The Theory and Practice of Sustainable Engineering

“He, only, merits freedom and existence
Who wins them every day anew.”[1]

[1] (Goethe, [1833] 1984, *Faust*, lines 11,575-76)

Preface and Operating Manual

"When in the Course of human events it becomes necessary for one people to dissolve the political bands which have connected them with another and to assume among the powers of the earth, the separate and equal station to which the Laws of Nature and of Nature's God entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the separation."

American Declaration of Independence

No one confuses a textbook with the American Declaration of Independence. Nonetheless, one may take guidance from that document: When the world and "human events" change to the extent that old ways of framing problems and designing solutions become increasingly inadequate, and a different kind of book is necessary, readers are owed an explanation. In this case, one has a book purporting to be an engineering textbook, yet even a cursory perusal reveals that there are more words than numbers; more sentences than equations; more qualitative than quantitative exercises; more policy observations than algorithms. What sort of engineering text is this, then, and what possible explanation for its obstreperous deviancy?

To begin with the second question, which will segue into the first: there are some fundamental issues with engineering, engineering education, and sustainability as an objective policy and design criterion – not to mention changing demands on the engineering profession, technology as a practice and a social force, and our society - that demand corresponding change in education:

1. Engineering education is increasingly broken. It tries to teach ever more complicated technologies, and problem solving in ever more complex social and environmental contexts, in a four year, highly reductionist and quantitative program that has been inadequate for years.[2] With the accelerating evolution of technology across virtually its entire frontier – biotechnology, nanotechnology, information and communication technology, robotics, and applied cognitive science, to name some of the most active salients – the education we are used to providing no longer produces the engineers society needs.

2. The sustainability discourse is increasingly broken. Serious and legitimate concerns about deep systems perturbations – climate change, shifts in biodiversity,

[2] You needn't take my word for it. Take a look at the recently released 2010 book, *Holistic Engineering Education: Beyond Technology*, edited by Domenico Grasso and Melody Brown Burkins, with chapters by people such as Jud King, who used to be Provost and Senior Vice President for Academic Affairs for the University of California, and Jim Duderstadt, who used to be Dean of Engineering, and then President, at the University of Michigan, and a number of other industry and engineering luminaries who, in one way or another, in elegant and direct prose, clearly highlight the inadequacy of current engineering education in the United States, Europe, and elsewhere, and its inability to produce graduates adequate to the ever increasing burden of modern engineering practice.

urbanization and aging demographics, energy systems, economic behavior – are trivialized by a dialog that seemingly increasingly turns in on itself, and becomes ever more a question of faith and belief among the self-anointed (despite being reified as "sustainability science" and for that matter "sustainable engineering"). Society is ill-served by the capture of sustainability issues by increasingly dogmatic and ideological factions.

3. Institutional, governmental and social ability to deal with the complexity of the anthropogenic world – the world of human activities, desires, and life that we have already built around ourselves, a world where systems dynamics are increasingly determined by human activities, intentional and unintentional – is broken. With issue after issue, in country after country, an inability to deal with complexity increasingly leads to shrill ideology and fragility as culture wars, within countries and among human belief systems, becomes the norm. Especially as technological change accelerates, destabilizing existing beliefs, cultural norms, and social morays, the reaction to complexity is not adaptation, but denial, and retreat into simplistic frameworks – fundamentalism of all kinds. If you want to solve problems in this complex world, though, you don't have that luxury – whether you're an engineer, a lawyer, a business executive, or an urban planner. But neither, because of the way we currently educate you, do you have the tools you need.

This book alone will not fix these and related issues, of course – even the usual authorial hubris can't pretend that. It tries, however, to do several things. Most importantly, it tries to sketch out the cultural, social, institutional, and environmental context within which engineering and, more broadly, technology systems are now situated. This obviously will not turn lawyers into biotechnologists, nor electrical engineers into sociologists, and it would be foolish to try to do so. One hopes, however, that it will begin to provide some frameworks within which understanding, communication, and solving of highly complex problems with significant technological dimensions, can occur. It also tries to break down some of the barriers that disciplinary boundaries, and reductionist methodologies, have created – not in the name of replacing reductionism, which remains a critical tool for scientists, engineers, and society, but with the goal of generating more capable professionals competent in their chosen field, but also able to integrate across other disciplines to address complex adaptive systems.

