Reviews of Economic
Development Literature and
Practice: No. 8

ECO-INDUSTRIAL DEVELOPMENT: A STRATEGY FOR BUILDING SUSTAINABLE COMMUNITIES

MARY SCHLARB
CORNELL UNIVERSITY

2001

U.S. Economic Development Administration

Eco-Industrial Development: A Strategy for Building Sustainable Communities

Mary Schlarb, M.P.S.
Work and Environment Initiative
Cornell University
105 Rice Hall
Ithaca, NY 14850

Tel: (607) 254-5089
Fax: (607) 255-8207
E-mail: mhs13@cornell.edu

This report was prepared under an award from the Economic Development Administration, U.S. Department of Commerce, award number 99-06-07462.

This publication was prepared by Cornell University. The statements, findings, conclusions, and recommendations are those of the author and do not necessarily reflect the views of the Economic Development Administration.

ACKNOWLEDGEMENTS

I wish to thank Kelly Robinson, Research and National Technical Assistance Division of the Economic Development Administration, and Ed Cohen-Rosenthal, Director of the Cornell Work and Environment Initiative, for their invaluable comments and suggestions. I would also like to thank Ernie Lowe of Indigo Development for making available his bibliography of eco-industrial literature, and Judy Musnikow, graduate student in Environmental Management at Cornell University, for identifying additional literature.

Mary Schlarb
May 2001

ABSTRACT

A growing number of communities in the U.S. and internationally are considering eco-industrial development (EID) strategies. EID is based on the idea that a flourishing economy and environmental health can coexist through strategies that integrate environmental, economic, and community development goals. The definition of eco-industrial development has been elusive to practitioners and scholars alike, and the concept continues to evolve as EID projects move from the conceptual stage to implementation. At its root, however, is an emphasis on fostering networks among businesses and communities to optimize resource use and reduce economic and environmental costs. The eco-industrial concept encompasses a range of approaches, including pollution prevention, byproduct exchange, green design, life cycle analysis, joint training programs, and public participation. Early projects sought to create closed-loop systems within the boundaries of an eco-industrial park (EIP). In past years, however, eco-industrial developers have broadened their scope to capture byproduct exchange opportunities in broader regional eco-industrial networks (EINs). This report reviews the interdisciplinary literature on industrial ecology theory and practice. It discusses the concept of eco-industrial development, defining its meaning, function, and range of applications in the economic and community development context. The objective is to describe both the benefits and challenges posed by eco-industrial development, and to assess a range of strategies and best practices for implementation.

Key words: eco-industrial development, industrial ecology, sustainable industrial development

INTRODUCTION

The notion that economic development must be sustainable is a pervasive view among economic and community development practitioners. Communities striving to retain and attract businesses are seeking new ways to balance economic, social, and environmental goals. Businesses have always searched for innovative technologies and partnerships to reduce costs and ensure economic sustainability. A growing number of businesses, however, have begun to incorporate more intensive social and environmental improvement standards into their operations. Businesses and communities alike now realize that conventional end-of-pipe pollution treatments that redirect or sequester waste and pollution are neither ecologically nor economically viable. Evidence of global warming, toxic contamination of residential water and air, and health effects to multiple species demonstrate how environmental compliance is no longer enough. Businesses and communities must adopt practices that significantly reduce emissions. Eco-industrial development, which is based on the idea that a flourishing economy and environmental health can coexist, offers an “invitingly concrete” (Chertow 1999) way to integrate and meet environmental, economic, and community development goals.

Eco-industrial development adds value to businesses and communities by optimizing the use of energy, materials, and community resources. While it draws from pollution prevention approaches focusing on the efficiency of individual firms, its unique contribution is its emphasis on inter-firm resource exchange linkages. Just as in natural ecosystems, interconnected entities form symbiotic relationships to assure survival and resource efficiency. For business, value is added as its waste byproducts, water, and energy are cycled back into the overall production stream of an industrial park or region. What was formerly considered waste can be used as raw materials for another product or firm (Hall, et al 1986; Frosch and Gallopoulos 1989; Allenby and Richards 1994; Garner and Keoleian 1995; Allen and Behmanesh 1996; Ayres and Ayres 1996; Lowe et al 1997a; Côté and Cohen-Rosenthal 1998; North and Giannini-Spohn 1999). This “closing of the loop” results in the conservation of natural resources and lower disposal and production costs. Eco-industrial development offers strategies to achieve greater efficiency through “economies of systems integration” (Ayres 1996), where partnerships between businesses meet common service, transportation, and infrastructure needs. Industrial ecology systems, if organized well, become a built-in incentive to minimize waste of materials, energy, water, and labor time.

In a community development context, lower costs for businesses translate into greater opportunities to reinvest in new jobs, training, and environmental management practices. Eco-industrial development suggests that maximizing resource efficiency involves assessing and optimizing underutilized community assets. Assets include human resources, natural habitats, cultural and aesthetic resources, and existing institutions. Resources might also include elements of a community typically considered detriments, such as brownfields and abandoned buildings, which can be renewed and mined for materials. Many current eco-industrial projects aim to revitalize and improve economically distressed communities, with particular focus on the environmentally sensitive redevelopment of brownfields and decommissioned federal properties such as military bases. The aim is to use a combination of “green” development approaches to ensure remediated sites are not re-contaminated. The benefits for communities are improved environmental health, enhanced resource efficiency, increased jobs, and more viable businesses. EID practitioners, however, have faced significant challenges related to financing eco-industrial projects, creating effective management systems, regulatory limitations, and developing mechanisms to ensure continuous environmental improvement and technological innovation.

Nearly 40 communities in the U.S. have considered eco-industrial networking strategies to attract new businesses and help make existing ones more viable. Many more communities and national agencies outside the U.S. are also investigating the potential for adopting eco-industrial approaches. With a few notable exceptions, however, these projects are in the earliest stages of development. This leaves a number of questions about how to plan, implement, finance, encourage, and evaluate eco-industrial projects. The literature on industrial ecology and sustainable development confronts these questions, but the limited number of existing eco-industrial parks or networks– and a dearth of quantitative data on results– has limited empirical research. Consequently, analyses tend to be more speculative in nature. Considerable research is needed to understand which organizational and financial structures can be supportive of eco-industrial activities (Ayres 1996).

The purpose of this paper is to synthesize and analyze the eco-industrial literature. It is the product of a comprehensive review of the interdisciplinary literature on industrial ecology theory and practice. It draws from a number of related areas, including industrial ecology, industrial clustering, sustainable design, and product life cycle analysis. This paper dissects the concept of eco-industrial development, defining its meaning, function, and range of applications in the economic and community development context. The objective is to describe both the benefits and challenges posed by eco-industrial development, and to assess a range of strategies and best practices for implementation as identified in the literature. After analyzing and synthesizing the central debates in the industrial ecology literature, a series of policy recommendations for overcoming common regulatory, information, financing, and management barriers is presented.

Due to the expansive body of literature on specific resource exchange technologies, this review does not directly address them. The intention is to focus on eco-industrial development as it relates to economic and community development, particularly in economically distressed communities. The report does not provide in-depth case studies, as those abound in the literature, and space limitations prevent analysis of their generalizability in sufficient depth. Where possible, however, brief examples of application of eco-industrial principles are included.

Defining Eco-Industrial Development

The definition of eco-industrial development has been elusive to practitioners and scholars alike, and the concept continues to evolve as EID projects move from the conceptual stage to implementation. At its root, however, is an emphasis on fostering networks among businesses and communities to optimize resource use and reduce economic and environmental costs. The eco-industrial concept encompasses a range of approaches, including pollution prevention, byproduct exchange, green design, life cycle analysis, joint training programs, and public participation. Some have emphasized pollution prevention, technological innovation, and other approaches to improving efficiency within single product lines. While these do play a role in eco-industrial development practice, the field has been moving towards a broader consideration of interconnected systems of firms within industrial parks or regions. Pollution prevention and other approaches are not mutually exclusive from this more systemic approach; in fact, single production line innovation is one of a number of possible approaches encouraged within formalized eco-industrial networks. What sets the field apart from pollution prevention is its focus on exploiting system-wide resource flows of member industries.

Eco-industrial development originates in the emerging field of industrial ecology, with additional roots in environmental management (Côté 1997; Nash and Ehrenfeld 1997; UNEP 1996). In a general sense, eco-industrial development is industrial ecology in practice. Industrial ecologists have transformed the way we view waste (e.g., Hall, et al 1986; Frosch and Gallopoulos 1989; Allen and Behmanesh 1996; Garner and Keoleian 1995; Allenby and Richards 1994; Ayres and Ayres 1996; Chertow 1998; Desrochers 2000; Allenby 1992). The underlying principle of industrial ecology is that commerce and ecology should unite such that production and distribution mimic and enhance natural processes (Hawken 1993).

The concept of an "industrial ecosystem" first received widespread attention when *Scientific American* published an article by two General Motors' researchers who suggested the days of finding an "open space beyond the village gates" for disposal of industrial byproducts were quickly passing (Frosch and Gallopoulos, 1989). Since that time, the concept of industrial ecology has captured the imaginations of a growing number of businesses and communities. At the most basic level, industrial ecology describes a system where one firm's wastes (outputs) become another's raw materials (inputs). As Paul Hawken (1993) describes it:

> …Waste equals food: An ecological model of commerce would imply that all wastes have value to other modes of production so that everything is either reclaimed, reused, or recycled…The restorative economy comes down to this: We need to imagine a prosperous commercial culture that is so intelligently designed and constructed that it mimics nature at every step, a symbiosis of company and customer and ecology.

Under this premise, firms form linkages with one another to reuse, recover, remanufacture, and recycle products and byproducts, adding value to economic activities. Industrial ecology takes its lesson from nature, which effectively and efficiently processes materials through an ecosystem. In the same way, industrial ecologists argue, industries can develop networks of businesses that create the most efficient processes of raw material extraction, production, product use, and waste disposal (Allenby and Richards 1994; Ayers and Ayres 1996; Frosch and Gallopolous 1989; Garner and Keoleian 1995; Gradel and Allenby 1995; Desrochers 2000).

Industrial ecology as an academic discipline has focused primarily on the interactions between commerce and the environment, within two primary domains: engineered systems and social networks. It is often defined in the context of manufacturing businesses; however, current eco-industrial practice and thought has recently moved to consideration a third domain that expands to include communities (McGalliard et al 1997, Côté and Cohen-Rosenthal 1998, Lowe 1997, North and Giannini-Spohn 1999). In the technical domain, industrial ecologists have studied the physical and chemical interactions involved in the recovery, refining, and reuse of materials, in the context of both single firms and a networked system of multiple firms. These industrial ecologists have adopted an engineering perspective, commonly focusing on the technological aspects of identifying opportunities for reducing pollution and wastes, often by exploring ways to use low-value byproducts as inputs for other processes. This is a technology-driven approach focusing on the infrastructure and technology for resource exchanges within individual manufacturing processes and among and between companies (e.g., Allenby 1994, Nemerow 1995, Allen 1996, Aupperle 2000).

The second domain takes a broader look at business systems and networks. It involves communities of businesses cooperating for greater environmental and economic performance than each can realize on its own (Ayres and Ayres 1996; Indigo Development 1998; Gertler 1995; Lowe 1997; Desrochers 2000). This perspective moves from considering only materials exchange to include other types of interconnections between businesses, such as sharing services, transportation (goods and people), and facilities.

Industrial ecology, however, has progressively moved beyond a consideration of materials recovery and exchange between companies, to a third domain: community-business interactions (Côté and Cohen-Rosenthal 1998). Eco-industrial development in practice encompasses a broader view of industrial ecology, based on the pursuit of the "three Es" of sustainable development: economy, environment, and equity. It seeks to develop symbiotic networks among and between businesses, community, and the public sector. It emphasizes fostering partnerships and networks to manage energy, water, and material resources in more sustainable ways. It considers interconnections between businesses or a particular eco-industrial park and the region's workforce, ecosystem, institutional, and community resources. In this domain, industrial ecology is a social construct. The key element is not technological solutions, but the social relationships and creativity generated by people (Christensen 2000, Cohen-Rosenthal 1999). As a body of literature, industrial ecology is divided between those favoring engineered systems and less prescribed network behavior.

The Shape of Eco-Industrial Development

Eco-industrial development projects have taken two primary forms in practice: eco-industrial parks and eco-industrial networks. Earlier discussions of potential eco-industrial connections looked to closed-loop industrial parks in which the right mix of firms could, with the appropriate production design and technologies, lead to a zero-emissions system (Pauli 1998). While elegant in theory, this notion has proven difficult in practice. Attracting the appropriate combination of tenants with the resources to invest in the most efficient pollution prevention technologies has not proven to be realistic; although, there are a few examples of sets of small-scale enterprises forming a "closed loop" with significant byproducts (Pauli 1998). Distressed communities, in particular, cannot afford to turn away potential businesses on the basis of failing to match the input or output needs of other firms. Small- and medium-sized enterprises, while perhaps striving for optimum resource and cost efficiencies, may not have the financial resources to invest in technologies allowing them to connect with neighboring industries. Even where an optimal combination of firms locates in a single park, questions of sufficient quantities and quality of feedstock resources have limited implementation of park-wide exchanges. Further, the externalities of the input, maintenance, and end use of the products are not fully factored in.

