Materials and the Environment
Materials and the Environment
Eco-Informed Material Choice
Second Edition

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Preface and acknowledgments

The environment is a system. Human society, too, is a system. The systems co-exist and interact, weakly in some ways, strongly in others. When two already complex systems interact, the consequences can be hard to predict. One consequence has been the damaging impacts of industrial society on the environment and the ecosystem in which we live and on which we depend. Some of these impacts have been evident for more than a century, prompting remedial action that, in many cases, has been successful. Others are emerging only now, and among them, one of the most unexpected is our influence on global climate that, if allowed to continue, could become very damaging. These and many other eco-concerns derive from the changing ways in which we use energy and materials. If we are to manage both responsibly we must first understand the origins, the scale, and the consequences of the ways we use them now. And that needs facts.

The book. This text is a response. It aims to cut through some of the oversimplification and misinformation that is all too obvious in much discussion about the environment. It explains the ways in which we depend on and use materials and the consequences these have. It introduces methods for thinking about and designing with materials when one of the objectives is to minimize environmental impact, one that is often in conflict with others, particularly that of minimizing cost. It does not aim to provide ultimate solutions—that is a task for future scientists, engineers, designers, and politicians. Rather it is an attempt to provide perspective, background, methods, and data—a tool-box so to speak—to introduce one of the central issues of environmental concerns, that surrounding the use of materials. It provides tools and data that equip you to form your own judgments.

The text is written primarily for students of Engineering and Materials Science in any one of the four years of a typical undergraduate program. Chapters 1 to 14 develop the background and tools required for the materials scientist or engineer to analyze and respond to environmental imperatives. Chapter 15 is a collection of profiles of materials presenting the data needed for analysis. The two together allow case studies to be developed and provide resources on which students can draw to tackle the exercises at the end of each chapter (for which a solution manual is available) and to explore material-related eco-issues of their own finding.
To understand where we now are, it helps to look back over how we got here. Chapter 1 gives a history of our increasing dependence on materials and energy. Most materials are drawn from nonrenewable resources inherited from the formation of the planet or from geological and biological eras in its history. Like any inheritance, we have a responsibility to pass them on to further generations in a state that enables them to meet their aspirations as we now do ours. The volume of these resources is enormous, but so too is the rate at which we are using them. A proper perspective here needs both explanation and modeling. That is what Chapter 2 does.

Products, like plants and animals, have a life cycle, one with a number of phases starting with the extraction and synthesis of raw materials ("birth"), continuing with their manufacture into products, which are then transported, used ("maturity"), and at the end of life, sent to a landfill or to a recycling facility ("death"). Almost always, one phase of life consumes more resources and generates more emissions than all the others put together. The first job is to identify which one. Life-cycle assessment (LCA) seeks to do this, but there are problems: as currently practiced, life-cycle assessment is expensive, slow, and delivers outputs that are unhelpful for engineering design. One way to overcome them is to focus on the main culprits: one resource—energy—and one emission—carbon dioxide, CO₂. Materials have an embodied energy (the energy it takes to create them) and a carbon footprint (the CO₂ that creating them releases). The other phases of life and materials play a central role in these also. Heating and cooling and transportation, for instance, are among the most energy-gobbling and carbon-belching activities of an industrial society; the right choice of materials can minimize their appetite for both. This line of thinking is developed in Chapters 3 and 4, from which a strategy emerges that forms the structure of the rest of the book.

Governments respond to environmental concerns in a number of ways applied through a combination of sticks and carrots, or, as they would put it, command and control methods and methods exploiting market instruments. This results in steadily growing volumes of legislation and regulation that, like it or not, require compliance. They are reviewed in Chapter 5.

As engineers and scientists, our first responsibility is to use our particular skills to guide design decisions that minimize or eliminate adverse eco-impact. Properly informed materials selection is a central aspect of this, and that needs data for the material attributes that bear most directly on environmental questions. Some, like embodied energy and carbon footprint, recycle fraction and toxicity have obvious eco-connections. But more often it is not these but mechanical, thermal, and electrical properties that have the greatest role in design to minimize eco-impact. The data sheets of Chapter 15 provide all of these. Data can be deadly dull. It can be brought to life (a little) by good visual presentations. Chapter 6 introduces the material attributes that are central to what follows and displays them in ways that give a visual overview.

Now to design. Designers have much on their minds; they can’t wait for (or afford) a full LCA to decide between alternative concepts and ways of implementing them. What they need is an eco-audit—a fast assessment of product life phase-by-phase, and the ability to conduct rapid “what if?” studies to compare alternatives. Chapter 7 introduces audit methods illustrated by case studies in Chapter 8.
The audit points to the phase of life of most concern. What can be done about it? In particular, what material-related decisions can be made to minimize its eco-impact? Material selection methods are the subject of Chapter 9. They form a central part of the strategy that emerged from Chapter 3. It is important to see them in action. Chapter 10 presents case studies of progressive depth to illustrate ways to use them. The exercises suggest more.

Up to this point the book builds on established, well-tried methods of analysis and response, ones that form part of, or are easily accessible to, anyone with a background in engineering science. They provide essential background for an engineering-based approach to address environmental concerns, and they provide an essential underpinning for studies of broader issues. Among these are questions of sustainability, the subject of Chapter 11. Central to sustainability is reliable provision of low-carbon power, the subject of Chapter 12. Ultimately, sustainability requires that we maximize material efficiency, explored in Chapter 13. Finally we examine forces for change and responses to them under the heading future options (Chapter 14).

Chapter 15, forming the second part of the book, is a collection of 63 one-page data sheets for engineering metals, polymers, ceramics, composites, and natural materials. Each has a description and an image, a table of mechanical, thermal, and electrical properties, and a table of properties related to environmental issues. They provide a resource that is drawn upon in the main text, enabling its exercises and allowing the methods of the book to be applied elsewhere.

The CES software. The audit and selection tools developed in the text are implemented in the CES Edu software, a powerful materials-information system that is widely used both for teaching and design. The book is self-contained—access to the software is not a prerequisite. The software is a useful adjunct to the text, enhancing the learning experience and providing access to data for a much wider range of materials. It allows realistic selection studies that properly combine multiple constraints and the construction of trade-off plots in the same format as those of the text.

What’s new in the second edition? The basic structure of the book remains the same, but within this structure there are many changes, partly in response to feedback from users of the first edition, partly necessitated by the rapid evolution of the study of materials and the environment. Here is a summary.

- All chapters have been edited, expanded, and brought up to date.
- Worked in-text examples illustrate reasoning or the use of equations.
- The Exercises at the end of each chapter have been greatly expanded (a solution manual is available from the Publisher).

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News-clips are incorporated into all the chapters. These are cuttings from the world press (almost all appearing in 2011) that help place materials issues into a broader context.

A new chapter, “Case studies: eco-audits” (Chapter 8), illustrates the rapid audit method.

A new chapter, “Materials for low-carbon power (Chapter 12),” is really an extended case study, examining the consequences on materials supply of a major shift from fossil-fuel–based power to power from renewables.

A new chapter explores material efficiency (Chapter 13). This means designing and managing manufacturing to provide the services we need with the least production of materials.

The datasheets of Chapter 15 have been updated and expanded to include natural and man-made fibers.

“Further reading” sections at the end of each chapter have been brought up to date with 2009, 2010, and 2011 citations.

Feedback from readers has been a great help in guiding the development of the second edition. Criticisms and suggestions from readers of this second edition will be very welcome.

Acknowledgments

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