And not just engineering professionals. To be sure, despite its qualitative appearance, this is an engineering textbook, but it is also a textbook for any student, of any age, who wants to better understand the strange, new anthropogenic world we have created for ourselves, and those who share the planet with us – and who wants to be able to rationally, ethically, and responsibly respond to the challenges and emergent behaviors that world is now tossing up for us. After all, it is not just the engineers that design the products and services that we use that need to understand more about context, and systems implications: it is those who write and pass the laws and regulations that provide us guidance and embody our ethics; who create policies for cities, states and countries; who educate all sorts of students to do all the wonderful things students do when they leave their colleges and universities; who run the firms and research parks and venture capital firms that ride new technologies to market, and into our lives, at ever faster rates;

and who by their consumption and activity decisions shape the globe. Sustainable engineering is the name of the book, but it requires more than just the engineers to make that desirable capability part of our human toolbox: it requires all of us. So although this is a book about sustainable engineers, it is meant for a broader audience. We all live in an increasingly human world that we have built together over many centuries and through many cultures, and it cannot be designed and built into the future as we wish it just by engineers. So this is not just an engineering text for engineering students, but also an engineering text for non-engineers.

A book such as this also necessarily delves into issues and debates that are highly charged. Accordingly, I also note in advance that, while I have tried to be neutral in some very conflicted areas, that effort might not always be successful. In my case, I come from an industry background, and have also spend time in government, at a national defense laboratory, and in academic positions, a set of experiences that no doubt provides some background for my perspectives. Moreover, if there is to be coherence in discussing very complex subjects, one must adopt particular perspectives: cubism works in art, but it is highly questionable when applied to engineering texts. So in those instances where description lapses into assertion, whether you as reader agree with me or not, you should note the validity of other perspectives. Authors cannot escape their experiences: if they help you understand more deeply even as you disagree with them, they are worthwhile; if they are simply biased, learn what you can from them and move on.

Even a cursory glance at the Table of Contents may raise other questions. Why, for example, a chapter on military technology? That's not part of the typical text, for sure. But the point is that the disciplinary boundaries and categories that we take for granted are shifting these days, more rapidly and unpredictably than they have in a long time. Implicit assumptions about what matters, and what doesn't, need to be rethought. So consider military operations and technology in that light. We live in a world where, for many reasons, military necessity and pressure drives technological evolution, and if emerging technologies are important, then one needs to be alert to developments in the military arena, because that's where a lot of these technologies will be coming from. Moreover, the strong line between military and civilian technologies was never really absolute, and it is growing weaker anyway: military systems increasingly include civilian components and assemblies, and on the other side changes in military doctrine in some countries, and the rise of terrorism targeting civilian environments, mean that civilian systems can no longer be thought of as isolated from organized military attack. If I want to attack American information and communication networks, for example, why should I try to attack the Pentagon, which is relatively well defended in cyberspace, when I can much more easily attack the information systems that are increasingly critical for the function of U. S. transportation, energy, water, financial, and other systems – all designed by engineers with little if any knowledge of cybersecurity? More subtly, it used to be that many students had at least some familiarity with military culture, technology, and strategy because of mandatory service requirements in many countries. Now, the rise of volunteer militaries means that one can no longer rely on that almost universal experience; a connection that used to be made through life experience now needs to be made through education. Both as a symbol of shifting categories, and as a substantive

topic for all educated technologists, this is a necessary chapter. It may be novel in such a textbook, but the world has changed. And so must education.