For these reasons, a dramatic shift has occurred in recent years. A growing number of communities have taken a broader approach to planning eco-industrial development, looking instead at regional or city-wide opportunities for resource exchange. A number of projects, for example, have investigated regional input and output flows to identify possible inter-connections (e.g., Kincaid 1999; Schlarb and Keppard 2001). Eco-industrial parks are still considered a possible format for eco-industrial development; however, such parks are now nestled within a broader regional context in which park tenants not only interact among themselves, but also with other firms in the region and with the surrounding community.

Whether an eco-industrial park or a broader eco-industrial network, at the core of industrial ecology is stronger business-to-business and business-to-community networks for greater resource efficiency within a context of constant interaction with the environment.

Eco-industrial parks

Eco-industrial parks offer a discrete setting where companies locate for maximum resource efficiency. The President's Council on Sustainable Development (1996) defines the eco-industrial park (EIP) as:

> A community of businesses that cooperate with each other and with the local community to efficiently share resources (information, materials, water, energy, infrastructure and natural habitat), leading to economic gains, gains in environmental quality, and equitable enhancement of human resources for the business and local community.

An EIP is similar to a conventional industrial park in that it is a contiguous property containing a number of tenants sharing a common management/ownership, infrastructure, services, and often a tenants association (Lowe 2000, 1997; RTI 2000; Kassinis 1997; Wallner 1997; Kassinis 1997; Surlock and Ward 1980). The innovation of the eco-industrial approach to park development is a focus on continuous environmental and societal improvement. Lowe points out that

> The economic self-interest of the property owner and management firm, public regulation and zoning, and the proximity of the companies on the site can make industrial parks relatively focused sites for innovation.

North and Giannini-Spohn (1999) describe the different visions associated with existing EIPs:

- Physically connect businesses into a network, with a goal of zero emissions,
- Restrict park to companies that generate no pollution or environmental technology firms,
- Restrict park to companies with environmental management systems in place and with excellent regulatory histories,
- Focus on park infrastructure, with energy-saving "green" buildings, buildings designed for re-use, recycled or deconstructed buildings, xeriscaping (landscaping for maximum water conservation), etc.

Eco-industrial networks

Industrial ecology has moved beyond the boundaries of an industrial park of collocated businesses to regional waste exchange networks, described as "virtual" eco-industrial parks or regional networks (Kincaid 1999; North and Giannini-Spohn 1997; Ausubel 1997; Wallner 1997). Eco-industrial networks (EINs) extend beyond a focus on localized byproduct exchanges to a broader agenda for improvement of environmental, social, and business performance. EINs can include community service programs, employee skills and environmental training programs, and other joint programs (McGalliard et al. 1999). As with collocated businesses in an eco-industrial park, virtual networks seek to optimize materials flow efficiency and economies of scale through resource recovery and exchange and other interconnections. These eco-industrial networks require an accessible, up-to-date communication mechanism for information exchange on available inputs and byproducts to be viable. An EIN often does not have the EIP advantage of common ownership and operation, and the leveraging of shared services, exchanges, and enhanced image. These broader networks, however, may bring the economies of scale required for developing a byproduct market.

Benefits of Eco-industrial Development

Eco-industrial development offers a number of potential benefits to communities and businesses. This approach seeks to bridge the perceived gap between the interests of businesses and communities by building partnerships. Public involvement processes allow businesses and community stakeholders to express interests and concerns and cooperate in generating development alternatives. The idea behind this collaboration is that many of the interests of industry and citizens overlap, and so mutually beneficial strategies for sustainable development exist. Below we discuss the interlinked benefits of building linkages among communities and businesses, including economic efficiency and profitability, job retention and growth, community development, and environmental stewardship.

Economic efficiency and profitability

The appeal of eco-industrial parks for tenant businesses and industrial development is the increased profitability and cost savings brought through economies of scale and added value to outputs (Gertler 1995). Value is added to byproducts as they cycle back into the production cycle as raw materials for another firm or process. With eco-industrial development, companies can find opportunity to improve energy and material use efficiency through waste exchange, recycling, and innovative technology and production processes. Regulatory penalties for harmful practices may also be eliminated or reduced. Increased economic efficiency within and among tenant companies will most likely increase the value of real estate for private and public developers (Cohen-Rosenthal and Smith 1999, RMI 1998). This is particularly true in the application of eco-industrial principles to brownfields.

Companies co-located in a park can share the burden of expenses for infrastructure and services, such as business services, waste management, purchasing, training and recruitment, recreation and childcare facilities, transportation, and other common costs of doing business. Umbrella permitting and environmental compliance certification is another potential sources of savings. Though not always possible, park-wide “umbrella” permitting can possibly facilitate a park-wide, rather than company-wide, certification process to cut down on paperwork and staff time (Weitz and Martin 1995, Cohen-Rosenthal and McGalliard 1996). Savings on production, disposal, and regulatory costs can make companies more viable, with positive repercussions in terms of jobs and tax revenues for towns.

While the focus of eco-industrial development has been on manufacturing, it can benefit the retail and other sectors as well. Eco-industrial approaches offer communities an opportunity to attract new businesses and jobs to previously undervalued areas. As businesses and their workforce locate (or remain) in a neighborhood, markets for retail services are strengthened. Similarly, as businesses find new uses for their byproducts, an eco-industrial development strategy can help identify upstream suppliers and downstream customers by finding new opportunities to join in exchange relationships. Services in the financial, communications, and administrative sectors may find new markets as local industries grow. Retail and other small-scale enterprises themselves can be involved in eco-industrial exchange relationships. Springfield, MA, for example, has proposed engaging small Main Street retail shops in a broader eco-industrial network through shared purchasing and services. While the proposed networking relationships for these stores do not involve large byproduct feedstocks, the ultimate goal is the same: the recovery and reuse of resources (Schlarb and Keppard 2001).

Job retention and growth

The literature has made little connection between eco-industrial development and job retention and growth, with some exceptions (McGalliard et al 1997; North and Giannini-Spohn 1999). Eco-industrial development supports job growth and retention in several ways. Its emphasis on building networks for resource exchange and recycling can help foster new businesses and new jobs. When companies reduce the cost of materials, waste disposal, and fines for failing to comply with environmental regulations, they can invest their savings in retaining employees and hiring and training new ones. Savings resulting from greater efficiency and economies of scale particularly benefit small- and medium-sized businesses. Many eco-industrial park projects have incorporated incentives for training and hiring minorities and women, salary improvement programs, and family-friendly policies. Emphasis on green design improves indoor workspace quality, and therefore, worker health and productivity. These factors result in higher employment for communities, better opportunities and working conditions for employees, and a more skilled and productive workforce for employers.

Community development

Proponents of eco-industrial approaches point to a host of economic, environmental, and social benefits for communities. The objective of these approaches is to add value to a municipality's economic base, strengthening its industrial, social, and supporting institutions in a way that attracts new businesses and retains existing ones:

> The appeal of the concept is that developers and communities that create eco-industrial parks seek to build a foundation for industrial development that is more competitive, more efficient, and cleaner than traditional industrial parks or regions. In addition, new business niches will be opened for recruitment or incubation of new companies that strengthen the local economy (Lowe 2001).

Eco-industrial development seeks to address environmental justice issues in the process by empowering communities to make their own decisions about what kind of industrial and commercial development will occur. Cases are well documented of economically distressed communities falling victim to the lure of quick income from landfills, hazardous waste dumps, and garbage transfer stations. In many instances local governments accept these businesses into their municipalities because they see no other alternatives. Often citizens living near these dump sites have no voice in the decision and are forced to live with the environmental and health consequences. Eco-industrial development emphasizes the need to involve the range of stakeholders in identifying community assets, problems, and alternatives, and in planning and implementing economic development programs.

Brownfields redevelopment poses a related environmental justice and community health issue eco-industrial development approaches may solve. Brownfields, or contaminated properties, are common blights in economically disadvantaged neighborhoods. People residing near these sites potentially suffer the negative health consequences of toxins presents in drinking water and soil (Meyer and Van Landingham 2000). They often also face acute challenges to attracting development projects and resources. The added costs and liability issues associated with brownfields cleanup and reuse make recruitment of industry especially difficult. The eco-industrial development strategies for maximizing resource efficiency, economic growth, and community sustainability offer a set of mechanisms for redeveloping these sites without repeating the contamination of past industrial activities. Brownfields are often located close to existing industrial centers, and military bases in particular have accessibility to multimodal transportation (Giannini-Spohn 1997).

Connecting eco-industrial development strategies to brownfields redevelopment raises a number of questions in need of further exploration. Although eco-industrial development in theory offers a more sustainable reuse option, it is not yet clear whether and how eco-industrial development in itself can affect the level, process, and speed of the remediation phase. There is also a need to explore whether there are appropriate brownfields remediation techniques that feed into EIP exchange relationships and how to recruit suitable tenant industries that are less polluting than those that contaminated the site initially. Another question is whether predetermining reuse of a site as an eco-industrial park would affect decisions on the appropriate level of cleanup, and therefore, its cost and timing.

In fostering stronger partnerships among citizens, businesses, government agencies, and non-profits, an eco-industrial park can enhance its host neighborhood. By revitalizing existing businesses, redeveloping brownfields, and attracting new businesses, eco-industrial projects can provide local residents with greater opportunities to work in their own neighborhood, and walk to their workplace. Several current eco-industrial projects provide incentives to businesses for hiring local workers (i.e., the Green Institute in Minneapolis and Cape Charles Sustainable Technology Park in Cape Charles, VA). Individuals and groups who are already networked in business and other partnerships can add the element of emergency response to the scope of their relationships. In Minneapolis, for example, as a result of eco-industrial networking, local businesses have combined resources to hire a security officer to prevent vandalism and theft. EIPs have also offered or shared services with the community, including day care, recreation, and transportation. While these community development benefits are not guaranteed outcomes of EID implementation, an eco-industrial framework can guide the process of strengthening communities.

Government can also find advantages in being involved in eco-industrial development beyond tax revenues. Stronger neighborhoods are easier to govern than fragmented ones. In a context of increasing devolution of decision-making, the federal government confronts the challenge of coordinating an array of complex and competing interests and priorities (Giannini-Spohn and Hendricks 2001). Eco-industrial development offers one approach to developing public/private partnerships to optimize resources and improve economic and environmental performance. Communities that have strong interpersonal relationships between citizens, businesses, and their supporting agencies already possess the channels of communication and interaction necessary for bolstered public education and decision-making. Eco-industrial approaches encourage individual firms to adopt measures to improve their performance voluntarily, rather than in response to regulatory mandates. Businesses that voluntarily adopt more ecologically sound practices do not need to be regulated as closely, leaving government agency financial and staff resources available to address other pressing community needs.

Environmental stewardship

Eco-industrial development seeks to promote environmental stewardship at the firm, industrial park, and community levels. The ultimate environmental goals of eco-industrial strategies are to reduce the use of virgin materials, decrease pollution, increase energy efficiency, reduce water use, and decrease the volume of waste products requiring disposal in landfills. This approach encourages companies to adopt innovative processes and technologies that reduce waste of energy, water, and materials. At the park level, EIP managers aim to minimize negative environmental impacts by basing siting, infrastructure, and recruitment decisions according to ecological carrying capacity. Businesses linked in eco-industrial networks form materials exchange relationships to decrease the amount of waste going to landfills and incinerators. Eco-industrial development encourages tenants and management to collaborate with the community to identify and support community-wide resource exchanges and recycling, reuse, and remanufacturing opportunities. Some EID projects have looked to environmental restoration of open space, reforestation and riparian repair, both as a park amenity and for environmental improvement. A corollary benefit to firms is an enhanced environmental image.

Risks of Eco-Industrial Development

Because eco-industrial projects are relatively untried or in the very early stages of development, there are a series of real and perceived uncertainties and risks associated with implementation. Many of the components are proven methods of managing organizations, materials and energy, but these are often combined in unique ways and for new purposes. We divide the risks identified in the literature into four primary categories: financial, interdependence, regulatory, and environmental.

Financial risks

The lack of proven successes on which to assess risk and a potentially longer payback period may cause the financial community to be reluctant to support eco-industrial development projects

(North and Giannini-Spohn 1999). Furthermore, materials exchange agreements will most likely be unsuccessful unless the recovered byproduct materials cost less than either their disposal cost or the price of comparable virgin materials. These added costs can constrain exchange opportunities (Pelletiere 1999). Lowe suggests that public developers may be more willing to help absorb these costs if they deem it in the public good. Calculating costs and savings in a longer timeframe, commitment on the part of larger companies to locate, public developer involvement, and obtaining significant signed leases will contribute to gaining the support of financiers (Lowe 2001, North and Giannini-Spohn 1999).

Risks of interdependence

Eco-industrial development's emphasis on collaboration, interaction, and interdependence raises a number of concerns. The transaction costs of working with the community and other businesses-- particularly competitors-- may be high in terms of time, labor, transportation, labor, recovery and exchange infrastructure, communication, and monitoring (Lowe 2001, Pelletiere 1999). Beyond added costs, businesses may be wary of entering into byproduct exchange relationships where the quantity and quality of supply is not guaranteed. Uncertainty over shifts in production and the ability of secondary markets to cope with excess or shortfalls of materials adds sufficient risks (Pelletiere 1999). Like any industry, EIP participants must have alternative plans in case a key component of their operation should falter. In this case, an EIP manufacturer requires a backup supplier, as would be the case under the conventional producer-supplier relationship. Inter-firm relationships are contractual like any other supplier relationship, and a third party can act as a broker (North and Giannini-Spohn 1999). Developing an alternate source of materials, however, may be more difficult or costly in the eco-industrial case. Firms that have entered into byproduct exchange relationships often invest in additional process and transport infrastructure to facilitate the exchange. If that relationship is interrupted and an alternate supplier is required, those earlier investments are potentially lost (Lowe 2001). Finding a comparable supplier of a particular byproduct in the region may also be difficult, requiring the firm to rely on virgin materials as an input substitution.

