LINKING SOCIAL SYSTEMS ANALYSIS TO THE INDUSTRIAL ECOLOGY FRAMEWORK

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In theory, industrial ecology is a powerful analytical tool that challenges us to think beyond a mechanistic, fragmented view of environmental problems (and solutions). Indeed, it provokes thinking about the holistic industrial system. Presently, however, the field tends to focus primarily on technical processes and quantitative, material-oriented analysis. This article invites a discussion about expanding industrial ecology's models by considering social systems analysis. Its purpose is not to argue for dismantling or replacing extant industrial ecology. Instead, by advocating that industrial ecologists link their perspectives with perspectives from social science, it is hoped that the existing strengths of the discipline can be augmented with an emphasis on social and broader systemic factors. This direction is consistent with more holistic thinking and the roots of the discipline.

Keywords: *industrial ecology; social systems; technical systems; organizational theory*

Industrial ecology has the potential to provide a powerful analytical tool for describing the flows of material and energy that connect business and the natural world. Its frameworks challenge scholars and practitioners alike to think beyond a mechanistic, fragmented view of environmental problems (and solutions) and instead to focus on the holistic industrial system. The strength of the industrial ecology framework is in its foundational principles, which hold that a Cartesian view of modularity among industrial ecosystems is poorly suited to solving the systemic sources of environmental problems (cf. Capra, 1982). Developed largely by engineers, industrial ecology's central unit of analysis is industrial organizations within broad-scale systems of facilities, regions, industries, and economies. Its goal is to reduce environmental burdens through systemwide changes (U.S. Environmental Protection Agency, 2000).

This system exists in a continuous feedback loop with materials and energy flowing between natural and industrial systems in three stages. First, natural materials are extracted from the earth and converted into raw materials and mechanical energy. Second, these raw materials and energy flows are worked into useable and saleable products. Third, resulting products are distributed, consumed or used, and disposed of by consumers. All three of these stages produce waste that becomes pollution. In sum, the focus of analysis is the "ecology" of the industrial enterprise. This includes the interconnected processes of raw material extraction, the production of goods, the use of those goods, and the management of the resulting wastes.

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But because it uses natural ecosystems as its model (R. Friedman, 2000), it often fails to capture critical human aspects of the industrial ecosystem—social interaction, culture, and institutions.

In this article, I posit that the prevailing systems view of industrial ecology is not complete. Contemporary industrial ecology is focused primarily on technical processes and quantitative, material-oriented analysis. It seeks to identify opportunities for closing material and energy flows by creating waste exchanges and other engineering systems or by developing more environmentally benign product designs and manufacturing systems. Thus far, industrial ecology has devoted only minimal attention to understanding the impact of social, economic, market, political, or strategic systems on industrial action. I seek to provoke a discussion about expanding the field's models by considering social systems analysis, a perspective that is consistent with the holistic emphasis present in early studies of industrial ecology (Allenby & Richards, 1994; Ayres & de Simonis, 1994; Graedel & Allenby, 1995; Lifset & Graedel, in press; Tibbs, 1992).

By omitting social factors in environmental analysis, industrial ecology is not prone to committing critical errors as far as its reach is presently defined. But it is, by design or by omission, perpetuating an engineering mind-set that sees environmental problems as purely technical and not political, cultural, or institutional in their essence. It overlooks the organizational and individual values embedded within industrial ecosystems that influence decision making and alter perspectives about energy and material (Rosen & Sellers, 1999). Consistent with some contemporary scholars of industrial ecology who are beginning to consider such factors (Cohen-Rosenthal, 2000; Ehrenfeld, 2000), I contend that individual cognition, organizational culture, and societal institutions all play an active role in directing the flow of energy, materials, and wastes in each stage, including materials extraction, manufacturing, consumption, and disposal.

Beyond the theoretical, there are also practical implications for the inclusion of social systems analysis. Although its technical focus may be useful in assessing the feasibility of transformational change in an industrial system, industrial ecology remains incomplete for implementing this change within a social environment. The field explains the "what" but not the "how" of solving industrial pollution problems (Andrews, 2000). To better understand the how, an infusion of systemic analysis from the social sciences is critical (Fischoff & Small, 2000).

There is a risk, however, to industrial ecology in accepting the challenge that I outline. There are serious questions about whether the field will become diluted. Will industrial ecology maintain a cohesive identity if its boundaries are broadened? Will this expansion only create a field in which everything exists under its umbrella? What subjects or approaches would not fall under the rubric of industrial ecology once the boundaries are broadened to include linkages with social systems analysis? How might the integrity and coherence of industrial ecology as a field or framework be maintained in these circumstances? For these valid concerns, this article is not proposing that extant industrial ecology be dismantled or radically restructured. More modestly, it is proposing that the field develop the natural linkages that exist with other disciplines that analyze social systems. Although an emphasis on material and energy flows at the expense of social factors may be a strategic choice (though perhaps not an explicit one) in building the industrial ecology field, this article seeks to call attention to the advantages of augmenting the field's domain of study to expand its scope of analysis and influence. The inclusion of social systems is not a threat to the integrity of the industrial ecology field. Instead, it is an acknowledgment that industrial systems contain more than materials and energy. They also include people, organizations, institutions, and other cultural elements.

Problems associated with the omission of these factors are increasingly evident as industrial ecologists have begun to grapple with issues such as the role of values in life cycle assessments and environmental decision making (Hertwich, Hammitt, & Pease, 2000); the relationships between technologies, industries, and socioeconomic institutions in industrial ecology analyses and the role played by decision making and policy development (Ruth, 1998); and the strategic perceptions and activities of firms within the competitive marketplace (Esty & Porter, 1998; Reinhardt, 1999). This article continues this research stream but with two critical points of emphasis that are consist with the roots of the industrial ecology framework. It makes a specific call that any industrial ecology linked to social systems analysis

- retains its focus on the industrial organization and not refocus on the level of the individual manager and
- retains its focus on the systemic aspects of the organization's environment and not refocus on the behavior of individual firms.