But of course, there is the obvious question: if education is already so overloaded, just how can this be jammed in on top of everything else? Isn't this the game you were rightfully decrying just a few paragraphs back? So to the operating manual, and how to use this book.

There are two ways that this subject, and this text, might be taught effectively. The first, which has a long tradition in engineering education at least, is to use this book to provide modules in existing courses, or as a supplementary text in sustainable engineering, green engineering, industrial ecology, sustainability law and policy, and environmental courses. This is worthwhile, but of course is fairly incremental.

The second is as the basis for a course in itself, which is what the book has been designed for. This is not as outrageous as it seems: almost all courses of study, including engineering, require distributional credits outside of the primary disciplinary area. In many cases, such courses are simply the easiest that the student can find outside the major (e.g., "The Feline Form in Comic History"). How much better to offer a course which meets distributional requirements, but does so by augmenting the understanding of the student – whether in engineering, policy, environmental studies, or whatever – with a working knowledge of technology, technological change, and the associated dynamics of social, cultural, and environmental systems. Thus, one need not fit the class within the core engineering tracks, but can substitute a more useful distributional course for others that may be somewhat idiosyncratic and ad hoc. Moreover, many schools are realizing that just as their engineering programs need a sustainable engineering component, their liberal arts, business and policy students need some exposure to technology and technology systems, and the engineering environment from which they flow. After all, it is a world increasingly defined by technology, and not just technocrats, but every citizen needs some familiarity with where and how technology comes to be.

Just as this text is nontraditional, so is a course structured around it. Simply saying such a course might be useful is accordingly inadequate. For that reason, a suggested course syllabus is included in Appendix A. Obviously, there are many ways such a course can be structured, and the intent is not to suggest that this is the best way to do so (to begin with, not all schools will have the same schedule as laid out in the Appendix). Rather, it is to offer a complete course rather than just a textbook, thereby easing adoption of what to many people may be unfamiliar, at least in an engineering curriculum. It is also included as an appendix, rather than as a part of the instructor's guide, because it may be helpful for readers of this volume, including students, to understand how the material translates into a course format. In a sense, this is metalearning: in addition to learning the substance of technical sustainable engineering, it is useful for the sustainable engineer to understand sustainable engineering itself as a process of change, and learn from that as well. Sustainable engineers will often be change agents, so learning how change may be introduced into an institution, be it a firm or a discipline, is part of the remit.

A word on style. Because this is intended to be used as a textbook, it is not heavily footnoted. That should not hide the obvious fact that any broad discussion such as this necessarily draws on the accumulated wisdom of many, many people, the author probably least among them. I have attempted to indicate the major sources that have helped me in various areas by adding an annotated bibliography to each chapter, where books that I have found useful and informative are identified. Where I have quoted directly or relied particularly heavily on an individual source, however, it has been noted either in the text or in a footnote.

In this regard, the outstanding work of Carolyn Mattick, who was instrumental in researching the graphics in this book, and in helping me create the course based on it, cannot be overstated. She has displayed a passion for understanding the data and the issues, and for helping to create new and innovative curricular materials, augmented by a working ethic that is all too rare these days. I deeply appreciate her contributions to this book and our on-going collaborative work on sustainable engineering; she cannot be blamed for the outcome, but without her it would be a far less interesting and complete effort. My thanks.

My thanks also to those many, many people I have worked with and learned from, and who have challenged me. Working across boundaries is difficult in part because one never knows new intellectual terrain as well as those who already inhabit it, and I have been very fortunate to have found colleagues who have been gracious enough to show me the many errors of my ways constructively and in good spirits. I also thank those from whom I learned via books, articles, and lectures: it may not have been personal, but their congealed knowledge, transmitted in various ways, has been and continues to be not just the basis for this work, but a source of joy and inspiration. I shan't name names, because I would inevitably leave out so many that I would be overwhelmed with guilt for the rest of my days; moreover, it would be unfair to those who helped me with such fair spirit to associate them with what I turned their wisdom into. For that, I must take full responsibility.

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