Cohen-Rosenthal (2001) counters this notion that a manufacturer must manage a greater level of risk as an EIP tenant than as a member of a conventional network or park. A current business trend is to develop stronger partnerships with fewer suppliers, substituting longer-term protection against supply chain interruptions with the risks and benefits of improved current performance. The automotive and telecommunication industries, for example, now emphasize stronger relationships with fewer suppliers to reduce costs and improve quality by tailoring more integrated and responsive systems of manufacturers. These companies see the more immediate benefits of lower costs, improved quality, and higher reliability as outweighing the longer-term risk of having fewer backup suppliers. Eco-industrial networks similarly seek stronger partnerships for more immediate cost reduction and improved quality. There is little data to compare the relative rates of risk in the long term between eco-industrial and traditional supplier relations. One might argue conversely that eco-industrial relationships are less risky because of its inherent reliability, cost
reduction strategies, cash liquidity advantages and common problem solving.

In some cases overcoming conventional competitive and independent relationships may be difficult (Lowe 2001). Pelletiere (1999) and Christensen (2000) contend that social familiarity and trust between parties (or a "common social matrix") may reduce perceptions of risk and relationships based on close individual connections or an institutional framework may reduce transaction costs. For example, the Industrial Symbiosis system in Kalundborg, Denmark faced fewer transaction costs because of an existing common culture, social relationships, and strong institutions. All of these facilitated the identification of potential exchanges and guarded against uncertainty (Bechtel Corp 1997). Further research must be done to determine whether a greater or different level of trust is required relative to conventional, highly integrated, multi-supplier, linear production systems (Pelletiere 1999).

Regulatory risks

A number of regulatory concerns have emerged in the planning of eco-industrial activities. There is considerable agreement that the existing regulatory structure in the U.S. poses substantial obstacles to enacting eco-industrial strategies (e.g., Desrochers 2000, Pelletiere 1999, Weitz and Martin 1995, North and Giannini-Spohn 1999; Lowe 1998). Businesses and EIP developers perceive risks of liability and confusion over definitions of hazardous wastes. The Resource Conservation and Recovery Act (RCRA), for example, limits handling and use of some hazardous waste materials, which can deter businesses from entering into a materials exchange relationship. Companies exploring the possibility of reusing another firm's waste must determine whether the material is restricted under RCRA or other acts, and which special permits or changes in water, air quality, solid waste, and wastewater regulations are required to enable material exchanges. The eco-industrial development literature discusses the need to increase the flexibility of federal, state, and local regulations to support more innovative and holistic approaches focusing less on single environmental media and more on the ecological system as a whole. A later section in regulatory concerns discusses some possible options for developing a supportive regulatory structure.

Environmental risks

Not all experts agree that closing the loop of production is a sufficient remedy to environmental degradation. Several authors have expressed a concern that byproduct exchange may encourage continued reliance on toxic materials and discourage technical innovation as companies invest in exchange infrastructure and customer-supplier relationships (McDonough and Braungart 1998, Chertow 1999, Lowe 2001). McDonough and Braungart (1998), shunning the "eco-efficiency" goal of byproduct exchange for the notion of "eco-effectiveness," emphasize pollution prevention options, such as process redesign and materials substitution, instead of what they label "trading toxics." Even in cases where participating companies collocate to reduce transportation or integrate their processes of production, those companies may be less motivated to develop more efficient pollution prevention technologies and processes than if they operated independently. The goal should be to seek continuous environmental improvement by designing products and processes that reduce the need to extract and use raw materials– toxics in particular– thus eliminating the need for recycling and exchange.

Ayres and Ayres (1996) are skeptical of the validity of this notion that developing profitable markets for wastes could result in higher production and reduced incentives for creating cleaner technologies. In their study of 12 families of toxins, they concluded there were almost no cases where this problem could arise. Further comprehensive studies on actual consequences of continued reliance on toxic materials are needed to determine whether there are cases where byproduct exchanges might discourage innovation.

ECO-INDUSTRIAL DEVELOPMENT STRATEGIES

The main innovation posed by eco-industrial development thought has been taking a whole systems approach to industrial and community development. But transforming diverse systems requires more than one boilerplate solution. Rather than focusing on one particular practice, EID therefore considers ways in which several approaches can be combined for greater resource efficiency. EID integrates a number of tools and strategies focusing on the design of production processes, products, and physical space (buildings and landscape), in a way that increases resource efficiency, lowers cost, and mitigates environmental impacts. Other strategies emphasize building business-to-business and business-to-community linkages on local and regional scales to facilitate exchange of materials, infrastructure, information, services, energy, water, natural habitat, and other resources. The goal of each of these diverse strategies is to optimize resource efficiency among the collective industries of a park or region (North and Giannini-Spohn 1998).

In the U.S., nearly 40 communities are in the planning or implementation stages of eco-industrial development projects, while many others are considering EID. Each eco-industrial project has sought to implement the combination of these strategies that are most appropriate and feasible for their location (Lowe 2001, Cohen-Rosenthal 2000, Chertow 1999). Lowe (2001) promotes incorporating as many of these strategies into the vision for an EIP as possible and desirable, rather than adopting a piecemeal approach. Each strategy, when implemented successfully, adds value to the park and becomes a valuable recruitment incentive. Similarly, North and Giannini-Spohn (1999) suggest that:

> ...The eco-industrial park [can] be viewed as a palette of strategies for increasing resource efficiency. While the ideal EIP or IE network would incorporate all of these strategies in the long-term, companies participating initially might add strategies incrementally as the business case for each becomes stronger.

Each strategy, and its application to eco-industrial development, is described below.

Resource Recovery, Pollution Prevention, and Cleaner Production

Closed production loops emerge from the elimination of wasted energy, water, and materials for cost savings within and among firms. "The goal is to minimize environmental impacts by changing either the way goods and services are produced (process technology) or the products themselves (product design)" (UNEP 1996). These systems promote recovery of end products and recycling of base materials and reusable industrial wastes back into the production process. This occurs either within one production cycle or through recovery and reprocessing of end-oflifetime products through product take-back and disassembly. Continuous process industries, such as petrochemicals, have long sought to channel every input into profitable output (Ausubel 1997). Chemical and energy engineers have developed technologies and processes that transform crude petroleum and other energy materials, air, water, and other inputs into liquid fuels, electricity, heat, fertilizer, and other outputs with potentially zero emissions. Industries that produce in batches, such as automobile manufacturers, are also making strides in developing integrated manufacturing systems with design for disassembly and reuse.

Much of the current thought on eco-industrial development points to the need to look at broader geographic ranges beyond a bounded industrial park to ensure economies of scale and sufficient supply of exchange materials. An EIP may have better opportunities to incorporate infrastructure that supports exchanges within these foodchains (e.g., common transport, warehousing byproducts for shipment to external customers, and common toxic waste processing facilities) (Lowe 2001); however, some communities are exploring ways in which broader networks can develop these exchange mechanisms.

Integration into Natural Ecosystems

Preventing and mitigating environmental impact requires designing eco-industrial parks in a way that considers natural ecosystem conditions and resources (UNEP 1996, Lowe 2001). Ecosystem planning principles include land use and efficiency, health and safety protection, and environmental protection (RMI 1998). The United Nations Environment Program has developed several design guidelines to enable industry to coexist with natural systems (UNEP 1996):

- Define the carrying capacity of the site, and design within those limits.
- Maintain the natural areas and indigenous vegetation as far as possible. Native vegetation/forests can minimize landscaping maintenance and provide shade and wind protection for facilities (permaculture, xeriscaping).
- Retain natural drainage systems and use constructed or natural wetlands to purify industrial or residential water and purify storm-water run-off.
- Increase density of development.
- Design sites with energy efficiency in mind, for example, to maximize passive and active solar building technologies.
- Create the potential for environmental synergies through location of companies to achieve easier servicing and industrial symbiosis.

The Green Institute, for example, has incorporated xeriscaping and roof gardens using indigenous prairie grasses as features of its facilities. The goal of xeriscaping is to reduce water requirements for landscaping through efficient planning and design, soil improvements, limited turf areas, indigenous species and low-water-use plants, efficient irrigation, and mulching. This has improved site aesthetics, reduced landscaping and water requirements, and supported conservation of native species. The Cape Charles Sustainable Technologies Park similarly has incorporated a number of green features. The park was sited and designed to maintain a natural wetlands area, home of an array of bird and other species. A boardwalk linking the park to a protected coastal area provides the community and park employees opportunities for recreation and appreciation of nature. Both the Green Institute and Cape Charles feature active and passive renewable energy technologies.

Industrial Clustering

Eco-industrial development projects have adopted industrial clustering strategies to build more efficient regional industrial ecosystems. The industrial clustering approach focuses on assessing a region's unique economic, industrial, commercial, and other resources to forge a comprehensive economic development plan. The underlying assumption is that regional economies consist of industrial clusters and their supporting economic infrastructure. Information Design Associates (1997) define industrial clusters as follows:

> Industry clusters are agglomerations of competing and collaborating industries in a region networked into horizontal and vertical relationships, involving strong common buyer-supplier linkages, and relying on a shared foundation of specialized economic institutions. Because they are built around core export-oriented firms, industry clusters bring new wealth into a region and help drive the region's economic growth.

Industrial clustering, like eco-industrial development in general, is based on the notion that networks of manufacturers develop cooperative relationships to optimize resources. A whole body of literature exists on manufacturing networks (e.g. Altern and Hage 1993, Stuber et al 1996). The emphasis in eco-industrial goes beyond a focus on single-sector clusters to clustering along a whole value chain. These clusters evolve from networks of interrelated, geographically concentrated industries and their suppliers and customers. Silicon Valley's computer technology cluster is one well known example of a manufacturing network, where computer chip manufacturers and component producers are clustered with hardware and software industries and their supporting economic and administrative institutions.

Industry has been a driving force behind this trend. As the economy continues to shift towards technology-intensive, knowledge-rich, and globalized industries, clusters of businesses connected geographically and by customer-supplier relationships have developed to become more competitive in the global market. Through this structure, companies both compete and cooperate to make most efficient use of human and technological resources to optimize opportunities. At the same time, supporting financial and educational institutions, service and infrastructure providers, and regulatory agencies develop within the cluster. By specializing towards the particular needs of industrial clusters in a region, such infrastructure can give participating businesses a comparative advantage over isolated firms. Strong and flexible relationships between commercial, industrial, agency, and civic interests is a prerequisite to effective clustering, creating "collaborative advantage" (IDeA 1997).

Sustainable ("Green") Design

Most existing eco-industrial projects have incorporated one or more sustainable, or "green," design features into their landscaping and facilities. The primary objectives of green design are to maximize water and energy resource efficiency, minimize waste, and maximize use of recycled and environmentally benign materials in the construction and operation of facilities. Features include:

- Increased energy efficiency through facility design or rehabilitation and renewable energy technologies.
- Cogeneration, or collecting and using otherwise "wasted" heat from the electrical generating process.
- Energy cascading, which involves using residual heat in liquids or steam from a primary process to provide heating or cooling to a later process, similarly optimizes energy resources of a system. For example, excess steam from a power plant or refinery may be used in a food processing plant, aquaculture enterprise, or greenhouse (Lowe 2001).
- Flexible building design for multiple use, allowing, for example, conversion from industrial/commercial to residential (McDonough 2000).
- Water resource efficiency is maximized through water cascading, where one manufacturer uses process water from another plant. Park infrastructure may include mains for several grades of water (depending on the needs of the companies) and provisions for collecting and using storm-water run off (Lowe 2001).

Anchor Tenant

Ayres (1995) and Chertow (1998) suggest establishing an eco-industrial park around one or more primary “anchor” tenants as a way to create a more definable set of possible inter-connections. The eco-industrial anchor tenant concept is loosely based on the real estate development strategy of using an anchor company to attract other firms to an industrial park or commercial facility. For example, a developer might market a shopping mall to a potential tenant based on the presence of a large department store that can draw customers. In the eco-industrial context, the anchor tenant strategy focuses on how the anchor industry can provide significant waste streams to “satellite” firms that can utilize the wastes in their own production processes. The type of anchor tenant and its byproducts therefore become a comparative advantage for attracting certain kinds of satellite industries.

The Red Hills EcoPlex: An Example of Developing an EIP around an Anchor Tenant

In Choctaw County, MS, a public/private partnership is developing the Red Hills EcoPlex, an EIP centered around a 440MW lignite-fired circulating fluidized bed power plant and an adjacent lignite mine. The project aims to attract a symbiotic mix of companies that can use the byproducts of the power plant (e.g., steam, fly ash, bed ash, residual thermal energy). Targeted industries therefore include intensive aquaculture, hydroponic green housing, poultry processing, and food processing. The adjacent lignite mine operations expose substantial quantities of clay, and marketing efforts have placed some focus on recruiting a brick manufacturer. The Red Hills EcoPlex has identified a number of primary target tenant industries, based on industry requirements and potential contribution to the EcoPlex symbiosis.