In the remainder of this article, I will discuss the industrial ecosystem in terms of the open system perspective, that is, in terms of its technical and social elements. I will describe how the environmental issue is distinct in its ability to engage both of these elements in affecting industrial activity. I will also provide an overview of several social science disciplines that theorize the social systems of the organization. And I will conclude with a challenge for the field by presenting two examples in which social and technical issues are tightly intertwined—material recycling and climate change controls.

THE OPEN SYSTEM OF INDUSTRIAL ECOLOGY

A concept from the social science literature that is applicable for the field of industrial ecology is that of the "open system" (Katz & Kahn, 1978; Scott, 1992). No organization functions in complete isolation, insulated from external interaction and control. In conceptualizing the extent of the open system, the firm relies on constituents in its external environment for both technical resources and social conceptions of the world around them. In the technical environment, firms rely on their external environment for resources such as raw materials, labor, and energy. Customers, suppliers, labor unions, financial institutions, and others provide technical resources on which the firm depends. Products and services are exchanged in a market such that organizations are rewarded for effective and efficient control of the work process (Scott & Meyer, 1992). But the full extent of an open system does not stop there. All organizational interests and actions are not internally defined, individually interpreted, enacted with deliberate foresight based on purely economic rationale, and always capable of being quantified on an accountant's ledger sheet.

The firm is also bound by influences from the social environment, embodied in rules, laws, industry standards, best established practices, conventional wisdom, market leadership, and cultural biases. The constituents previously described and others (such as social activists, the local community, the government, and the general public) interpret the external environment for the firm. What is considered a valid product, how it should be made, how workers should be treated, and how the

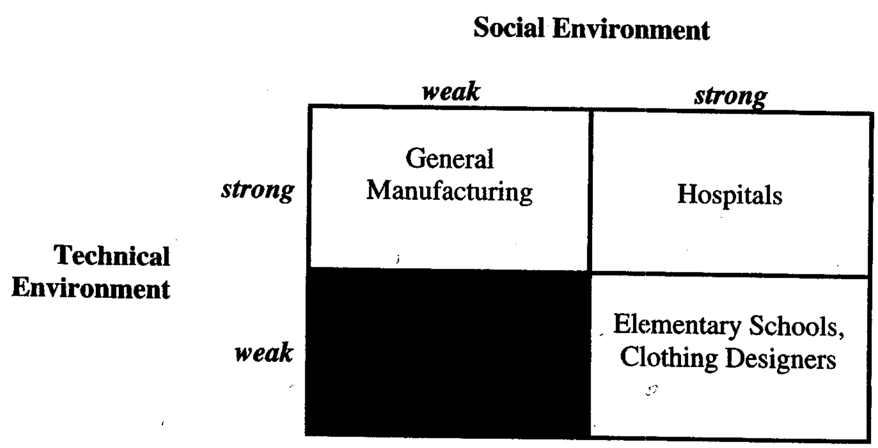

FIGURE 1: The Social and Technical Components of the Open System
Source: Scott (1992).

environment should be protected are all socially defined. The market, government rules and regulations, civil law, or the less formal expectations and constraints of education, culture (personal, familial, institutional, or societal), custom, and mores all play a role in defining issues for an organization (Hoffman & Ventresca, 2002; Scott, 1995; P. Stern & Fineberg, 1996). In fact, the social environment defines even the nature of what constitutes a technical resource. The presence and purpose of all technical constraints are mediated by cultural and contextual influences. The presence of such influences directs attention toward the firm's social environment, one that is derived from a field of actors whose influence is socially based.

Rather than juxtaposing these two components of the open system, the technical and social (or institutional) environments are conceptualized as always present. Technical environments channel organizational behavior through physical, product, and resource constraints. They have known goals and known means. Social environments channel organizational behavior through protocols, processes, and procedural arrangements. They are more ambiguous and less certain. Although both are always present, it is their level of primacy that varies. Figure 1 depicts how varying levels of primacy might play out (Scott, 1992, p. 133).

Some organizations face environments that have high technical constraints and low social constraints (the northwest quadrant). These might include commodity product manufacturers, whose technical constraints on resource flows far outweigh the social challenges of their purpose and place within the market. Other firms face both high technical and social constraints (the northeast quadrant). These might include hospitals, whose operations are constrained by strong demands for high technical proficiency as well as strong demands from society regarding their purpose, meaning, and goals. Firms facing high social and low technical constraints (southeast quadrant) might include elementary schools or clothing designers, whose products are based more on ideological and perceptual grounds than technical considerations. Finally, there are few firms that might be described as facing low social and technical constraints (southwest quadrant). This would constitute a loose variant of a closed system, in which the firm is free of the constraints of the external environment. Not even a monastery exists within a closed environment, instead relying on food, building materials, and so forth. So this quadrant is drawn blank.

ENVIRONMENTAL ISSUES FROM AN OPEN SYSTEMS PERSPECTIVE

Environmental issues have distinct elements in an open systems perspective. They blend the social and technical pressures, pushing all firms affected by the issue into the northeast quadrant. Over the past quarter century, demands for environmental responsibility have been in a constant state of rapid evolution, the source of which has originated outside the corporation. These demands are composed of a blend of social and technical characteristics that make this issue distinct from other pressures with which the organization is familiar. On one hand, it has social dimensions similar to other social issues such as gender equity, affirmative action, or labor relations. On the other hand, it has technical and economic components that make it similar to other strategic issues such as consumer demand, material processing, or competitive strategy. But in both cases, it is the fact that this issue merges social and technical dimensions that creates implications for organizations and institutions and that makes environmentalism such a challenge. And this challenge has important implications for research, scholarship, and practice, which will be discussed later.

