Summary

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Likely only the very brave will reach this point after having studied all of the "materials" (no pun intended) presented in this book. Most students will have used this book a bit as one chooses courses, focusing on what is needed, interesting, and/or challenging. For the reader, we would now like to raise some crosscutting concepts that any student of this information should consider.

To a large extent this book presents sets of chapters with insight into specific areas. In many cases the chapters present technology-specific views and understanding of the current state of the art or state of affairs for the specific area. The more technology-specific chapters provide an idea of what is needed in order to advance specific technologies, and present a picture of how that technology or the situation brought about by the technology may evolve.

The exceptions are Part I and two chapters in Part V, which look at some of the crosscutting areas of environment, energy flows, and materials availability. These parts help to establish the complexity of the interrelationship of all of the other chapters. Overall this can be viewed as a series of "grand challenges," technical, economic, and social, all of which affect both energy and the environment. Solutions to these challenges may be be found only by combining two or more of the approaches in the following sections. It should be clear that the ultimate solution must lie in a matrix of new energy sources and energy-efficiency measures, coupled with an evolution of the way in which we live (if possible without decreasing our standard of living), while meeting the goals of cost, efficiency, and minimizing impact.

We know very little about the interactions between technological approaches when they are implemented globally. For example, recently there has been much discussion of the application of bio-char (charcoal created by the pyrolysis of biomass) for the purpose of sequestering carbon. (J. Burges, 2010, The Biochar Debate, Chelsea Green Publishing). The result of the process is charcoal, which is then put back in the soil. This has the potential to restore fertility to over-cultivated land. However, the process uses energy and has other environmental impacts, the bio-impact of large amounts of charcoal dispersed in the soil is unknown, and the process must be compared with alternative approaches. The interplay of the environment, economics, social priorities, and human impact is complex and not understood regarding the application of bio-char. Understanding that interplay of all the diverse alternatives presented in the book adds multiple dimensions that make the issue fascinating but also frustratingly hard. In fact, this clearly illustrates that one size does not fit all, e.g., an approach that may work well for fields in India or areas with vast amounts of downed timber in the USA might not be usable at all elsewhere, i.e., in many parts of Europe or Africa. As is discussed below, there are many non-technical aspects to consider, an issue that we, as scientists and engineers, mostly prefer not to acknowledge.

Clearly, being able to meet the challenges posed by energy and environmental needs is a very complex problem with no "one" unique solution.
The primary way to understand this may be to apply the new science of complex systems. Interestingly, to date there is not a clear definition of that science; however, a reasonable attempt goes as follows: “a system composed of interconnected parts that as a whole exhibits one or more properties (behavior among the possible properties) not obvious from the properties of the individual parts.” This is certainly the case for the environment alone, but, when coupled to our diverse uses of, and needs for energy, this is even more the case.

A clear ultimate goal of humankind is to develop a sustainable and equitable way to live worldwide. However, even the definition of sustainability is not clear:

- the ability to be sustained for an indefinite period without damaging the environment and without depleting a resource;
- a means of configuring civilization and human activity so that society, its members, and its economies are able to meet their needs and express their greatest potential in the present, while preserving biodiversity and natural ecosystems, and while planning and acting for the ability to maintain these ideals for future generations;

and, from the Brundtland Commission,

- “meeting the needs of the present without compromising the ability of future generations to meet their own needs.”

These definitions raise the issue of environmental vs. technological sustainability. While there is overlap between the two, it is the technical aspects of sustainability that tend to be emphasized, as this book has done. Nonetheless, there are many connections in the chapters, and certainly in reality, between technology and environmental sustainability, and between these and the need globally to maintain biodiversity.

Achieving sustainability requires a global scale. The world has flattened considerably, in large part due to the increase in international commerce and the ease of travel worldwide. These developments encourage global conversations about the kind of issues presented here. However, the considerable diversity of cultures, languages, per-capita income, and political priorities are all obstacles to being able to implement a global strategy. An apparent solution for North America or Western Europe will be very different from that in India and China, which in turn will be very different from that in sub-Saharan Africa or the Maghreb region. But true sustainability must entail a coupling of different solutions, emphasizing again that there is no “one” solution. A number of factors must be taken into account, including the following.

- **Complexity** – we have already noted that both the existing state (situation) and the new final sustainable state will be complex systems. The change from one state to the other must occur on a large number of length scales from global to individual.
Historically, lack of global sustainability is in part due to emergent behavior whereby use patterns in the developed world impact all systems globally. Consequently it may be that emergent behavior can also catalyze global change – i.e., economic incentives may change global use and generation patterns.

- **Socioeconomic factors** – it is increasingly clear that the global economy is constrained by social factors and that these social factors are constrained also by environmental factors. Engines of change must therefore address all three, the economy, the social factors, and the environment. In addition, security is embedded in all three, and, while this is predominantly a national issue, it must be addressed also globally with respect to the stability and vulnerability of any solution. The complexity of trying to achieve a solution in which all the conditions are optimized does not exist at present for any technology. Thus, for example, we cannot jump to an all-renewable energy economy directly, but need to wean ourselves from conventional fuels by gradually implementing a range of solutions employing diverse technologies when they become ready for large-scale deployment. Just as we must be willing to adapt to a diversity of solutions, we must also begin to develop a more realistic set of expectations. Much of the world has wanted to live like North Americans, Western Europeans, or the Japanese, but these countries can themselves not afford to live that way anymore. It is thus unrealistic for the rest of the world or ourselves to expect that we can consume resources at such a non-sustainable level. Rather we must assess what is realistic vs. time and begin to change our lifestyles.

- **Life cycle** – many of the systems and resources discussed in this book have multi-generational time constants. Coal supplies can last for hundreds of years, we expect a photovoltaic system to run for at least 25 years and nuclear power plants for 50–75 years, and the sustainability of biomass must be viewed on a time scale of 5–20 years. Clearly this is another complex system, but it also shows the importance of life-cycle analysis for each new system. Thus, the scarcity of certain critical rare-earth elements, In and Te for example for the scale of anticipated technology deployment have come to the forefront. Thus we must begin to look at where rare elements can be best deployed, how they can be recycled, and how we do this on a global scale.

- **Interconnectivity** – while nearly all approaches presented in this text can be implemented locally, they will really only have the desired impact if implemented globally. This means that, as above, we need start viewing energy/environment as a complex system with a global length scale requiring solutions...
on that length scale. That will require an increased level of economic connectivity, global data sharing, and long-term support for the various approaches in order to give them a chance to reach deployment. Integration on this length scale will cause social barriers to be removed and change our global interdependence, which may have significant ramifications for global politics and explains the need to develop binding ways to implement change on a global scale. The Kyoto Accord (and the Montreal one, before that) is an example of the beginnings of this kind of approach.

- **Equity** – currently there are tremendous global inequities in food, energy, income, and standards of living. To develop an ultimately sustainable world, we need look at achieving equity in these areas not only as a moral imperative but also as a practical necessity. The latter will be especially clear to those students versed in thermodynamics (Appendix A), which teaches us about the instability of systems with widely different potential energies (“social thermodynamics”).

Key to you, the reader, is that the perspective you have gained from studying parts or all of the book will help you to advocate actions/decisions that help to drive us toward a sustainable future. This is a key role for everyone, i.e., no one can afford to be a spectator, whether in terms of making appropriate life decisions, advocating suitable political decisions, or as a technologist/researcher to develop solutions. We hope that the information in this book will help you to set out, or continue, on your journey.