Life Cycle Assessment

Life cycle assessment (LCA) is a tool for assessing the total environmental impacts of a product, building, or process from raw materials extraction to disposal, or “from cradle-to-grave” (UNEP

1996, Stahel 1998). LCA considers the inputs and outputs of production at all stages of the value chain, from extraction, processing, and manufacturing, to distribution, retail, consumption, and disposal. The ultimate goal is to minimize resource use by streamlining design and including reusable or recyclable materials. LCA of the production of a motor vehicle, for example, would assess the environmental impact throughout the entire supply chain of mining the metals, producing component parts, final assembly, maintenance, and end of life disposal or recycling. Environmental impacts include energy use, air pollutants, hazardous wastes, toxics emissions and dollar estimates of external air pollution costs (CMU 2000). Eco-industrial development strives to encourage individual firms along the supply chain to reduce these impacts through technological innovation, materials substitution, and finding alternatives to byproduct disposal through exchange relationships with other firms.

Job Training

Eco-industrial development can optimize labor resource efficiency by emphasizing the development of joint skills training programs for local residents (Cohen-Rosenthal 1998, North and Giannini-Spohn 1999). Eco-industrial practitioners consider what types of training and education are available and how partnerships between businesses, local educational institutions, and trade associations can meet local training needs (McGalliard, et al. 1997). By combining training resources, participating firms can reduce their individual workforce development costs.

The particular labor skills required in an eco-industrial park or regional network depend on the types of industries involved. Joint programs, however, can reduce the training costs of meeting common skills needs (e.g., environment, health and safety, workplace skills, basic math and reading, skilled trades, higher level production or engineering skills). Programs offering tax breaks and other incentives to participating employers can support these efforts (North and Giannini-Spohn 1999). The Green Institute, for example, has developed a training program in environmental careers including brownfields, deconstruction, GIS mapping, landscaping and installation and maintenance of renewable energy systems. A partnership with another non-profit agency provides workforce recruitment and development within the federal Empowerment Zone.

Environmental Management Systems

Industrial parks adopt environmental management systems to address potential and existing environmental impacts of industrial activities. Park managers provide environmental services, such as water and sewage management, hazardous waste treatment and disposal, and environmental health and safety training for employees (UNEP 1997). UNEP's manual, *The Environmental Management of Industrial Estates,* describes an environmental management framework that includes the following elements:

- An explicit policy statement of environmental goals and objectives;
- Mechanisms for ensuring the achievement of these goals, such as by-laws and economic instruments;
- Supporting services
- An environmental audit function; and
- Enforcement mechanisms.

The international environmental certification system, ISO 14001, is perhaps the most well known example of an EMS. This certification signals to potential tenants and to consumers that a basic level of environmental compliance is being met, which adds a comparative advantage for the certified company in the global arena in terms of corporate image. EIPs, such as the one in Londonderry, NH, require ISO 14001 certification from their tenants and facilities. Obtaining ISO 14001 certification, however, does not guarantee that the company or industrial park is implementing an EMS. Some experts have challenged whether receiving the ISO 14001 certificate has become an end goal rather than a means to moving beyond compliance. To avoid this dilemma, environmental management systems should provide a framework for continuous environmental improvement, rather than merely documenting compliance with minimum standards.

Deconstruction and Demanufacturing

Several eco-industrial developers have adopted a strategy of recruiting firms involved in deconstruction, demanufacturing, dematerialization, and other "decomposer" activities (Côté 1994). These enterprises extract valuable materials from waste streams for reuse by other industries. This occurs naturally through "scavenger" companies that collect particular items, or can be a conscious strategy of demanufacturing. Attracting these types of operations to an EIP may help move it closer to the goal of reducing resource use and becoming a closed-loop system. Below are two examples of such "decomposer" industries: deconstruction and demanufacturing.

Deconstruction refers to the process of disassembling buildings to salvage building materials for reuse and recycling. Similarly, demanufacturing involves the disassembling of products, such as computers and electronic equipment, into component parts that can be reused or recycled. As with the other eco-industrial strategies mentioned in this report, the ultimate goal is to reduce reliance on virgin materials and decrease waste going to landfills and incinerators in ways that provide jobs and economic development opportunities.

Deconstruction can significantly reduce use of virgin materials and disposal of demolition wastes in landfills, while creating new jobs. Potential profits from deconstruction activities can also provide companies with incentives to remove vacant structures, perhaps on brownfield sites, that reduce the property value of neighborhoods. Materials that are "mined" from abandoned buildings include architectural components, such as banisters, mantles, window frames, doorknobs, wood flooring, and plumbing fixtures. Structural components that can be recovered include structural timbers, wood framing, steel reinforcements, and bricks. Because deconstruction is more labor-intensive than traditional demolition, it promotes job creation, while requiring minimal training. Local neighborhoods can benefit from job creation, small business development opportunities, conservation of resources, and savings in disposal costs.

The Green Institute in Minneapolis, MN, for instance, has turned the existence of numerous abandoned buildings in an inner-city neighborhood from a liability to an asset by developing the ReUse Center and DeConstruction Services, a neighborhood-run business that salvages and resells building materials. Some of these materials were used in the construction of the Green

Institute's own environmental award-winning building. Communities and developers elsewhere can similarly reuse deconstructed materials for the structures within their eco-industrial parks.

Efforts are underway in Austin, TX; Endicott, NY; and other areas to create eco-industrial parks and networks based on demanufactuing or disassembly industries. Focused principally on computers and electronics, these companies disassemble reusable components for use in remanufacturing of products and recycling of mainly plastics. Desired tenants include the firms involved in the actual dematerialization, as well as the remanufacturers, recyclers, and related collection and transport support enterprises. Materials that currently go mostly to landfill therefore become feedstock resources for multiple industries. Dematerialization occurs mostly in the design phase, where one finds ways to use fewer materials in the product itself. IBM in Endicott, for example, uses its learning from disassembly activities to help designers make improvements in the amount and kind of materials required for new electronic equipment.

Technological Innovation and Continuous Environmental Improvement

Continuous environmental improvement is a cornerstone of eco-industrial development. As mentioned in the discussion of environmental risks above, avoiding a reliance on toxic materials requires continual technological and design innovations that reduce use of hazardous inputs and outputs in production. Through research and development, businesses can also refine waste to be of sufficient quality to become an input. As Desrochers (2000) states, "Because of technical innovation, the market process is in continual flux. Old products and markets disappear, while new ones emerge and make creative use of what were until then waste products."

Public agencies have already provided support for research and development of industry ecology technologies. In the U.S., for example, the government funded feasibility studies for site-specific eco-industrial development (Department of Commerce, Economic Development Administration); combined heat and power technology (Department of Energy); computer models for identifying waste exchange opportunities (Environmental Protection Agency); and a Handbook of Codes, Covenants, and Restrictions for Promoting Eco-industrial Development (Environmental Protection Agency). Further public investment in applied research and commercialization of experimental technologies can bolster eco-industrial efforts in the form of byproduct exchange technology development programs and grants (Giannini-Spohn and Hendricks 2001).

Public Participation and Collaboration

Eco-industrial projects can find comparative advantage in building partnerships between businesses, government, citizens, and other groups holding a stake in sustainable industrial development (Côté and Cohen-Rosenthal 1998, Cohen-Rosenthal 2000). For this reason eco-industrial developers have often adopted community based planning tools to build relationships and inform planning efforts. As with the other strategies listed above, stakeholder participation optimizes an area's resources, in this case, human capital. Involving multiple stakeholders fosters social networks to support eco-industrial development activities. To build these linkages, eco-industrial practitioners have used a number of participatory tools, including participatory action research, search conferences, community visioning workshops, design charities, and surveys, interviews, and focus group discussions. The main function of these activities is to provide mechanisms for stakeholders to share their concerns, interests, and ideas for optimizing community assets and overcoming challenges. Ideally, development plans will incorporate these views in ways that both strengthen the outcomes and build public acceptance. Public/private partnerships sometimes require an external agent to catalyze the process of coming together, and so external consultants are often hired to facilitate and synthesize information.

In Cape Charles, VA, for example, a group of citizens, state and local government representatives, business interests, design professionals, and others conducted a visioning process to generate alternatives for revitalizing their stagnant economy. The result was the Cape Charles Principles, a set of five objectives to guide the sustainable redevelopment of the community. Using these Principles, the town designed the Cape Charles Sustainable Technologies Park, often considered the first EIP to open in the U.S. Minneapolis, MN; Chattanooga, TN; and Baltimore, MD have used similar processes.

CURRENT PRACTICE

Kalundborg, Denmark

Industrial ecologists have focused on Kalundborg, Denmark as the preeminent modern case of successful byproduct exchanges and eco-industrial networking. There is some debate in the literature, however, regarding the applicability of the Kalundborg system of byproduct exchanges to other cases. As many analysts are beginning to suggest, Kalundborg offers not a technological model to be replicated, but inspiration for other communities seeking to optimize their own specific set of community resources.

Kalundborg's Industrial Symbiosis is the collaboration between five primary independent industrial enterprises for mutual economic and environmental benefit. It is based on a series of bilateral commercial agreements on three different kinds of projects: recycling water, exchanging energy at different levels, and recycling waste products. The Aeneas Power Plant, for example, produces a waste stream of steam and heated water. This water warms the tanks of a fish farm, while the steam is used by the municipality for heating and by Novo Nordisk, a pharmaceutical company. Novo Nordisk, in turn, pipes organic sludge waste to farms to use as fertilizer. Cooperation between businesses was voluntary, but conducted in close collaboration with regulatory authorities (Christensen 1994). By 1998, the Symbiosis agreements have amounted to some $160 million in savings. This level of cost savings and improved environmental performance becomes a competitive advantage for participating companies.

The many bilateral connections that make up the Industrial Symbiosis systems developed over nearly three decades. The resulting web of interconnections was not planned from the beginning, but has developed through the initiative of individual managers forging bilateral byproduct exchanges with managers of other companies with whom they were already acquainted. Kalundborg has thus been described as a "non-project" (Christensen 2000) and a "wonderful accident" (Cohen-Rosenthal, personal communication).

Desrochers (2000) cautions that industrial ecologists are "reading too much into Kalundborg." He sees Kalundborg's Industrial Symbiosis as being only one case of a practice that has occurred for hundreds, even thousands, of years. While this is a valid point, Kalundborg adds a new element or lesson to the study of byproduct exchanges. Its primary innovation is not technical in nature, but sociological (Cohen-Rosenthal 2000). Analyses often seek to identify the conditions that allowed the Kalundborg network to develop, often with a focus on the technologies required for the Symbiosis to work (e.g., Bechtel 1997, Ehrenfeld and Gertler 1997, Ayers 1996, Gertler 1995). It is becoming clear, however, that the technological connections that have made the Symbiosis possible cannot be reduced to a simple boilerplate to be replicated by other communities. Jørgen Christensen, who as a Vice President of Novo Nordisk was involved in developing some of the connections, admits Kalundborg's success is based more on good luck, common sense, and close interpersonal relationships than technology: "Technology makes it possible…but people make it happen." (2000). Gertler (1995) adds that the Kalundborg system is the result of "creative business sense and deep-seated environmental awareness."

U.S. and International Cases[1]

A number of eco-industrial projects are in the planning or development stages in North America, South America, Europe, Asia, and South Africa. In the U.S., a number of regional networks of eco-industrial practitioners, policy makers, and funders are beginning to emerge. The U.S. Economic Development Agency (EDA), Environmental Protection Agency (EPA), and National Oceanic and Atmospheric Administration (NOAA) are supporting the National Center for Eco-Industrial Development, which is administered by Cornell University and the University of Southern California. The Canadian Eco-Industrial Development Network similarly facilitates information exchange between practitioners. Parallel networks are developing in Europe, and more recently, Asia.

In 1996 the President's Council on Sustainable Development chose four pilot sites to investigate the potential for applying eco-industrial strategies (PCSD 1996). Several of these had false starts and have not come to fruition, but some were successful. Most other U.S. sites are in the planning and early implementation stages, and so there is not yet sufficient data to determine rates of success and the financial and environmental implications. In this section we will highlight three cases. Numerous others are listed at Cornell Work and Environment Initiative's web site at <www.cfe.cornell.edu/wei/eid.html>.

In Cape Charles, Virginia eco-industrial development is already beginning to demonstrate its promise. The area's high unemployment and a faltering economy spurred local government officials and citizens to come together to create an eco-industrial development plan. The result is the Port of Cape Charles Sustainable Technologies Industrial Park, an eco-industrial park fully leased in its first phase of building. The Park currently consists of a multi-tenant building designed with the flexibility to accommodate a range of light manufacturing firms. The public-private management partnership provides a set of codes, covenants, and restrictions to encourage and reward both environmentally sound practices and involvement with the local communities. Currently the Park is only minimally involved in actual waste exchanges; however, the management expects this will change as new firms take advantage of special incentives for networking between businesses on-site and with people and businesses in the surrounding

---

[1] The cases presented here are adapted from Schlarb and Cohen-Rosenthal 2000.

community. The building includes green design features, such as solar panels, maximum energy efficiency and skylights for natural daylighting of workspaces. The Park also houses a shared tenant and community space, and preserves 25 out of 50 acres for wetlands and wildlife.