Social Systems Implications

On its most fundamental level, environmentalism is a social movement much like gender equity, civil rights, and labor relations. It has constituent groups that lobby for social change on all levels of society. These social groups connect the values of their causes with their personal identities, creating a value congruence that is a potent force for social change. These activist organizations have little material stake in organizational output yet influence that output through ideological activism. They become what may be described as cultural or institutional entrepreneurs (Fligstein, 1997; Lawrence, 1999), driving change in the norms, values, and beliefs of organizational systems.

The composition of environmental constituencies, however, is less well defined than that of some other policy issues with strong social movement stakeholders. Membership in the environmental movement is indeterminate (Beck, 1992). Other issues of organizational concern have a clear constituency. In settling issues of labor relations, managers negotiate with workers and union officials. In settling issues of civil rights or gender equity, there are female, minority workers and national organizations set up to represent them. However, with the environment, there is not a demographic or well-structured political constituency, either among proponents or opponents of particular environmental policy initiatives. Opposition to environmentalism on the grounds of threatened material interests or aversion to state intervention would be easier to explain than environmental advocacy (Buttel, 1992). A high-quality environment tends to be a public good, which when achieved cannot be denied to others, even to those who resist environmental reforms. For many environmental issues, those who act to protect the environment can expect to receive no personal material benefits (Buttel, 1992). So, the firm is left to decide who is a legitimate representative for environmental concerns.

Organized environmental nonprofit groups often represent environmental constituencies. But the indeterminant nature of many environmental policy issues and solutions also means that it attracts a wide range of supporters cutting across social, economic, and demographic lines. Other stakeholders include employee groups, labor unions, community groups, consumers, environmental activists, investors, insurers, the government, industry competitors, internal managers, and recreational enthusiasts (such as hunters, fishers, boaters, etc.) (Hoffman, 2001b). Beyond this breadth of field-level constituencies, the field surrounding environmental issues is also distinct for its engagement of two other actors.

First, there is the natural environment itself. The prominence and power of environmental change act as another form of social pressure, placing demands on social, political, economic, and technical institutions that are different from other demands the organization faces. Events such as species extinction, acid rain, expansion of the ozone hole, the collapse of fisheries, and health impacts due to ongoing or accidental contamination focus attention (often with the help of the media and others motivated by a variety of reasons) on these occurrences (Kasperson et al., 1988; Kasperson & Kasperson, 1996). Although open to social interpretation and enactment (Hoffman & Ocasio, 2001), environmental events, nonetheless, force organizational interests to devote resources and attention to the issue. In essence, the environment itself becomes a salient social activist.

Second, there is a social constituent that is not yet social. Environmental issues typically raise basic issues of intergenerational goods, boundaries, and resource claims (Wade-Benzoni, 1996). The vast geographic scales and longtime horizons involved to preserve the long-term viability of the ecosystem on behalf of future generations are difficult to represent adequately in policy discussions. Because future generations cannot express their interests in social debates, their needs are open to social interpretation and enactment by cultural and institutional entrepreneurs much like the interpretation of environmental events (Okrent & Pigeon, 2000). The inclusion of these two unconventional actors expands the range of the firm's social system and creates greater challenges for both managers and researchers.

Technical Systems Implications

Whereas issues such as affirmative action and gender equity transcend industries and have little direct effect on production processes or product development, environmentalism also has a technical component, directly challenging how organizations handle material resources and produce goods and services. Over the past 40 years, this challenge has been continually evolving. For example, when conservation groups and a wilderness ideology prevailed in the early part of the century, environmental policy issues were cast primarily in terms of managing natural resources for social benefit. As modern environmental activists entered the policy space in the 1960s, the ideologies shifted and the agenda issues became the protection of natural ecosystems. With the entry of employee groups and community groups in the mid-1970s, the issues focused on workplace safety and community right to know; then, with insurers in the mid-1980s came an integration of risk management. In the recent period, the introduction of investor groups in the early 1990s brought a challenge to the core firm strategies and objectives, and the growing influence of customers in the late 1990s turned attention to a redefinition of product development.

The systemic technical features of environmental issues directly challenge core strategy and production processes—how organizations source raw materials, how they handle them, how they produce goods and services, how they dispose of production by-products, and what becomes of produced goods once consumed. Over the past three decades, the technological demands for corporate environmental responsibility have shifted from removing only visible levels of contaminants from effluent streams to now removing concentrations in the parts per billion range and, at times, parts per trillion. Beyond process emissions, environmental issues also mandate changes in the content of product development. Legal environments have evolved to mandate the public disclosure of emission levels and product contents as well as the potential health effects of those chemicals. This creates daunting technological challenges for the firm (Hoffman & Ehrenfeld, 1998).

The effects of these demands are not universal. Some industries, such as oil and chemicals, face greater challenges in both the measurement and the control of hazardous emissions. And within industries, different companies face differential challenges in developing new products, processes, or raw materials in the face of environmental demands. The technical challenges of environmentalism add a new dimension to the strategic landscape, one that will often decide which firms will succeed and which will fail. Field-level responses to environmental issues can cause the elimination of entire product markets, such as those for chlorofluorocarbons and DDT. They can also cause the formation of new markets as they did for freon substitutes, in the wake of the 1987 worldwide ban on chlorofluorocarbon production.

Often, firms are required to collect data, initiate change, and develop an understanding of their processes and products at levels that are not considered necessary for traditionally accepted strategic reasons. Thus, the very purpose of technological action becomes redefined. The boundaries of the organization and the scope of constituents involved in what were once termed *internal* decisions are transformed. The purpose of engineering calculations becomes redefined to include concerns and analysis of the social, political, economic, and cultural context in which they are conducted. New concepts such as waste minimization, pollution prevention, and product stewardship are finding their way into all aspects of operations, from process design to product development.

