the process starts with a block or sheet of material that is etched or machined away to leave the desired shape or pattern. These processes necessarily produce waste in the form of excess material removed that does not form part of the finished product. Much of this waste, however, can often be recycled in-house and reused, creating the most efficient form of recycling.

Additive manufacturing has the potential to be much more environmentally friendly. Materials are deposited layer by layer, making the process naturally less wasteful than subtractive manufacturing. Various additive processes are likely to play an increasingly important role in manufacturing from here on out. Still, 3-D printing—a subset of additive manufacturing—is not without its drawbacks and could lead to increases in materials usage if excitement over its possibilities creates a huge demand for 3-D printers in every household. Building and operating printers requires an expense of materials and energy. Unless the printers are used to create products that would otherwise be made with more wasteful methods, they may be inadvertently increasing waste.

Part IV: Next steps to motivate change

Many companies have taken steps to make manufacturing less wasteful, but there is still plenty of room for improvement and opportunity to effect greater change. Change can come about through internal or external motivation. In the case of businesses and industries, external motivation arrives in the form of laws and regulations designed to restrict undesirable practices or certifications designed to encourage desirable practices. While a segment of the business community will be internally motivated to "do the right thing" as part of company culture, external motivators are needed to effect widespread change. Chapter 9 puts into perspective various industry and government efforts to regulate and certify businesses. Are certifications and reporting standards achieving their desired goals, or are they creating unnecessary paperwork and falling short?

The final chapter aims to help readers translate the information from the previous chapters into action. In our roles as citizens, employers, employees, and consumers, we have the power to encourage positive change. Entrepreneurs can consider how they want to incorporate choices in materials, manufacturing, and suppliers into their company's culture as they grow. Those working at a company can use what they learn to propose new practices at their workplace or decide it is time for a career change. Consumers can influence supply and demand through what they choose to buy or avoid and can educate themselves to better understand how their purchases can make a difference. Everyone has a role to play in moving toward a vision of more sustainable, less wasteful manufacturing.