In an economically disadvantaged neighborhood of Minneapolis, Minnesota, a group of citizens concerned about the social and environmental implications of a proposed waste site established the Green Institute to oversee alternative eco-industrial networking projects. The Green Institute built the Phillips Eco-Enterprise Center (PEEC), a commercial facility for high-growth, innovative businesses producing products and services to help restore the environment while providing living-wage jobs to the area. In addition to the ReUse Center and DeConstruction Services, the Institute seeks other recycling and exchange opportunities among the tenants, off-site businesses, and the local community. The PEEC building has won awards for its sustainable design features, which take into special consideration occupant health and energy and material efficiency. For example, the building cuts energy use by about 55% through a geo-thermal exchange heating and cooling system, and has 100% day lighting for all work areas.

In contrast to the Cape Charles and Minneapolis cases, the Town of Londonderry, New Hampshire is using eco-industrial development to address the flipside of economic development: how to limit the negative effects of growth that is too rapid. In response to Londonderry becoming one of New Hampshire's fastest-growing communities, residents have mobilized to preserve the town's agricultural heritage and promote environmentally and culturally appropriate development. The Londonderry Ecological Industrial Park, an outcome of this mobilization, is one of the nation's prime examples of eco-industrial synergies. This project demonstrates how earlier notions of creating self-contained, closed-loop systems have expanded beyond park borders. For instance, one tenant of the Park, a plastics recycling company, purchases waste plastic from Stonyfield Farms Yogurt, a firm located next to the Park. The Park has also attracted AES, a power company that will develop a 720 megawatt combined cycle natural gas power plant for the site and will use treated wastewater pumped from the City of Manchester's Waste Water Treatment Facility. The Londonderry eco-park therefore demonstrates the Park's management has been in discussions with other possible tenants about similar synergies. A positive consequence of AES's locating in the Park is that in order to meet the Park's environmental standards, which are overseen by a citizen committee, the company has revolutionized environmental design of power plants.

Cape Charles, the Green Institute, and Londonderry demonstrate both the promise and challenges of eco-industrial development in the United States. Of three primary eco-industrial strategies—ecological design, linkages with local community, and business networks—each project has made significant progress in at least two. Each park has successfully integrated community, local government, and business input-- with some degree of public oversight-- into the parks' design and management plans. They have also pushed the envelope on ecological design of industrial production facilities and workspaces, winning green design awards for innovation and energy and material efficiency.

The most significant challenge to the realization of eco-industrial concepts in the United States, however, has been forging the kinds of environmentally sound and economically efficient business connections found in Kalundborg. Londonderry is probably the most advanced U.S. case in terms of forming formal linkages between companies for the exchange of material and waste. The Green Institute, while currently lacking a formal residuals exchange network between its tenants, harvests what was once considered community waste at a profit. Cape Charles has an eye on future business exchanges, but for now is focusing on recruiting environmentally conscious and socially responsible tenants.

These and other communities have quickly realized that the duplicating Kalundborg is neither possible nor necessarily desirable, given local cultural, ecological, and economic conditions. Rather, they are adopting, adapting, and creating strategies that are most environmentally, socially appropriate, and financially feasible.

Conditions Favorable to Eco-Industrial Development

There has been considerable discussion regarding which conditions are supportive of eco-industrial development (e.g., van Der Ryn and Cowan 1996, Ayres and Ayres 1996, Gertler 1995, Pelletiere 1999). Pelletiere (1999) summarizes what he considers a consensus among industrial ecologists on three criteria for establishment of a successful eco-industrial network, adding a fourth, less-emphasized element:

1. The supply of by-products must meet existing demand (and vice versa);
2. Firms must form relationships based on close individual connections or an institutional framework that reduces transaction costs;
3. There must be a sufficient number of compatible firms within close proximity to one another that ensure stable quantities and quality of byproducts;
4. There must be regulations in effect that increase the price of disposal and motivate the firms to seek symbiotic relationships with other firms (Gertler 1995).

He concludes that while transaction and regulation are important to the success of eco-industrial networks, "it is the proximity of diverse and compatible firms that is at once their greatest obstacle and the greatest opportunity in making industrial symbiosis economically feasible" (1999). Others similarly emphasize that this issue of scale is integral to the success of by-product exchanges (e.g., van Der Ryn and Cowan 1996). Desrochers presents the case that large cities are perhaps the ideal location to enact byproduct exchange, because they are they only places where there exists the requisite volume of material for cost-effective resource recovery and exchange. "Waste must be forthcoming in a steady stream of uniform volume to justify its exploitation, and the fashioning and maintenance of these streams is the supreme difficulty." (Talbot 1920, in Desrochers 2000).

PLANNING ECO-INDUSTRIAL DEVELOPMENT

The literature debates the relative potentials for self-organizing, market-based (private planning) versus centralized (public planning) approaches to fostering eco-industrial networks. A number of industrial ecologists have explored the possibility of substituting a planning approach for the self-organizing process that evolved in Kalundborg (Hawken 1993; van Der Ryn and Cowen

1996, Lowe 1997, Côté 1997, Côté and Cohen-Rosenthal 1998). Paul Hawken (1993) portrays this possibility for designing new estates:

> Imagine what a team of designers could come up with if they were to start from scratch, locating and specifying industries and factories that had potentially synergistic and symbiotic relationships.

The UNEP (1997) has published guidelines for planning new eco-industrial estates and building networks, and a number of U.S. communities have initiated eco-industrial park planning efforts (e.g., Cape Charles, VA; Red Hills EcoPlex, MS; Londonderry, NH; Burlington, VT; Minden, LA; Fort Devens, MA). Planning departments of several other communities or regions are exploring ways to plan regional eco-industrial networks (Triangle J, NC; Springfield, MA; Minden, LA).

Other industrial ecologists consider market drivers to be more instrumental to achieving positive results (Desrochers 2000, Côté and Cohen-Rosenthal 1998, Lowe 1998). Most companies, particularly small- to medium-sized ones, are not in a position to form exchange relationships with other firms unless they demonstrate the promise of lower costs, higher profit, and increased market opportunity. Lowe (1998) cautions that over-planning to create the "right" mix of firms will inevitably constrain recruitment of EIP tenants; thus, a recruitment strategy should develop a set of target industries that fit with the area's existing industrial mix and resources.

Desrochers (2000) takes issue with the public planning approach, arguing that public planning efforts are not likely to outperform market forces. Cost, he says, is the more powerful driver of waste prevention and resource recovery, as demonstrated in the Kalundborg system, which he believes developed "entirely through market forces":

> …many policy analysts argue that public planners can copy and even improve upon Kalundborg…EIP advocates often argue that public planners, following a hierarchy of consciously chosen objectives, can outperform private agents whose priority is to maximize profit rather than promote sustainable development…[However] no Kalundborg company ever acted on its own upon opportunities that did not fit within its core business, no matter how environmentally attractive they were. And when government intervention forced a linkage, the venture lost money.

Desrochers forwards a convincing argument that in a market economy, those at the locale are better equipped to deal with a problem than an often-distant planner. However, this takes a narrower view of planning, focusing more on the regulatory role of policy planners than other roles. But regulation is the only part of planning efforts. In the context of existing eco-industrial efforts, public planners serve more to catalyze dialogue between businesses and help businesses and communities identify networking opportunities. Several authors have identified possible roles public planners can play in these efforts (Andrews 1999, Martin 1996, Deppe et al 2000):

- Recruiting companies to fill a void that may occur when key suppliers or customers move or go out of business;

- Modeling the network of exchanges to reveal new opportunities;
- Researching technologies and markets for currently unmarketable byproducts;
- Serving a clearinghouse function to facilitate communication and information-sharing with and among companies on resource exchange opportunities and potential sources of funding;
- Convening public education and participation programs.
- Integrating public functions with the EIP, such as public transportation, road planning, school to work transitions, etc.
- Facilitating permitting of desired new practices

The public facilitator/convener role is particularly important when attempting to foster eco-industrial development in the broader community development context. Market forces may drive the formation of networks in regions with an existing industrial base, but what of towns that are trying to revitalize, retain, or attract businesses? Many of the U.S. cases mentioned in this report are distressed communities looking for sustainable ways to develop their lagging economies. These towns and neighborhoods view eco-industrial development as a "hook" to attract businesses without sacrificing the environment or social fabric of their communities. Waiting for companies to realize the benefits of sustainable development to their core drivers is not an option, particularly if those businesses are already considering closing or moving away.

Public planners have intervened in these cases to work with multiple stakeholders—businesses, residents, institutions—to identify those opportunities that will meet their particular interests, whether resource exchanges, shared services, workforce training, etc. Once these alternatives are identified, market forces take over as industrial park managers, chambers of commerce, and economic development offices recruit business tenants and develop exchanges. In the context of community and economic development of distressed communities, these public/private partnerships may be an important element of successful eco-industrial planning.

IMPLEMENTING ECO-INDUSTRIAL DEVELOPMENT

A growing body of literature addresses the issues communities and developers confront in the planning and implementation of eco-industrial development projects (e.g., Lowe 1997 and 2001, North and Giannini-Spohn 1999, Côté and Cohen-Rosenthal 1998). These include suggestions for how to adapt eco-industrial concepts to local conditions, financing and risk, park management, information management and communication, evaluation, and marketing and recruitment.

Financing

Perhaps the first issue that comes to the minds of communities and developers when considering eco-industrial development is how to finance these activities. Potential sources of funding include mainstream investment companies, local commercial banks, pension funds, and insurance companies. Other options might include large foundations, municipal bond financing, and state economic development funds. Municipalities, public and private utilities, and other public and private entities have also supported eco-industrial development projects, with an expectation of benefits from new economic development (Lowe 1998).

North and Giannini-Spohn (1999) present a comprehensive analysis of financial concerns and opportunities raised in implementing eco-industrial projects. They argue convincingly that because eco-industrial activities to this point have been limited, financiers and investors have difficulty assessing risk, listing four primary points of uncertainty:

1. Businesses and financiers are uncertain of how many secondary activities that may be required to underwrite in order to participate in an EIP.
2. Lack of precedence on which to base rates of financial returns operates to limit investor enthusiasm;
3. Concern about unique codes, covenants, and restrictions (e.g., deed restrictions). Financiers are leery of any restrictions that may impede their ability to resell or transfer a property should they acquire a financial interest.
4. As with any potential new firm, existing businesses may regard a new EIP as a competitor and politically may not support public financing of infrastructure development.

The uncertainty associated with eco-industrial projects may be mitigated as more data on the economic consequences of these strategies come in. There is therefore a need to document these projects well. The emergence of socially and environmentally responsible funds may also consider other indicators, including increased resource efficiency.

Management

Because EIPs are often centrally controlled, there are unique opportunities for coordinated and coherent application of environmental management principles (UNEP 1996). EIPs move from a consideration of single companies to focus on systems in a way that balances individual company and community interests. The diversity of companies and community stakeholders requires a clear definition of environmental and social responsibilities and accountability at the community, agency, and firm levels.

Three management structures have emerged in eco-industrial development practice (Ayers, 1996; RTI 2000; Côté 1997):

- Professional management companies
- Tenant-run boards
- Public/private partnerships or co-ventures

These structures are not necessarily mutually exclusive. A number of combinations of these management structures have emerged. In virtually all cases, for example, a public/private partnership is desirable to optimize access to land, community resources, and financing. Tenant-run boards can help professional management companies better identify opportunities for inter-firm synergies. The composition of management will depend on local preferences and requirements.

As with conventional industrial parks, management responsibilities can range from provision of a minimum of services, such as centralized sewage treatment, waste disposal, and sewage systems, to more comprehensive approaches, including environmental certification, energy audits, environmental training, and emergency preparedness. Management responsibilities for both conventional parks and EIPs typically include planning and site selection, construction, provision of infrastructure and services, establishing an environmental management system, monitoring emissions and media quality, enforcing regulations and codes, and reporting environmental quality.

Because eco-industrial approaches seek an even broader set of connections between companies, EIP managers have additional responsibilities. They must develop an accessible and up-to-date communication infrastructure so that tenants can build relationships and share information on possible resource exchanges and shared services (Deppe 2000). EIP managers are also responsible for added physical infrastructure to handle hazardous waste, and water, energy, and materials flows. Seeking funding in conjunction with federal, state, and local programs providing incentives for environmental improvements, workforce training, or community economic development may also be required. Cohen-Rosenthal (2000) proposes that there be a systematic approach to EIP management, rooted in core business drivers. A primary function of an EID network is to continuously seek management and environmental improvements supporting these drivers.

Whichever management structure is adopted, the goal of continued environmental improvement requires adaptive management to respond to technological innovation and changes in markets (Lowe 2001). Chertow (1999) cautions that creating the requisite level of cooperation for multi-party exchange is a slow process and therefore may require an evolutionary process of incremental formation of exchange relationships. Ayres (1996) suggests that management must be non-hierarchical, flexible, and open so that there is room for individual firms to make the necessary adjustments on which exchange networks depend.

Information Exchange and Clearinghouse

For an eco-industrial park or network to be successful, a reliable mechanism for long-term collaboration must be established at the technical level among the participating firms (Ayres 1996). Firms within a park or a regional network rely on information management systems to facilitate the flow of materials within an EIP, the surrounding community, and the region. EIP or network management must also serve an educational and marketing role to overcome barriers to adoption of eco-industrial principles. Businesses in general, and small and medium-sized firms in particular, are limited by low awareness of environmental issues and regulations. In addition, they are usually oriented to sales maximization rather then cost minimization through pollution reduction measures (Smolenaars 1996). There is therefore a need to overturn the dominant individualistic, business-as-usual models through education (Chertow 1999), perhaps by demonstrating to firms how inter-firm collaboration can help them decrease pollution and meet their regulatory requirements. An EIP management entity can address these problems by serving an information clearinghouse function, providing guidelines and suggestions for improving energy efficiency, resource conservation and waste minimization, cleaner production technologies, and emergency response.