Beyond conceptions of technology, environmentalism challenges economic conceptions of the firm. Unlike other social issues that deal with equity and the fair distribution of opportunity and wealth, environmental issues increasingly affect basic business economics, effectively redefining the conceptions of production in industry (Hoffman & Ehrenfeld, 1998). Technical environmental pressures have redefined fundamental economic models of consumption and production, resulting in a net change in efficiency. For example, a recent debate has emerged over the economic impact of climate change controls. Some estimates predict a drain on GNP by as much as 3.5% if aggressive emission-reduction targets are set. Others estimate that modest controls on greenhouse gas emissions would not damage the economy, that the world has significant opportunities to control emissions by making its energy systems and automobiles more efficient. This more efficient use of energy is estimated to increase GNP by 1% or 2% (Stipp, 1997).

In essence, technical pressures for environmental protection create an alteration in the institutions that define the core objectives of the firm and the basic conceptions of production. Shareholder equity may remain the single most important criterion for corporate survival. Yet environmental concerns change the notion of what is equitable for the shareholder. The "rules of the game" (M. Friedman, 1970, p. 126) have changed such that managers act in the best interests of their investors by considering environmental protection in their decisions. Today, executives from corporations such as Ford, BP, Dow, Monsanto, DuPont, and Union Carbide actively espouse the benefits of proactive environmental management while instituting programs for community relations and involvement (Frances, Busenberg, Cohen, & Chess, 2000), product stewardship, pollution prevention, and environmental leadership, all in the name of increasing corporate competitiveness and

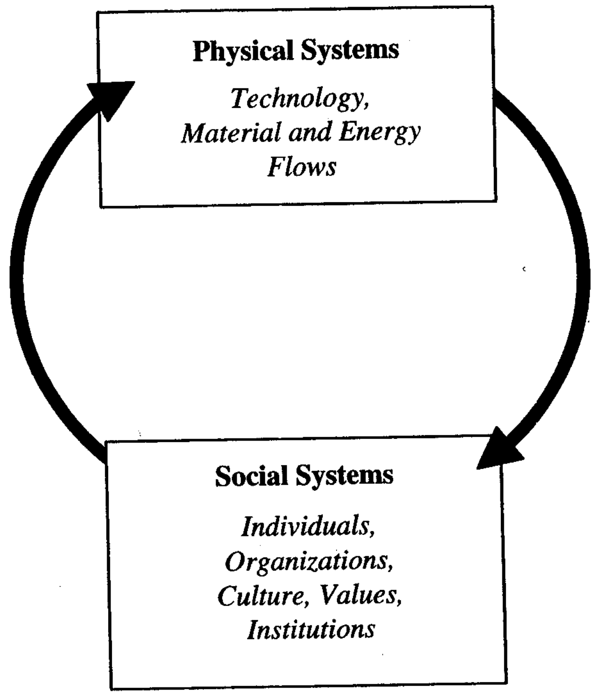

FIGURE 2: Linking Material and Social Systems

shareholder equity. Although there are challenges to a genuine and comprehensive merging of economic and environmental strategies (Luke, 2001), these changes represent an evolution of organizational purpose and boundaries that makes environmental issues distinct as an empirical topic for organizational inquiry.

Merging the Technical and the Social

As depicted in Figure 2, physical and social systems are tightly interconnected. For example, the birth control pill emerged at a time when cultural mores demanded it and, in turn, was instrumental in causing social change in the form of the sexual revolution. The automobile both caused and was a consequence of suburban lifestyles in the United States (Smith & Marx, 1994). So ultimately, although technological activity may be the direct cause of environmental problems, it is the social systems that guide both the development and the impact of that activity (Bazerman & Hoffman, 1999; R. Thomas, 1994). For example, although the book *Silent Spring* (Carson, 1962) was not the first critique of DDT, it was written at a time when social consciousness was awakening to the dangers of synthetic chemical applications and yielded rapid social change involving President Kennedy, scientific academies, and the chemical industry (Hoffman & Ocasio, 2001). Technical change followed the social debate, and DDT was banned in 1968.

This merging of technical and social systems is one reason that the environmental issue is both interesting and challenging for scholars and managers. Consider the following question: What is a waste? Seemingly simple, it has been anything but clear or consistent. Firms are not free to decide what is a waste and how and where it is to be disposed. They are bound by the definitions prescribed by the social, legal, and technical environments. Consider a more specific example—at what point is a waste solvent considered a waste? Presumably after it is used and discarded. But what if that discarded waste is collected and recycled? It effectively becomes the feedstock for the recycler. Should it be regulated as a hazardous waste in the interim? The Safety-Kleen Corporation (the recycler) won a decision in court that it was not (Hoffman, 2001a). This socially defined answer saved them a considerable sum of money in permitting fees, gave them a strong position in the competitive market, and set an important precedent, not without controversy. The resulting court decision was the product of opinions from industry, government, and environmental activists. In the end, what was technically considered a wasted resource versus a feedstock resource was socially debated and defined.

Social constraints on the environmental implications of corporate activity do not exist solely in the courts. Firms are not free to define environmental risk management practices alone. They are bound by the norms and values of the insurance industry. Firms are not free to develop their own property in a fashion they deem consistent with their own economic objectives. The community will decide the validity of development projects through zoning government requirements and political protests. Firms are not even free to decide whether legal compliance is socially acceptable. In 1986, the Polaroid Corporation faced an attack from Greenpeace for being the number one discharger of toxic waste into Boston Harbor. Despite being in full compliance with the Massachusetts Department of Environmental Quality permits, the group published a report titled "Polaroid—Instant Pollution: #1 in Toxic Waste" and hung a banner outside the company's Waltham facility, on a bridge over well-traveled Route 128, proclaiming the company the biggest polluter in Massachusetts. This provoked Polaroid's CEO to start a toxic waste reduction program beyond that required by law (Nash, Nutt, Maxwell, & Ehrenfeld, 1992). Each of these examples exemplifies the merge of social and technical elements of the open system in defining individual corporate environmental management (Hoffman, 2001a).

DISCIPLINARY APPROACHES TO ENVIRONMENTAL ISSUES

Bringing together technical and social systems, the study of the natural environment and industrial activity lies at the juncture of the physical and the social sciences. It lies in disciplines that seek to understand the behavior of natural ecosystems, either as separate entities or in their relation to social systems. The way we understand these systems as separate entities is through the physical sciences of chemistry, toxicology, biology, physics, entomology, and others. In fact, the study of the environment has been on the agenda of the modern physical sciences for long enough that boundary-spanning research specialties such as ecology are now recognized areas of research and professional standing.

