1. Background and concepts: an introduction

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The use of materials and energy for production and consumption leads to changes in the sizes and compositions of stocks of substances in nature, including ores in the ground, synthetic materials in the water, and greenhouse gases in the atmosphere. In addition, effects can be found in stocks in the human domain, machines in factories, consumer goods purchased by households, and the knowledge embedded in materials, libraries, and institutions. Flows cause changes in stocks connecting the different subsystems of the environment, economy, and society with each other. It is those changes in stocks, the associated changes in flows, and the interdependent changes in society, economy, and environment to which the chapters of this book are dedicated. Their viewpoint is decidedly one that considers stocks, flows, and behaviors from the perspective of industrial ecology, a newly emerging area of research attempting to provide a consistent material and energetic description of human production and consumption processes in the larger context of environmental and socioeconomic change.

In this volume, specific attention is given to changes in production processes and changes in their organization at the firm, industry, and larger industrial ecosystem level, where the industrial ecosystem is conceived as the interplay of producers, consumers, and regulatory agencies that exchange materials, energy, and information with each other and their environment. A companion volume (Ruth and Davidsdottir 2009) focuses on the dynamics of regions and networks in which the material, energy, and information flows occur.

Many of the processes that characterize such interplay are variable and changing over space and time: new technologies emerge and old ones are replaced, new materials and energy sources are developed, consumer needs and preferences evolve, and new resources and environmental repercussions are discovered. Regulatory interventions into material and energy use by consumers and producers alter, and often are guided by changes both at the process and larger system level. For example, new understanding of the human health impacts of a material or recognition of

global environmental harm from greenhouse gas emissions have prompted restrictions on the use of select substances, promotion of particular technologies, or implementation of incentives to reduce emissions.

Typically neither the activities of producers, consumers, and regulatory agencies occur immediately in response to each other or to changes in the environment, nor are they typically in direct proportion to each other. Detection of environmental insult, for example, can take years or decades. Changing technologies, behaviors or institutions, likewise, is never instantaneous, and if and when they occur, they do so with respect to a combination of past situations and expectations of the future. The resulting time delay and often non-linear cause-effect relationships between actions and reactions in the industrial ecosystem make the understanding of their dynamics and the management of their behaviors daunting tasks.

A myriad of connections between system components – producers, consumers, and the environment in interaction with each other – does not simply result in the complexity of industrial ecosystems; instead, such complexity is fundamentally and inherently related to our ability to comprehend and explain them through multiple disciplinary perspectives required to encompass the relevant system features. For example, an engineering perspective will provide valuable information on material and energy conversions, gaps that may exist between existing practices and ideal conversion processes, and alternatives to close those gaps. Economic, legal, and institutional analyses will be able to provide insights into opportunities and constraints for closing such spaces. Biological information will help quantify impacts of material and energy use on the living environment. Public health insights can be used to assess implications for public and community health. Computer modeling may be required to relate the various pieces of information on the dynamics of industrial ecosystems to each other and make that information relevant to decision makers in the public, private, and non-profit sectors. How that information is perceived and acted on, in turn, depends to a large degree on psychology, organizational structures of industry and government agencies, and the roles and responsibilities of civil society.

The complexity of dynamic industrial ecosystems results from the several possible interactions at the physical and technological levels, the many pathways through which their ramifications permeate environmental, economic and social systems, and the numerous, diverse perceptions and actions of the individuals making up those systems. A simple change anywhere in an industrial ecology may be buffered and never exert larger-scale system impact, or it may ripple through the many interconnections among system components to ultimately determine new behaviors, new material and energy flows, and new feedbacks among those components. The breakthrough associated with

the steam engine stimulated the industrial revolution, a combination of institutional and technical changes triggered the agricultural revolution, and the merger of information and telecommunication technology gave rise to an ever proliferating internet. Simple physical descriptions of the associated material and energy flows provide only one relevant piece of information to understand those changes.

An extension of physical descriptions of systems change to encompass a broader socioeconomic and environmental context allows analysts to better comprehend bifurcations developmental trajectories. Choosing multiple disciplines means embracing the complexity of industrial ecosystems. Most importantly, though, a diverse, multidimensional approach allows for the identification of added degrees of freedom for system intervention to promote self organization and resilience outside the simply physical world.

In recent years, heightened interest in the dynamics of industrial ecosystems has been developing. Scholars and practitioners, from varied backgrounds and with different purposes in mind, attempt to gain a deeper understanding of the important features and dynamics of industrial ecosystems, some through analogies, others through application of first principles, yet others through case studies and modeling-based inquiries. Given the novelty of their perspective and the diversity of their approaches, the products of their work are widely dispersed in individual book chapters and journal articles. Yet, as interest in these perspectives is growing among researchers and decision makers, the need to bring or hold the newly developing strands of interdisciplinary scholarship together, and to identify their relationships and differences, is rising. Without such an effort, continued fragmentation may result in lost opportunities to develop synergies among research programs and in reduced impact on thinking in industrial ecology, environmental research in general, and investment and policymaking.

This volume covers basic and advanced analytical concepts and tools to explore the dynamics of industrial ecosystems at the firm, industry, and larger ecosystem levels. Rather than remaining theoretical and conceptual, the bulk of the material presented here makes its case through the application to very specific issues, keeping in mind both the needs for methodological advancement as well as issues of proof-of-concept and applicability.

The volume is organized in three parts. This first part presents analogies and analytical concepts pertinent to understanding the dynamics of industrial ecosystems and offers a reflection on the use of those analogies and concepts, their limitations and potential extensions. In doing so, it provides both an historical and conceptual frame for the remainder of this book.

The subsequent two parts focus on different analytical approaches and their application to important components and processes in industrial

ecosystems. Each of these sections contains its own introduction, provided by one of the leaders in the respective field. Part II focuses on stocks and flows dynamics at the firm and industry level – one more of an engineering nature, the other more concerned with the economic issues of stocks and flows dynamics; however, both provide significant overlap in their concern and approach. Part III turns to the use of agent-based modeling and organization behavior theory to better understand and represent the dynamics within firms and the larger institutional environment within which they choose to use materials, energy, and technology to produce goods and services for sale to other firms and final consumers. Here, as elsewhere in the book, connections are made between those dynamics and the associated changes in environmental quality.

The volume concludes by drawing on the knowledge gained in previous chapters and the various areas of research to which they are related, and it offers directions for further scientific inquiry and applications.

REFERENCE

Ruth, M. and B. Davidsdottir (eds) (2009), *The Dynamics of Regions and Networks in Industrial Ecosystems*, Cheltenham, UK and Northampton, MA, USA: Edward Elgar.