Foreword

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With this book, Matthias Ruth and Brynhildur Davidsdottir have made an important and substantial contribution to the still evolving field of industrial ecology. In the years that have transpired since the emergence of the idea that economic and industrial systems generally exhibit features analogous to natural ecosystems, the field has taken root. Industrial ecology now has associated with it activities in many universities, consultants with programmes based on industrial ecological principles, and applications of these principles showing up in corporate strategy, product design and public policy. The key principles spring from the above-mentioned ecological analogy and include such notions as loop closing and symbiosis, mimicking forms and processes found in *healthy* ecologies. The first chapter in the collection expands and comments on connections between the field and natural ecosystems.

The stressed term above, 'healthy', lends a normative dimension to the field, beyond the merely descriptive character of analogies. Environmental management and its successor concept, sustainability, have become firmly embedded in high-level societal activities in virtually every economic sector and industrialized nation. The relevance of these terms is tied to a still-growing consciousness of the fragility of the Earth's ecosystem and its criticality as the primary life support system of our species and indeed all life. International consensus about global warming and its impact on climate has now heightened interest in acting to preserve the environment for the present and for future generations.

Among many potential pathways toward sustainability, one stands out as the choice of most industrial and governmental strategies: eco-efficiency. Eco-efficiency, the idea of providing more value for less impact, is contained in many other prescriptive statements, such as dematerialization, decarbonization, detoxification, factor X reduction, cradle-to-cradle, and so on. Healthy ecosystems are naturally 'eco-efficient'. They recycle the nutrients found in their local environment by closing material loops. Detritivores turn the wastes produced in the food web into nutrients for species in other places in the web. The source of energy is renewable solar energy. It is only a very small jump to get from this observation to a normative possibility for industrial ecology: produce a more sustainable world by designing economic and industrial systems to look and behave more like ecosystems.

This possibility has taken hold in several important areas, for example, in the design of technological artifacts (design for environment) and in the design of industrial organization (eco-industrial development). In both of these cases, analytic and design tools, based on material and energy flows, have been developed and applied. Other analytic models and tools have been developed for larger systems, such as national or regional material economies (flows), but these have not achieved the level of design applications as the above two cases. It would seem, based on a patently unscientific assessment by this author, that the 'simpler' the system, as in product systems, the more the ideas of industrial ecology have found their way into practice. 'Simple' in this sense has several aspects, temporal and organizational. Products generally have shorter lifetimes than industrial systems, especially looking at common consumer products such as automobiles, mobile phones or computers.

The present generation of industrial ecological models and tools largely springs from relatively static analyses. The assumptions that are made in applying the tools generally assume that the context of the analysis approximates the conditions during the actual lifetime of the system under the analyst's lens. These tools also generally do not take into account sociological and organizational processes that are involved in putting the prescriptions into play. Again, for product systems, this limitation is not critical as to technical considerations although it is part of the reasons that the outcome that the designer or strategist had in mind may turn out differently.

Furthermore, these first generation models are almost exclusively based on assumptions of linearity with respect to the technical components and on normal rationality with respect to the human elements, in those cases where consideration of actor behavior enters the analytic framework. And finally, much of the work reflects the reductionist nature of the technical disciplines on which industrial ecology rests. This statement should not be read as a criticism of this sociological fact, but merely as an argument for expanding the intellectual basis for what has been the mainstream of research and analysis within industrial ecology.

If one stops for a moment and thinks about the more complex situations mentioned above, the next generation of analytic and design tools will have to incorporate models of processes that more realistically reflect the messy way that the world does, unfortunately for analysts, really work. As the editors of this volume point out, this requires that new ideas must be injected into industrial ecological thinking and research. For example, ways to account for changes in material stocks over long periods are now being incorporated into frameworks for analyzing material flows in large and long-lasting systems, as several chapters indicate.

Readers who have read my recent writings know that I believe that the limits of the present linear models, including those representing ecosystem processes, correspondingly limit the ability of the workers in the field to muster convincing arguments that industrial ecology can be a powerful new frame for thinking about and acting towards sustainability. Eco-efficiency thinking is extremely important in revealing ways to stop and even reverse the apparently inexorable trajectory towards breakdown and destruction of the natural world, with consequent immense potential social implications. But eco-efficiency, like efficiency in any setting, ignores possible absolute limits to growth. William Jevons, writing in 1865, noted that coal consumption in England eventually rose in volume even after the large increase in efficiency produced by Watt's steam engine. Jevons's notion lives today in the current notion of the rebound effect which implies that eco-efficiency (creating wealth in the process) will produce more investment and more consumption, eventually outstripping any gains from technological improvements.

Several of the chapters in this book delve into the area of complexity, invoking new models for the evolution of technical and associated human systems. This work helps make clear the important distinction between the complicated and the complex. The kinds of systems of interest to industrial ecologists have always been complicated, involving many interwoven processes, but processes that have been examined as separate pieces of the overall puzzle and with linear analytic bases. Typical product systems that have been examined often have hundreds of components and many tens of distinct materials involved, producing impacts on various environmental media in different places and times. Certainly not simple, but not complex. Complexity is reserved for systems that cannot be effectively analyzed by such reductionist methods. The key outcomes are the results of interconnected, often non-linear processes that cannot be reduced to analytic statements. Such systems may exhibit unpredictable and discontinuous behavior, possibly flipping from healthy regimes to unsustainable states. Human behavior and its role in establishing the dynamics of such systems cannot be modeled on standard concepts of rationality, even using Simon's notion of bounded rationality. The typical assumptions of stable preferences must be relaxed because the time frames involved are much longer than present models comfortably allow.

Models based on complexity foundations are much more likely to lead to more effective applications in dynamic circumstances, the primary setting for this book as the title denotes. This contextual feature is important when it comes to designing eco-industrial development, implementing national material and energy policies, and in governing product life cycles and supply chains.

This volume takes a large step into the world of complexity and other mostly uncharted domains in industrial ecology. The principle publications in the field, including the *Journal of Industrial Ecology*, have begun to include articles that fall outside or overlap the 'traditional' bounds of the field. (One should hesitate to use the term 'traditional' for a field as young as industrial ecology.) This collection of chapters is the most comprehensive assemblage of work that systematically probes the edges of the field from the perspective of many disciplines. The individual authors are leaders in their particular areas of expertise. For this reason alone, the book contains material that should support for many years the research of those working in the field and others who would like to enter it. Sustainability is a global problematique; the authors, appropriately, are drawn from around the globe.

Symbiosis is a core notion in industrial ecology. Drawn from ecology, it means simply the interaction of two or more organisms that produces mutual benefits. In a metaphorical sense, the whole is greater than the sum of the parts. So is the case for this book. Unlike many excellent edited volumes containing related, but independent parts, the overall contribution to the emerging field of industrial ecology is larger than the aggregate value of the chapters. Such an outcome is rare for volumes like this. The editors and authors deserve congratulation and kudos for their work.

REFERENCE

Jevons, William (1865), *The Coal Question: An Inquiry Concerning the Progress of the Nation and the Probable Exhaustion of our Coal-mines*, London and Cambridge: Macmillan and Co.