In contrast, attention to the natural environment within the social sciences is relatively new both in research traditions and professional infrastructure and lacks such established cross-disciplinary research fields. Subspecialties in many social science disciplines and associated professional fields such as law, economics, philosophy, theology, ethics, sociology, psychology, and political science do focus on environmentalism, each investigating the linkages between social and environmental systems in its own specialty idiom of characteristic research questions, designs and evidence, and implications. Each of these offers a different vantage point, allowing for a contribution to a complementary synthesis of ideas for explaining social and organizational behavior (Allison, 1971; Fischoff & Small, 2000) as it relates to the natural environment. Below is an overview of five disciplinary vantage points for studying the social systems of environmental issues.

Perspectives From Economics

Scholars within the field of neoclassical economics tend to consider the nature of pollution and the environment with a long-standing set of policy approaches around the issues of "externalities" and "market failures." In this domain, pollution is a public "bad" that results from waste discharges associated with the production of a public "good." The harm caused by these discharges is the "consequence of an absence of prices for certain scarce environmental resources (such as clean air and water)" (Cropper & Oates, 1992, p. 675). Left unregulated, economists observe that private firms do not choose "socially efficient" levels of environmental protection (Tietenberg, 1992). They "externalize" these environmental costs and thus avoid paying the full social costs of the environmental damage they cause (Baumol & Blinder, 1985). To provide the needed signals for correcting the market and providing economic incentives for good environmental behavior, economists prescribe the introduction of surrogate prices such as unit taxes, effluent fees, or tradable credits (Hahn & Stavins, 1991).

Perspectives From Ethics

The field of ethics focuses on the nature and morality of human conduct. It mixes descriptions of what presently is with prescriptions of what ought to be. It is a normative discovery of human values derived from science, metaphysics, aesthetics, epistemology, philosophy, and judgments of intrinsic values (Hargrove, 1989). Traditionally, these fields have concerned themselves with an account of the morality of culture and of the right and wrong of interpersonal relations. Environmental ethics takes traditional ethics one step forward, acknowledging that humans inhabit natural communities and that this requires an expansion of ethics to consider human responsibility for nature (Holmes, 1988). More specifically, it argues the thesis that human populations, nonhuman animals, and nonsentient nature are all morally considerable. They may not be counted by the same metric, but each counts in moral calculations because each has intrinsic value. Whereas traditional ethics places humans at the center of the moral universe, environmental ethics expands the scope of that universe and the human being's place within it (Eliot & Gore, 1983).

Perspectives From Law

Scholars in the field of law focus on the equitable distribution of rights and liabilities. The legal system is devoted to avoiding or rectifying perceived wrongs that are the result of human or nonhuman action. It is the product of a society's collective and conflicting values, which are incorporated with scientific knowledge and are reflected in laws. It is built on the foundation of common-law decisions and principles, which is overlain with a later statutory system that attempts to correct the deficiencies of the earlier one. Decisions are the product of logical arguments based on legal precedent and supporting evidence. The focus of these decisions is on the property and personal rights of citizens. These rights include the rights to use the property we own in the manner that we chose, the right to enjoy our own property without unreasonable trouble from our neighbors, and, finally, the right we have (or think we have) to a "decent environment" in which to live (Hoban & Brooks, 1996; Revesz, 1997).

Perspectives From Sociology and Organizational Studies

Scholars from the fields of sociology and organizational studies emphasize attention to field-level systems and focus on the cultural and institutional systems of which individuals and organizations are a part. They attend to the systemic organizational contexts in which the mechanisms of ethics, law, and economics are based (R. Stern & Barley, 1996). Analyzing the attitudes, values, and beliefs within communities of organizations (Meyer & Scott, 1992; Powell & DiMaggio, 1991; Scott, 1995; G. Thomas, Meyer, Ramirez, & Boli, 1987; Zucker, 1988), they offer insights about how social perception and enactment of environmental issues take place and, therefore, highlight both the fundamental sources of environmentally destructive behavior and the enactment of solutions (Dunlap, 2002; Hoffman & Ventresca, 2002; Schnaiberg, 2002). The field goes beyond assessments of strict individual action to question exactly what are the fundamental sources of those actions. The form of this influence is manifested in three levels of institutions: regulative, normative, and cognitive (Scott, 1995). Each level differs in the degree to which it is visible and ranges from the directly coercive to the taken for granted (Zucker, 1983). Yet these three levels form a composite of institutional pressures that create descriptions of collective reality for the organization—explanations of what is and what is not, what can be acted upon and what cannot. As the institutional field establishes new codes of conduct, the emergent institutions will reflect these evolving perceptions (Orssatto & Clegg, 1999), both as a source of empowerment (e.g., defining what they can do) and as a source of control (e.g., limiting options for consideration) (Fligstein, 1992; Jepperson, 1991). For example, much sociological analysis has centered on the cultural shift from anthropocentric (human-centered) to ecocentric thinking (humans are one of many species inhabiting the earth) (Catton & Dunlap, 1980; Colby, 1991; Gladwin, Kennelly, & Krause, 1995; Purser, Park, & Montuori, 1995). The field is now centering on a social constructionist approach to addressing these key themes that do not "uncritically accept the existence of an environmental crisis" but rather focus on the "social, political and cultural processes" by which environmental issues, problems, and solutions are given attention and defined (Hannigan, 1995, p. 30).