Considering broader regional eco-industrial networks, a number of tools have been developed to facilitate cooperation. The U.S. EPA, for instance, has developed the DIET/FAST computer software programs designed to assist decision makers and planners in identifying combinations of industrial facilities that exhibit economics and environmental potential for an eco-industrial park at a given location. Several groups around the U.S. and other regions have created materials exchange programs, web site directories, and catalogues. In Long Island City, New York, the Industrial Waste Recycling and Prevention (INWRAP) program has helped businesses implement waste reduction and recycling programs. Participating firms have achieved gross savings averaging over $1,000,000 per year through reducing, reusing and recycling their by-product and waste materials (LICBD). The program has established the web-based NY Wa$teMatch, a searchable database of intended to match waste generators and potential reusers. Similarly, the Southern Waste Information Exchange, Inc., a non-profit organization located in Tallahassee, FL, has created the SWIX Clearinghouse which lists, in print and web form (<www.ElectronicXchange.org>), services, products, or equipment wanted and available for exchange or recycling (SWIX 2000). Universities and chambers of commerce have been instrumental in facilitating information gathering and exchange.

The Burnside Cleaner Production Center: A Mechanism for Information Exchange and Education

The Burnside Industrial Park Cleaner Production Centre in Dalhousie, Nova Scotia, exemplifies this clearinghouse role. The Centre was established in 1995 to provide information on waste minimization, pollution prevention, and cleaner production to the Park's approximately 1,300 businesses. It uses a multi-faceted educational approach to disseminate information on industrial ecology concepts, tools, and available resources to businesses and the surrounding community. The Burnside Centre achieves its mission by actively fostering relationships among tenant firms and raising awareness of potential exchange opportunities identified through surveys, plant visits, and interviews. Its four primary areas of focus are packaging, used building materials, materials management for community arts and schools, and chemical exchange (Smolenaars 1996).

Marketing and Recruitment

Eco-industrial parks must develop a strategy for proactive, targeted recruitment of new tenants for reusing facilities and property (McGalliard, et. al. 1997). To be competitive with other industrial parks, an EIP must first meet the basic criteria of any conventional park: access to markets and supplies, labor resources, availability of infrastructure and transportation, economic incentives, and quality of life (Cohen-Rosenthal 2000, 1998, etc.; Lowe 1998). Eco-industrial parks have the added marketing advantage of potential improvement in economic and environmental performance through synergistic relationships with other companies. A marketing strategy for an EIP might feature a firm's potentially enhanced public image as an environmentally and socially conscious enterprise. By sharing marketing costs, companies within an eco-industrial park or network can reduce expenses.

Evidence suggests that, with the exception of a growing number of "green" firms, most companies will be most attracted by economic performance features. A survey of Springfield, MA firms, for example, indicated that companies would be more likely to participate in an exchange networks if the potential for lower materials and disposal costs, or profit from sales of reusable byproducts, were clearly demonstrated. Similarly, developers of the Red Hills EcoPlex in Choctaw County, MS, have emphasized the economic development benefits of locating at the facility over environmental advantages (Smith 1999).

Potential byproduct exchanges, along with the business, environmental, and community goals for an EIP will in large part determine what type of industries will be recruited. It is the function of park management to identify which industries are appropriate and then promote the unique characteristics of the EIP in recruiting potential tenants (WEI 1997). Tenant representation in the management team has been used as one way to ensure recruitment efforts target appropriate potential byproduct exchange partners. Recruitment targets should not be rigid, however, because developers, whether public or private, must balance the needs of filling the EIP with the constraints of finding synergistic matches. Eco-industrial marketing and recruitment plans, such as Cornell Work and Environment Initiative's targeted recruitment studies for Cape Charles, VA, (WEI 1997) and the Red Hills EcoPlex in Mississippi (WEI 2000), developed a set of target industries based upon each region's particular industrial mix.

In many cases, public agencies can bolster marketing and recruitment. Local and state economic development agencies and commerce departments have actively supported marketing and recruitment efforts by eco-industrial developers. Local and regional chambers of commerce have also played a significant role in promoting byproduct exchange activities, particularly in broader regional networks. Giannini-Spohn and Hendricks (2001) note that the President's Council on Sustainable Development, by naming the Cape Charles EIP as one of four eco-industrial development pilot projects, contributed to its success recruiting tenants, despite the area's previous difficulties recruiting new economic development opportunities. Public entities can thus publicize and promote promising eco-industrial projects by recognizing superior environmental performance above mandated compliance standards.

Monitoring and Evaluating Performance

Eco-industrial activities should be continually monitored and evaluated for environmental, social, and economic performance. Economic data is particularly important at this early stage of EID adoption to determine whether eco-industrial development can truly be cost-effective for businesses and communities. Firms and industrial parks are required by law to report on compliance with regulations such as the Clean Air and Clean Water Acts. These reports, however, traditionally have not included sustainability indicators, such as quality of life, job growth, community service, and other aspects of social and environmental life. EIPs, often through codes, covenants, and restrictions, have addressed these issues by encouraging or requiring tenants to report on social and environmental impacts beyond compliance with regulatory statutes. Maureen Hart (1999) provides a useful guide to developing a series of sustainability indicators, and UNEP (1997) looks specifically at developing environmental performance objectives. Beyond their regulatory functions of requiring firms to report environmental performance, government agencies can support development sustainability indicators to more accurately evaluate environmental and economic performance through technical assistance programs.

Public agencies can support all aspects of management listed above, not only through regulatory and funding measures, but also through the creation of national information centers and dissemination of best practice through national workshops (Giannini-Spohn and Hendricks 2001). Some of the greatest barriers to resource efficiency are poor management, low environmental awareness, and inadequate knowledge of available technology. Web sites, such as that of the Department of Energy's Center of Excellence in Sustainable Development (<www.susainable.doe.gov/toolkit/tookit.shtml>), provide resources on community development, sustainable design, land use planning, industry, economics, and other aspects relevant to eco-industrial development. The National Center for Eco-Industrial Development, with the support of the U.S. Economic Development Administration, is building a web site to provide links and resource guides specifically related to eco-industrial development (<www.usc.edu/schools/sppd/research/NCEID>).

REGULATORY ISSUES

A number of regulatory concerns have arisen in discussions among government, industry, NGOs, and researchers considering eco-industrial development (Andres, et al 1998; Pelletiere 1999). Environmental policies can support– but at this time probably limit– the development of eco-industrial parks or networks. In this section we will describe how current regulatory mechanisms present obstacles to implementation and suggest external and internal regulatory frameworks and market-based mechanisms that can add incentives for adoption.

External Regulations

Desrochers (2000) and Pelletiere (1999) point to how regulation of hazardous waste in the U.S. currently thwarts industrial symbiosis, often discouraging or restricting the identification and implementation of creative solutions. Overcoming regulatory obstacles and developing policies supportive of eco-industrial development is therefore a priority.

Several authors point to potential or actual conflicts between hazardous materials transfer regulations and waste exchange opportunities (Weitz and Martin 1995, Desrochers 2000, Pelletiere 1999). One of the greatest areas of concern is liability:

> EIP industries confront liability issues when one or more industries are treated under a regulatory umbrella within an EIP. Difficulty arises when one or more companies fail to abide by the established code of ethics. Is the single company or all companies liable in the case? In addition, monitoring releases from individual industries under a single permit is difficult, especially if industries exchange materials. The mixture of large, medium, and small firms within an EIP necessitates addressing relative burdens with equitable alternatives (Weitz and Martin 1995).

At the PSCD's Brownsville, TX demonstration site, for example, companies expressed a concern about their potential liability if they entered a relationship with another company to exchange byproduct materials. They were concerned that, if the production or use of a product containing secondary materials had a serious health or environmental concern, the company that supplied the secondary materials also could be held liable for damages.

Regulatory definitions of what constitutes a hazardous waste pose additional concerns. In the U.S., the Resource Conservation and Recovery Act (RCRA) and other federal statutes (e.g., the Clean Air Act, Clean Water Act, Comprehensive Environmental Response and Liability Act, Toxics Releases Inventory, and the Toxic Substances Control Act) make little distinction between solid and hazardous wastes and secondary materials that might be reusable. The RCRA "derived from" rule, for example, considers any material derived from a listed hazardous waste itself to be a hazardous waste, and the obstacles for delisting a derived material are so great that generators and recyclers simply will not spend the time, effort, and resources required (Lowe 1998, Weitz and Martin 1995). This makes it difficult for companies to reuse and recycle materials that are not contained in a closed-loop recycling system. Definition of "source" also presents a challenge. Changing permits for particular points of emissions within a factory would require an unwieldy amount of paperwork. It may also cause firms "grandfathered" under old Clean Air Act rules to be subject to stricter standards.

A third regulatory issue is single-medium permitting. Most legislation regulating environmental performance addresses a single medium. The Clean Water Act regulates water; the Clean Air Act, air; and so on. In some cases, this regulation on a medium-by-medium basis may not reduce pollution levels by individual companies that shift emissions from one medium to another. For example, burning solid wastes to mitigate a particular hazard pollutes the air. Then soils and water bodies can be contaminated when particulates are captured by rainfall (Ayres and Ayres 1996). For EIP development to be successful, a multimedia approach to regulation is therefore necessary. Issuing true multimedia permits, however, is a complicated process requiring a change in statutes, and therefore a significant amount of time (Weitz and Martin 1995).

Adopting eco-industrial strategies for brownfields redevelopment poses a combination of concerns. Current regulations, liability concerns, and high cost of cleanup of brownfield sites contaminated with toxics and heavy metals are disincentives for companies and developers to locate on or around a brownfield rather than a greenfield. Regulatory bodies must therefore provide more incentives for companies to develop on brownfields. Weitz and Martin (1995) suggest offering industrial tax credits or exemptions, the savings from which can be used in conjunction with state and federal funds for brownfields cleanup. Exemptions must be high enough to at least offset cleanup and remediation costs.

The number of regulatory concerns that have emerged with respect to eco-industrial development indicate a clear need for external regulations to support EIP development (RTI 2000; Lowe 1998; Côté 1997; Martin, et al 1995; Weitz and Martin 1995). The literature suggests the following reforms:

1. Development of EIPs requires maximum regulatory flexibility (e.g., Wallace 1995, Lowe 1998, RTI 2000). Existing regulations that limit resource recovery and exchange need to be modified, and unclear regulatory definitions should be clarified. Balancing the tradeoffs between regulatory strategies that meet aggressive environmental standards and

ones that encourage innovation, such as eco-industrial development, will be a challenge. Adopting a phased approach may be most realistic, where regulators focus first on modifying existing regulations to encourage pollution prevention and then progressively evolve regulations to support a fully collocated EIP (Weitz and Martin 1995).

2. Streamline permitting and reporting processes (Lowe 1998, Weitz and Martin 1995, Cohen Rosenthal 1996). Reporting could be consolidated (“one-stop”) across federal and state programs to eliminate redundancy and streamline the timing and data requirements. Eco-industrial development strategies that bring a number of organizations into a common association may offer opportunities to establish common permitting and reporting strategies. “Umbrella” permitting and certification promoting facility-wide permitting can reduce the cost of permitting and encourage the facility to develop and implement pollution prevention and/or closed-loop recycling technologies. The appropriate mechanisms for doing this, however, must be investigated because modifying a process or technology may require time-consuming amendments. In New Jersey, for example, facility-wide permits were rejected by all but the largest facilities because trying to cover everything with one permit was considered too complicated. Businesses may not favor umbrella permitting because it might obligate them to reveal total releases. Questions of liability may also be a disincentive for joining a regulatory association because it is unclear whether each member firm will be liable for the noncompliance of any plant under the permit (Lowe 1998).

3. Promote multimedia permitting to encourage more regulations that focus on reducing *total mass emissions* for an entire facility and discourage facilities that shift pollutants between media, such as water, air, hazardous waste, etc. (Lowe 1998).

4. Take a systems approach, integrating economic and environmental performance issues into policies and regulations (Lowe 1998). For example, the Department of Commerce, which is concerned with the competitiveness of industrial sectors, works with the EPA, which is responsible for protecting air, land, water, and waste, to regulate and monitor the economic and environmental performance of industries or sectors. Currently, the U.S. Federal government does not have a single department or agency responsible for supporting or overseeing eco-industrial development initiatives; rather, several agencies have supported eco-industrial projects and technical assistance projects. Some of these agencies have begun to coordinate interagency efforts to support eco-industrial development (e.g., U.S. EDA, U.S. EPA, and NOAA). Such interagency efforts can support a systems view to identify solutions to both economic development and environmental pollution problems.