Perspectives From Systems Dynamics

Finally, system dynamics is a methodology for understanding how complex systems change over time. The central concern of system dynamics is to understand how all the objects in a system interact with one another in the presence of accumulation and delays (Forrester, 1961, 1969). It develops complex models that link internal "feedback loops" within the structure of a large system through which objects and people interact. A change in one variable affects other variables over time, which in turn affects the original variable and ultimately the entire system. The modeling linkages in these feedback loops may be based on technical, legal, political, or network ties. Thus, it links both social and technical systems in its models. Bringing all these complex subsystems into a unifying computer model simulation, the system model's output is an analysis in terms of its equilibrium or its tendency for imbalance or "overshoot" (Meadows, Meadows, & Randers, 1972). For example, when studying environmental problems in the global system, systems dynamics has been used to link subsystems based on population growth, pollution, nonrenewable resource use, food production, land fertility, land development and land loss, industrial output, services output, and jobs (Meadows, Meadows, & Randers, 1992).

THE CHALLENGE FOR INDUSTRIAL ECOLOGY

Each of these disciplinary perspectives holds quite distinct concerns. In each, the study of environmentalism is described in the standard terms of the discipline. In each, there are distinct models for describing the motivations and drivers of organizational action as part of an overall system. In each, there are scholars working at the edge of the discipline to take advantage of the distinct features of environmentalism as a theoretical and empirical pivot for further research. Each intellectual tradition approaches the issue from a different angle, using different terminology, asking different questions, and yielding different answers. Each also has a set of voices making links between the disciplinary standards, research, and policy and practice issues.

If industrial ecology wishes to consider how to implement systemic changes within human populations, it must do more than simply identify system linkages in material and energy supply chains. It must consider how to get organizations to think and act systemically within their social ecologies. Organizations must, for example, move beyond the belief that economic growth and environmental protection are largely incompatible and that environmental protection must, by its very nature, reduce economic competitiveness (Palmer, Oates, & Portney, 1995; Walley & Whitehead, 1994). Beliefs and values, although manifested on the individual level, are formed and perpetuated on the systemic level. These lie in the social institutions of government regulation, educational curricula, professional standards, international agreements, market dynamics, political arenas, and public opinion, among others. Tools such as life cycle, material flow, input/output, and industrial metabolism analyses can aid in the whole-scale systemic analysis of the material aspects of industrial systems. But to implement the solutions they uncover, they must be augmented with tools and disciplines that consider the dynamics of social systems. Systemic environmental solutions require a tie between technical and social systems. They require linkages to the social science disciplines previously outlined.

Making these links in research can be seen as an opportunity for industrial ecology scholars in their efforts to be complete, realistic, multidisciplinary, and practically applicable. In the implementation of transformational systemic change, it is crucial to deal not just with material considerations of the physical sciences but also with considerations of what motivates individual and organizational action found within the social sciences.

For example, if automakers can successfully shift to alternative fuel vehicles, the ultimately successful design will carry with it a whole host of both social and physical issues. If electric or fuel cell vehicles prove to be the power source of the future, what will happen to the system of gasoline filling stations that have become a fixture on the American landscape? Will electric filling stations, hydrogen (or other fuel) filling stations, or battery replacement stations take their place? If so, will they be operated by oil companies, chemical companies, or electric utilities? What would such a shift mean for the thousands of auto mechanics and repair stations around the country? Are the necessary skills complementary to those for gasoline engines? Will mechanics be retrained for the new types of mechanical problems inherent in electric motors or fuel cells, or will a newly educated type of repair specialist replace them? How will a new industry of parts suppliers be developed with the economies of scale to bring the price of parts down to a level that will make the entire automobile cost efficient? And will consumers easily accept new types of automobile-fueling procedures? Even simple language will evolve in describing the driving experience. In an electric car, what does it mean to "step on the gas?"

The answers to each of these questions will be extremely complex and will require change from every sector of the economy and society. In an effort to understand all aspects of the industrial ecosystem, social and technical systems must be studied in a concurrent and interconnected way, something few if any disciplinary research groups have been able to do. What follows are two examples to highlight this point. In each case, industrial ecology principles expose the opportunity for environmental impact reduction, but social, economic, and political principles are critical in their implementation. In other words, the technical systems could be optimized but only through optimization of the social systems.

Materials Recycling

Consider the straightforward process optimization involved in materials recycling. Shown in Figure 3, feedstocks for materials such as paper, glass, plastic, and aluminum are extracted and processed, manufactured into a product at which time it is used by the consumer, who then disposes of it in the downstream waste management process of collection, processing, and ultimately disposal. Using life cycle and material flow analyses, it is apparent to an industrial ecologist that this process is too linear, does not conserve the value added upstream, and holds the potential for material gains through recycling, remanufacture, or reuse. Through material balance calculations and systems optimization (which may include systemswide financial calculations), changes may be developed that can reduce overall material flows and virgin resource extraction. But how would such change be implemented? Any attempt to implement these changes must consider the motivations of individual actors, the policy regimes in which they operate, and the institutional constraints of the overall social system.

For example, there are political, economic, and market institutions that must be considered. In the 1980s, municipalities in the northeast established mandatory programs to recycle newspaper. Soon, the supply far outweighed the demand and falling costs in the marketplace undercut the incentive to recycle (Tietenberg, 1992). Efficient recycling can only take place when the necessary economic signals, physical capacity, industrial interaction, and consumer demand are developed and integrated. Contractors must collect and sort municipal and industrial garbage. Manufacturers must invest millions of dollars to develop the processing capacity to recycle these materials. A system for collectors and recyclers to find each other to exchange the raw material must be developed. And a new market for recycled material must emerge. None of these steps can work without the others working in tandem. Supply without balance in capacity or demand is ineffective. And forcing one part of the equation without attention to the others will invite failure.