Internal Regulation: Codes, Covenants, and Restrictions

Internal codes, covenants, and restrictions, or CCRs, provide a means to encourage tenants to perform beyond compliance with external regulations (Deppe 2000; Côté 1997). CCRs are defined as "internal land-use controls and standards that are legally enforceable and applicable only to a specified property” (UNEP 1997). Eco-industrial developers have sometimes expanded the scope of CCRs to include social guidelines and to promote environmental technologies and processes, such as resource recovery and exchange (Weitz and Martin 1995). These CCRs are becoming more standard as businesses and government seek to cooperate to meet pollution prevention goals. The advantage for companies is that they can better control their timeline and objectives-identification than outside regulators (Weitz and Martin 1995). Cornell's *Handbook on Codes, Covenants, and Restrictions for Eco-Industrial Parks* (2000) provide examples and guidelines for developing and implementing CCRs.

Market-Based Incentives

Market-based financial incentives may be more effective mechanisms for encouraging businesses to adopt eco-industrial approaches than external or internal regulations (Côté 1997; Desrochers 2000, Weitz and Martin 1995, Gertler 1995). Several market-based mechanisms have been proposed (Weitz and Martin 1995). The government has already implemented financial incentives or disincentives that make it profitable for polluters to reduce use of resource and energy or generation of waste. Other options include tax credits or exemptions, subsidized interest loans, and innovative technology grants linked to environmental performance. Giannini-Spohn and Hendricks (2001), however, caution that artificial incentives such as these, if not carefully designed, might discourage innovation for improved efficiency of operations.

Research, Development, and Technology Transfer

There is a need for more technology transfer programs promoting available pollution prevention and waste exchange programs. The government could provide industrial ecology technology development grants to investigate possible closed-loop connections, recycling and reuse opportunities, shared inputs, improved efficiencies of energy and materials use, and life-cycle design. These types of grants are available to some extent, but a greater emphasis should be placed on pollution prevention, rather than the conventional focus on remediation and control.

ADVANCING ECO-INDUSTRIAL DEVELOPMENT

Anecdotal evidence suggests that the emerging eco-industrial projects in the U.S. and abroad are successfully employing these strategies for sustainable economic and community development. Empirical data on cost savings, environmental impact, and other success indicators, however, are lacking. Academic institutions and emerging regional, national, and international networks of eco-industrial development practitioners are already sharing experiences and advancing common research agenda on best practices. The eco-industrial parks and networks themselves, however, must generate clear successes and document them quantitatively in order to build understanding of—and confidence in—this approach among the business community, economic development practitioners, financiers, agencies, communities, and researchers. Continued research into regulatory, financial, technological, social, and other concerns will inform implementation of eco-industrial strategies and help develop methods for lowering risks and optimizing opportunities. By addressing these issues, the community of practitioners and researchers will be better able to determine whether eco-industrial development does indeed offer a concrete, viable approach to achieving sustainable economic and community development.

This report has presented a number of ways public agencies can support these efforts, beyond funding specific projects, summarized below:

- Improve regulatory measures to discourage pollution and encourage greater resource efficiency. This requires regulatory flexibility and clearer definition of language to accommodate byproduct exchanges that improve overall environmental performance.
- Develop appropriate market-based incentives, possibly including taxes and technology development grants, to encourage adoption of eco-industrial approaches.
- Provide mechanisms for education, outreach, and research to build understanding and awareness of eco-industrial models of business and economic development. Web-based information resources and national workshops can be further developed to foster better management, improved environmental practices, and greater economic-efficiency.
- Build partnerships between public and private entities to capture community, financial, and information resources.

BIBLIOGRAPHY

Abe, Joseph M., Patricia E. Dempsey, and David A. Bassett. 1998. *Business Ecology: Giving Your Organization the Natural Edge*. Boston, MA: Butterworth-Heinemann.

Allen, David T. and Nasrin Behmanesh. 1994. "Wastes as Raw Materials." In Braden Allenby and Deanna Richards (eds.), *Greening of Industrial Ecosystems*. Washington, DC: National Academy Press.

Allenby, Braden. 1992. "Industrial Ecology: The Materials Scientist in an Environmentally Constrained World," *MRS Bulletin*, 17: 3: 46-51.

Allenby, Braden and D. J. Richards (eds.). 1994. *The Greening of Industrial Ecosystems*. Washington: National Academy Press.

Alter, C. and J. Hage. 1993. *Organizations Working Together*. London: Sage Publications.

Andrews, Clinton J. 1999. Putting industrial ecology into place: Roles for environmental planners. *Journal of the American Planning Association* 65, 4:364-375.

Andrews, C., D. Rejeski, R. Socolow, and V. Thomas. 1998. "Linking industrial ecology to public policy," Workshop Report. Available at http://radburn.rutgers.edu/andrews/projects/iepp/iepprpt.pdf.

Angel, David P. and Michael T. Rock (eds.) 2000. *Asia's Clean Revolution: Industry, Growth, and the Environment*. Sheffield, UK: Greenleaf Publishing.

Ashford, N. and R. P. Côté (eds.). 1997. Special Issue of *Journal of Cleaner Production* on Industrial Ecology. Oxford: Elsevier Publishing. 5:1-2.

Aupperle, Ken. 2000. "Smart Growth, Urban Sprawl, and Sustainable Development: Partnerships Provide the Foundation." Policy Forum on Urban Sprawl, The Center for Environmental Studies in Budapest. (April 3).

Ausubel, Jesse H. 1992. "Industrial Ecology: Reflections on a Colloquium," Proceedings of the National Academy of Sciences 89(3):879-884.

Ausubel, Jesse H. 1997. "The Virtual Ecology of Industry." *Journal of Industrial Ecology* 1(1):10-11. Available at http://phe.rockefeller.edu/VirtualEco/index.html.

Ausubel, Jesse H. 1998. "Industrial Ecology: A Coming of Age Story," *Resources* 130:14. (Winter). Available at http://phe.rockefeller.edu/RFF_IE/.

Ausubel, Jesse H. and Hedy E. Sladovich. (eds.). 1989. *Technology and Environment*, Washington, D.C.: National Academy Press. Proceedings Of The First Conference On Industrial Ecology, sponsored by National Academy of Engineering.

Ayers, Robert U. 1996. "Creating industrial ecosystems: a viable management strategy?," special issue on "Environmental Management of Industrial Estates," *Industry and Environment*, UNEP, 19:4:7-13. (October-December).

Ayres, Robert. 1996. "Creating industrial ecosystems: a viable management strategy?" *International Journal of Technology Management*, 12:5-6.

Ayres, Robert U. and Ayres, Leslie. 1996. *Industrial Ecology: Towards Closing the Materials Cycle.* London: Edward Elgar Publishers.

Baas, Leo and Frank Boons. 2000. "Sustainable Development and Industrial Ecology." Erasmus University, Rotterdam, the Netherlands. Presented at the Symposium Towards New Management Systems', University of Manchester, UK. (June 30).

Bechtel Corporation. 1997. *Development of Technically Feasible Materials Exchange Scenarios*. Bechtel Corporation.

Block, Dave. 1998. "Ecoindustrial Parks are Ready to Take Off." *In Business*. 18-21. (September-October)

Boyle C. A. and B.W. Baetz. 1997. "A Prototype Knowledge-Based Decision Support System for Industrial Waste Management: Part II. Application To A Trinidadian Industrial Estate Case Study." *Waste Management*. 17(7):411-28.

Business Council for Sustainable Development. 1997. "By-product Synergy: A Strategy for Sustainable Development, A Primer." Mexico: Business Council for Sustainable Development.

Carnegie Mellon University (CMU), Green Design Initiative. "Economic Input-Output Life Cycle Assessment." Carnegie Mellon. 2000. Available at http://www.eiolca.net.

Chertow, Marian R. 2000. "Industrial Symbiosis: Literature and Taxonomy." *Annu. Rev. Energy Environ.* 25:313-37.

Chertow, Marian R. 1999. "Industrial Symbiosis: A Multi-Firm Approach to Sustainability." Eighth International Conference of the Greening of Industry Network. (November 15).

Chertow, Marian R. 1998. "Waste, Industrial Ecology and Sustainability." *Social Research*, 65:1. (Spring).

Cohen-Rosenthal, Ed, Tad McGalliard, and Michelle Bell. 1995. "Designing Eco-Industrial Parks: The North American Experience." WEI Papers, Cornell University WEI Website. Available at http://www.cfe.cornell.edu/wei/EIDP/design.html.

Cohen-Rosenthal, Ed and Tad McGalliard. 1996. "Designing Eco-Industrial Parks: The US Experience." *Industry and Environment.* UNEP. 19:4:14-18. (December).

Cohen-Rosenthal, Ed. 1998. "Eco-Industrial Development: New Frontiers for Organizational Success." Proceedings Fifth International Conference on Environmental Conscious Design and Manufacturing, June 1998. WEI Papers, Cornell University WEI Website. Available at http://www.cfe.cornell.edu/wei/eipnewfrontiers.htm.

Cohen-Rosenthal, Ed. "Making Sense Out of Industrial Ecology: A Framework for Analysis and Action." Ithaca, NY: Cornell Work and Environment Initiative. Available at http://www.cfe.cornell.edu/wei/papers/sense_files/sense.htm.

Cohen-Rosenthal, Ed (ed.). 2001. *Eco-Industrial Strategies: Unleashing Synergy between Economic Development and the Environment*. Sheffield, England: Green Leaf Publishing (Forthcoming).

Cohen-Rosenthal, Ed. 2000. “A Walk on the Human Side of Industrial Ecology.” *American Behavioral Scientist*. 44:2: 245-264. (October).

Cohen-Rosenthal, Ed and Mark Smith. 2001. “Eco-industrial Development: The Creation of Value.” Urban Land Institute. Spring. (Forthcoming)

Côté, Raymond 2000. “It’s Not Waste Until It’s Wasted.” *Alternatives Journal*. 26:1:32-27.

Côté, Raymond. 1995. “Supporting Pillars for Industrial Ecosystems.” *Journal of Cleaner Production*, 5:1-2:67-74.

Côté, Raymond. 1996. “Industrial Ecosystems: An oxymoron.” *Ecocycle News.* Ottawa: Environment Canada. 4. (Summer/Fall)

Côté, Raymond, et al. 1994. *Designing and Operating Industrial Parks as Ecosystems.* Report of the project “The Industrial Park as an Ecosystem.” Halifax, Nova Scotia: Dalhousie University, School for Resource and Environmental Studies.

Côté, Raymond, T. Kelly, H. Reid, T. Smolenaars. 1996. The Industrial Park as an Ecosystem: Cross Sectoral Case Studies. Halifax, Nova Scotia: Dalhousie University, School for Resource and Environmental Studies.

Côté, Raymond, T. Kelly, J. MacDonnell, T. Mermer, R. Murray, T. Smolenaars. 1996. The Industrial Park as an Ecosystem: Sectoral Case Studies. Halifax, Nova Scotia: Dalhousie University, School for Resource and Environmental Studies.

Côté, Raymond and J. Hall (eds.). 1995. The Industrial Ecology Reader. Halifax, Nova Scotia: Dalhousie University, School for Resource and Environmental Studies.

Côté, Raymond. 2000. “Exploring the analogy further.” *Journal of Industrial Ecology*. 3:2-3: 11-12.

Côté, Raymond. 1997. “Whither Industrial Ecology: The role of the ecological industrial park.” Seminar presented at Johnson School of Management, Cornell University. Ithaca, New York.

Côté, Raymond. 1998. "Industrial Ecosystems - Evolving and Maturing," *Journal of Industrial Ecology*, I:3.

Côté, Raymond P. 1998. “Thinking like an ecosystem.” *Journal of Industrial Ecology*. 2:2:8-10.

Côté, Raymond P. and E. Cohen-Rosenthal. 1998. “Designing eco-industrial parks: a synthesis of some experiences.” *Journal of Cleaner Production* 6:3-4:181-188.

Côté, Raymond P. and J. Hall. 1995. "Industrial Parks as Ecosystems," *Journal of Cleaner Production.* 3:1-2.

Côté, Raymond P. 1999. “Industrial ecology and small business: Experiences from Burnside Industrial Park.” Presented at a US Environmental Protection Agency workshop, November 16, Washington, DC.

Côté, Raymond and Thomas Plunkett. 1996. Industrial Ecology: Efficient and Excellent Production. A book chapter in *Achieving Sustainable Development*. Environment and Sustainable Development Series, Vancouver: University of British Columbia Press.

Christensen, Jørgen. 2000. "The Industrial Symbiosis at Kalundborg." Presentation to the Eco-Industrial Development Roundtable, Mississippi State University. (February).

Deppe, Maile, Tom Leatherwood, Peter Lowitt, and Nick Warner. 2000. "A Planner's Overview of Eco-Industrial Development." Presented at the American Planning Association Annual Conference 2000, Eco-Industrial Session, New York, April 16, 2000.

Deppe, Maile. 2000. *Handbook on Codes, Covenants, Conditions, and Restrictions for Eco-Industrial Development.* Ithaca, NY: Cornell Work and Environment Initiative.

DeSimone, Livio D. and Frank Popoff. 1997. *Eco-efficiency: The Business Link to Sustainable Development.* Cambridge, MA: The MIT Press.

Desrochers, Pierre. 2000. "Eco-Industrial Parks: The Case for Private Planning." Bozeman, Montana: Political Economy Research Center. Available at http://www.perc.org/rs1_xsum.htm.

'Eco-Industrial parks: Economic Advantage through Environmental Performance." Green Base Conversion Strategies, Technical Brief #3, September 1997.