So, what kinds of social considerations have been relevant in implementing a recycling system? To policy and economics scholars, the answers lie in regulatory and market institutions (Lave, Hendrickson, Conway-Schempf, & McMichael, 1999). For example, to facilitate raw material supply, government-instituted curbside recycling grew from only 1,000 communities in 1988 to nearly 7,000 by 1995 (and nearly 9,000 by 1996) (Lounsbury, 2001). From 1994 to 1995, wastepaper collection increased from 24 to 39 million tons, waste glass increased from 2.5 to 3

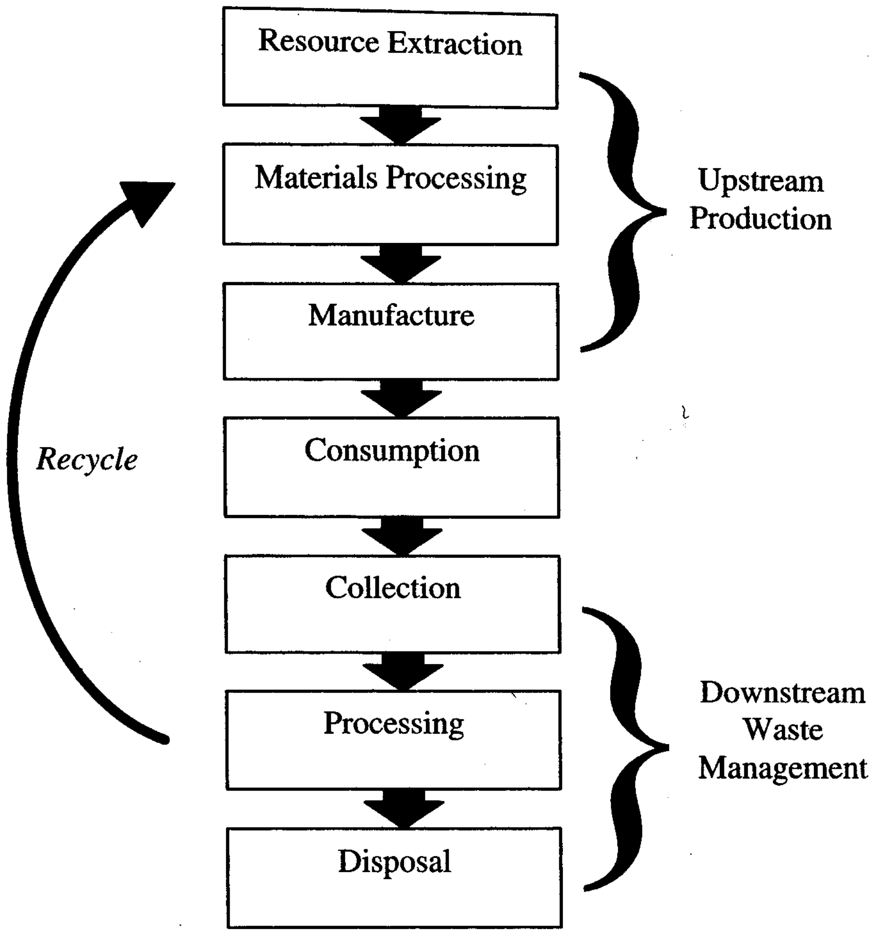

FIGURE 3: Paper Life Cycle

million tons, and waste plastic increased from 181,500 to 690,000 tons (Feder, 1995). To reduce the transaction costs for buyers and sellers of recyclable material to find one another, the Chicago Board of Trade established a commodity exchange for waste glass, paper, aluminum, plastic, and other recyclable materials in October 1995. To bolster demand for recycled paper, President Clinton signed an executive order in 1993, mandating that government agencies use 20% recycled paper for its printing and writing.

But, in the end, what was needed was action by corporations within an industrial ecology. Why would companies initiate action for change? To strategic management scholars, the answers lie in the opportunities for competitive advantage. For example, in the United States, paper companies capitalized on the growing market for recycled paper by increasing plant capacity by 4 million tons from 1995 to 1996, compared to a mere 700,000 tons from 1993 to 1994 (Holusha, 1995b). Overall, the industry invested $7.5 billion in capital expenditures from 1988 to 1995 (Holusha, 1995c). Companies such as Waste Management and Browning Ferris Industries (BFI) provided capacity for collection and sorting of waste materials. BFI alone increased its recycling revenues from $32 million in 1990 to $359 million in 1994 and $550 million in 1995, whereas operating income from recycling jumped from $1.3 million in the second quarter of 1994 to $23.2 million in the second quarter of 1995 (Holusha, 1995a).

But why did governments establish regulations and companies undertake such actions? For organizational scholars, the answers lie in the underlying beliefs and values that guide institutional and organizational action. For example, Lounsbury, Geraci, and Waismel-Manor (2002) analyzed testimony at formative congressional hearings in 1969 and 1970 to understand how political dynamics helped to shape the consensus meaning of alternative recycling technologies, incineration, and solid waste management. They found that even though a virtually uncontested waste industry consensus emerged in the 1970s that valorized incineration over recycling practices, incineration and recycling practices appeared to be equally viable in congressional testimony. But political dynamics critically shaped the regulatory outcome, and the emergence of a market efficiency logic provided a foundation for the marginalization of recycling practices. In another example, Bansal and Penner (2002) investigated individual interpretations of the recycled newsprint issue within four newspaper publishers in Michigan and found that the cultural interpretations of the recycling issue's feasibility and importance as well as the organization's responsibility for contributing to the issue were important in discriminating between organizational responses.

Finally, how can the system of regulation, market pricing, and regulatory policy reach a stable equilibrium? For economics and systems dynamics scholars, the answers lie in the balance between the complex variables of multiple interconnected systems. For example, the price for a ton of waste office paper grew from $15 in 1993 to $85 in 1994, a ton of waste newspaper increased from $30 in 1993 to $55 in 1994, a ton of corrugated cardboard increased from $35 in 1993 to $110 in 1994, and a ton of steel cans increased from $30 in 1992 to $110 in 1994 (Holusha, 1995b). But demand soon outstripped supply such that prices for recyclable material peaked in 1995 and fell through the late 1990s. The Chicago Board of Trade recyclables exchange has since been closed, whereas many other online exchanges have emerged to fill the void. And Waste Management and BFI have both retrenched in municipal recycling, and other companies have acquired both. BFI is thought by many to have overextended on recycling. The future remains unclear on whether prices for recovered materials will stabilize at levels that can sustain ongoing municipal recycling. And this lack of clarity is based on social systems that influence corporate action.

Climate Change Controls

How do we define the problem of and the solution to global climate change? From the materials perspective of industrial ecology, the solution becomes an issue of place. The solution to the climate change problem lies in the question, "Do we like where we are putting carbon?" (Socolow, 2000). But if the Kyoto Protocol is implemented, the solution becomes an issue of social and political change as well. New economic and physical infrastructure must be developed to resolve many issues. International institutions must be developed to measure and disseminate national and global carbon emission levels. They must also find a means to verify those measurements, enforce national goals and timetables, and establish an international trading system that efficiently minimizes transaction costs. National institutions must be developed to apportion the country's goals among individual industries within the economy. And, then, market economics and corporate strategy become critical concerns.

Will policy makers ratify the Kyoto Protocol, and will companies endorse the changes it requires? The answers lie in both the technical and social systems of the organization. Any attempt to limit the emission of greenhouse gases will have a direct impact on the price of energy. Any change in the price of energy will have a direct impact on the cost structure of virtually every sector of the economy. But whereas some economic models predict a cost to GDP of nearly 2%—an amount roughly equal to the $150 billion per year we presently spend on all environmental regulatory programs now in place in the United States—others predict that if these models use more optimistic assumptions, GDP could rise by an equal amount. A report by the World Resources Institute found that 80% of the variance in these economic models is caused by seven key assumptions: (a) Alternative energy becomes cost competitive; (b) markets respond efficiently to higher fuel prices; (c) low carbon options, such as natural gas, expand; (d) international joint implementation of emissions rights is instituted; (e) government revenues from selling carbon permits are used as tax breaks to stimulate investments; (f) costs—health and compliance—from air pollution are reduced; and (g) climate change damages, such as droughts and floods, are averted (Stipp, 1997).

Some of these assumptions are dependent on corporate action, such as the development of competitive forms of alternative energy or the expanded use of low-carbon fuels such as natural gas. Others are dependent on policy makers and the ultimate form of the final treaty, such as the development of international trading in emissions rights or the use of government tax breaks to stimulate investments in low-emission technologies. Finally, some assumptions are dependent on consumers, such as the efficient response of the economy to higher energy prices and whether people will drive less or lower their thermostats if the cost of energy goes up. In each case, the issue is not only technical but also related to key socioeconomic structures.

Again, underlying these structures are concerns for cultural and institutional beliefs about the viability of climate change controls. These beliefs are formed at the level of the organization and at the level of society. In the end, to deal strategically with the potential for controls on greenhouse gas emissions, companies must break down old ideas about environmental issues and replace them with new ideas that acknowledge their complementarity with strategic issues (Redefining Progress, 1997). Although industrial ecology can expose the opportunities of changes in material and energy systems, the motivations for organizations will come from concerns regarding the social systems in which they operate. Will governments negotiate a treaty that allows them adequate flexibility to respond strategically? Will consumers respond by buying low-emission products? Will insurance companies cut back on investments in and underwriting of carbon-intensive industries? Will competitors take advantage of first-mover opportunities by adopting programs for early emissions reductions?

Levy and Rothenberg (2002) examined the differences in response strategies between auto companies in the United States and Europe toward the global climate change issue and found that corporate strategic interests were premised on a company's own particular history, as well as sense-making frameworks applied in interactions with its external constituents, such as industry associations, universities, the media, and national and international governance structures. It is this attention to the social systems of the industrial organization that will determine what kind of strategy a company will take and whether the solutions identified by industrial ecology can be implemented.

CONCLUSION

The domain that industrial ecology presently occupies generates important contributions to solving environmental problems. Its potential is much greater, however, to the extent it reconnects with its roots (Bey, 2001) and fosters an even broader systemic viewpoint, one that moves beyond primary technical efforts. Because the industrial ecosystem is composed of both technical and social systems, the contributions of the field in analyzing both the former and the latter are critical to the search for solutions to the environmental context of the industrial organization (Cohen-Rosenthal, 2000). And so, this article presents a challenge to industrial ecology. The challenge does not require that the field be dismantled or replaced but, rather, that it augment its present course by developing linkages with social systems analysis. This type of industrial ecology would make it more feasible to solve environmental problems because it would enable deeper consideration of the practical feasibility of the technical solutions it proposes.

In the end, when industrial ecologists are faced with questions of how to implement the material system changes that they propose, they often flounder with questions of values, culture, human interests, and institutional design. Their technical equations and numerical analyses leave them poorly equipped to respond to the social aspects of transformational change. Without an appreciation of these aspects, industrial ecology perpetuates an engineering mind-set that relies on input-output data without appreciating the social and political aspects of both how those data are developed and, more important, how they are interpreted and acted upon. Quantitative analysis of technical data alone will not convince a community to accept a new industrial facility in its midst, an environmental group to endorse a corporate initiative, an investor group to invest in a self-professed sustainable company, a government official to rely on promises of environmental stewardship, a consumer to purchase a green product, or a corporate board of directors to invest in a new technology that reduces material or energy use. In bringing about transformational change involving each of these constituents and others, industrial ecologists might consider the social systems in which their technical analyses are applied. These are the domains in which social scientists can offer vital contributions if the field is to become a more viable contributor of practical solutions to environmental problems.

The challenge of studying multilevel and cross-level phenomena in a single discipline is daunting. Rather than present itself as a "grand theory" that seeks to assess all elements of this industrial ecosystem, this article has identified other social science disciplines that are systemic in focus and promising candidates with which the field of industrial ecology can create linkages. The important consideration in accepting this challenge is that it is consistent in many ways with industrial ecology's unique theoretical identity—the focus on the industrial ecosystem as a whole. My main point is that theorizing the industrial ecosystem, as a whole, is more feasible when insights and perspectives from social systems analysis are linked with industrial ecology's analysis of technical systems.

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