Ehrenfeld J, Gertler N. 1997. Industrial Ecology in Practice: The Evolution of Interdependence at Kalundborg, *Journal of Industrial Ecology*. 1:1:67-79

Engberg H. 1993. Industrial Symbiosis in Denmark. New York: New York University, Stern School of Business

Erkman, Suren. 1997. "Industrial Ecology: A Historical View." *Journal of Cleaner Production.* 4:4.

Ferri, Mark R. and Jackie Defola. "A Case for Eco-Industrial Development." *The Cap Gemini Ernst & Young Center for Business Innovation Journal*. Online.

Fleig, Anja-Kathrin. 2000. "Eco-Industrial Parks as a strategy towards Industrial Ecology in developing and newly industrialised countries." Report prepared for GTZ, Berlin.

Forward, Gordon and Andrew Mangan. 1999. By-Product Synergy. *The Bridge.* 29:1. (Spring). Available at http://www.hatch.ca/expertareas/sustainabledevelopment/default.htm.

Frampton, Matt. "Corporate Re-Use." *Center for Neighborhood Technology*. Online.

Frosch, Robert A., and Nicholas E. Gallopoulos. 1989. "Strategies for Manufacturing," *Scientific American*. September, pp. 144-152.

Frosch, R.A. 1995. "The Industrial Ecology of the 21st Century," *Scientific American*. September.

Frosch, R.A. 1996. "Toward The End Of Waste: Reflections On A New Ecology Of Industry, " *Daedalus*, 125:3:199-212.

Fujita, Tsuyoshi. 1999. "Planning Environmentally Sound Urban Renovation Strategies and Estimation of Their Performance," Proceedings from the CCP International Workshop on

Construction of ReCycle-Oriented Industrial Complex Systems with Environmental Sound Technology at Societal Experimental Sites" Project. pp. 188-197.

Garner, Andy and Gregory A. Keoleian, Gregory A. 1995. "Industrial Ecology: An Introduction." University of Michigan National Pollution Prevention Center for Higher Education.

Gertler, Nicholas. 1995. *Industrial Ecosystems: Developing Sustainable Industrial Structures.* Available at http://www.sustainable.doe.gov/business/gertler2.html.

Gertler Nicholas and J. Ehrenfeld. 1994. Industrial Symbiosis in Kalundborg: Development and Implications. Program on Technology, Business, and Environment Working Paper. Cambridge, MA: MIT.

Giannini-Spohn, Suzanne. 1997. "Eco-Industrial Parks Offer Sustainable Base Redevelopment." *ICMA Base Reuse Consortium Bulletin*. The International City/County Management Association. (May).

Giannini-Spohn, Suzanne. 1997 "Eco-Industrial Parks: One Strategy For Sustainable Growth." *DEVELOPMENTS.* Washington, DC: National Council for Urban Economic Development. (January 15). Available at http://www.smartgrowth.org/library/ecoind_strategy.html.

Giannini-Spohn, Suzanne and Bracken Hendricks. 2001. "The Role of Government in Eco-Industrial Development." In *Eco-Industrial Strategies: Unleashing Synergy between Economic Development and the Environment*. Sheffield, England: Green Leaf Publishing (Forthcoming).

Grant, Jill. 1996. "Designing Industrial Parks for the Future." *Plan Canada*. 36:3:17 22. (May).

Graedel T. and B. Allenby. 1995. *Industrial Ecology*. Englewood Cliffs, N.J: Prentice Hall.

Hall, Charles, S. Cleveland, J. Cutler, and Robert Kaufmann. 1986. *Energy and Resource Quality: The Ecology of the Economic Process.* New York: John Wiley & Sons.

Hamner, Burton. 1998. "Industrial Ecology in East Asia," *Journal of Industrial Ecology*. I:4:6-8.

Hart, Maureen. 1999. *Guide to Sustainable Community Indicators.* Second edition. North Andover, MA: Hart Environmental Data.

Hauff, Michael and Martin Wilderer. 1999. "Industrial Estates - The Relevance of Industrial Ecology for Industrial Estates," *Green Business Opportunities*, 5:2.

Hawken, Paul. 1993. *The Ecology of Commerce*. New York: Harper Business.

Information Design Associates (IDeA). 1997. *Cluster-Based Economic Development: A Key to Regional Competitiveness.* Washington, DC: U.S. Economic Development Administration.

Hollander, Justin B. 2000. *Analyzing the Effectiveness of the Eco-Industrial Park to Promote Sustainability*, M.R.P. Thesis, University Of Massachusetts Amherst.

Jelinski, L.W. et al. 1992." Industrial Ecology: Concepts and Approaches." Proceedings of the National Academy of Sciences.

Kasardsa, John D. “Time-Based Competition and Industrial Location in the Fast Century.” *Real Estate Issues.* (winter).

Kassinis GI. 1997. *Industrial Reorganization and Inter-firm Networking in Search of Environmental Co-Location Economies*. Dissertation. Princeton University

Keckler, S. E. and D. T. Allen. 1999. “Material Reuse Modeling: A Case Study of Water Reuse in an Industrial Park.” *Journal of Industrial Ecology*. 2:4:79-92.

Kharbanda, O. P and E. A. Stallworthy. 1990. *Waste Management: Towards a Sustainable Society*. New York: Auburn House.

Kimura, M. and M. Taniguchi. 1999. “Zero Emission Clustering; Achieving Zero Emission.” Presented at Eco 1999 International Congress, Paris.

Kincaid J. 1999. Industrial Ecosystem Development Project Report. Research Triangle Park, NC: Triangle J Council of Governments. Available at http://www.tjcog.dst.nc.us/ieprept.pdf.

Klee, R. 1999. “Zero Waste in Paradise.” *BioCycle*. 40:2:66-67.

Klee, R. J. and R. Williams. 1999. “Emerging International Eco-Industrial Projects; Casebook: Asia, The Pacific and Africa.” Report for the USEPA Office of Policy, Planning and Evaluation, Washington, DC.

Long Island City Business Development Corporation, http://www.licbdc.org/inwrap-wstmtch.htm.

Lowe, Ernest A., Stephen R. Moran, and Douglas B. Holmes. 1997a. *Eco-Industrial Parks: a handbook for local development teams.* Oakland, CA: Indigo Development.

Lowe, Ernest. 2000. “Fieldbook for the Development of Eco-Industrial Parks.” Research Triangle, NC: Research Triangle Institute.

Lowe, Ernest. 2001. “Introduction to Eco-Industrial Parks.” draft for Asian Development Bank. (Forthcoming).

Lowe, Ernest A. 1997b. “A Strategic Review of Sasol’s *ChemCity* Eco-Industrial Park.” Report for South African client, Sasol Chemicals, prepared by Indigo Development..

Lowe, Ernest A. 1997c. "Creating By-Product Resource Exchanges for Eco-Industrial Parks, *Journal of Cleaner Production.* 4:4.

Lowe, Ernest, John Warren, and Stephen Moran. 1997. *Discovering Industrial Ecology: an executive briefing and sourcebook.* Cleveland, OH: Battelle Press.

McDonough, William and Michael Braungart. 1998. “The NEXT Industrial Revolution.” *The Atlantic Monthly.* October.

“Managing Waste in an Industrial Park Ecosystem.” Canadian Waste Management Conference. Saint John, New Brunswick, Oct. 6-8, 1993

Manahan, Stanley. 1999. "Industrial Ecology - Environmental Chemistry and Hazardous Waste." Washington, DC: Lewis Publishers.

Mangan, Andrew, Carole Burnham, and David Groberg. (year unavailable). "By-Product Synergy: A Tool for Sustainable GHG Emission Reductions." Available at http://www.hatch.ca/ExpertAreas/sustainabledevelopment/Default.htm.

Martin, Sheila et al. 1995. *Developing an Eco-Industrial Park: Supporting Research, Volume 1, Final Report*, Research Triangle Institute Project Number 6050, Research Triangle Park, NC:RTI.

McGalliard, Tad, Bruce Clemens, Michael Gresalfi, Bruce Fabens, and Ed Cohen-Rosenthal. 1997. "Eco-Industrial Development and Re-Industrialization in Oak Ridge." Proceedings from the Fifth Annual Conference on the Recycling and ReUse of Radioactive Scrap Metal, Knoxville, TN. Available at http://www.cfe.cornell.edu/wei/BR97_FIN.HTM.

Mehalik, Matthew M. 2000. "Sustainable Network Design: A Commercial Fabric Case Study." *INTERFACES.* 30:3. (May-June)

Meyer, Peter B. and H. Wade van Landingham. 2000. "Reclamation and Economic Regeneration of Brownfields." *Reviews of Economic Development Literature and Practice: No. 1.* Washington, DC: U.S. Economic Development Administration.

Nash, Jennifer and John Ehrenfeld. 1997. "Codes of Environmental Management Practice: Assessing Their Potential as a Tool for Change." *Annu. Rev. Energy Environ.* 22:487-535.

National Academy of Sciences. 1992. *Proceedings* from the NAS Colloquium on Industrial Ecology, May, 1991. Washington, DC: NAS.

Nemerow, Nelson L. 1995. *Zero Pollution for Industry, Waste Minimization Through Industrial Complexes*. New York: John Wiley & Sons.

North, Jonathan and Suzanne Giannini-Spohn. 1999. "Strategies for Financing Eco-Industrial Parks," *Commentary*. (Fall).

O'Rourke, Dara, Lloyd Connelly, and Catherine Koshland. 1996. "Industrial Ecology: A Critical Review." *International Journal of Environment and Pollution*. (February).

Pauli, Gunter. 1998. *Upsizing: The Road to Zero Emissions*. Sheffield, England: Greenleaf Publishing.

Peck and Associates and Raymond P. Côté. 1997. "Promoting Eco-Industrial Development: Exploring benefits, challenges, drivers and opportunities for progress in Canada." A report to Environment Canada and Industry Canada, Ottawa.

Peddle, M. T. 1993. "Planned Industrial and Commercial Developments in the United States: A Review of the History, Literature, and Empirical Evidence Regarding Industrial Parks and Research Parks." *Economic Development Quarterly*. 7:1:107-124.

Pelletiere, Danilo. 1997. *Defining the Ecoindustrial Landscape: The Role of Agglomeration, Industrial Parks and Economic Exceptionalism*. Thesis (M.A.). Washington, DC: George Mason University.

Pelletiere, Danilo. 2000. “Eco-restructuring and the ‘Friction of Distance.’” in Jorg Kohn, John Gowdy, and Jan Van der Straaten. *Sustainability in Action: Sectoral and Regional Case Studies*. Cheltenham, U.K.: Edward Elgar Pub.

Pelletiere, Danilo. 1999. “Proximity, Uncertainty, and Regulation and the Development of Ecoindustrial Networks.” Proceedings from the Industrial Ecology and Sustainability Conference, Troyes, 1999.

Power Magazine. 1998. “Red Hills Goes Green; Large CFBs to Anchor Eco-Industrial Park.” *Power Magazine.*

President's Council on Sustainable Development. 1996. *Eco-Efficiency Task Force Report.* Available at http://www.whitehouse.gov/PCSD.

Reid, H. 1995. “Wasted Opportunities: A case study of the waste diversion barriers facing small businesses in Burnside Industrial Park.” Dartmouth, NS.

Research Triangle Institute. 2000. “Eco-Industrial Parks: A Case Study and Analysis of Economic, Environmental, Technical, and Regulatory Issues,” Executive Summary, Research Triangle Park, NC: Research Triangle Institute. Available at http://www.rti.org/units/ssid/cer/parks.cfm.

Richards, Deanna and Ann Fullerton (eds.). 1994. *Industrial Ecology: U.S.-Japan Perspectives*. Washington, DC: National Academy of Engineering.

Richards, Deanna J. (ed.). 1996. *The Industrial Green Game: Implications for Environmental Design and Management.* Washington, DC: National Academy Press.

Robins, R. 1991. “Waste Not: Garbage as an Economic Resource for the Northeast.” Boston: Conservation Law Foundation.

Rock, Michael T., David P. Angel, and Tubagus Feridhanusetyawan, “Industrial Ecology and Clean Development in East Asia.” *Journal of Industrial Ecology*. 3:4:29-42.

Rocky Mountain Institute. 1998. *Green Development: Integrating Ecology and Real Estate.* New York: John Wiley & Sons, Inc.

Salvesen, David. 1996. “Making the Industrial Parks Sustainable.” *Urban Land*. February:29-32.

Schlarb, Mary and Barry Keppard. 2001. “Springfield Eco-Industrial Baseline Study.” Report submitted to the City of Springfield, MA and the Chelsea Center for Recycling and Economic Development. Ithaca, NY: Work and Environment Initiative, Cornell University.

Schlarb, Mary and Ed Cohen-Rosenthal. 2000. “Eco-Industrial Developments.” *Sustainable Architecture White Papers*. New York: Earth Pledge Foundation.

Schwarz, Erich J. 1996. "Recycling-Networks: A Building Block Towards a Sustainable Development." International Solid Waste Association, 1996 International Congress Proceedings

Schwarz, E. and K. Steininger. 1995. “The Industrial Recycling-Network Enhancing Regional Development.” Research Memorandum No. 9501. (April).

Schwarz, Erich J. and Karl W. Steininger. 1997. "Implementing nature's lesson: the industrial recycling network enhancing regional development." *Journal of Cleaner Production*. 5:1-2.

Shi Han. 1998. "ECO Investment Promotion for Environmentally Sound Technology for the Taihu Basin." Environmentally Sound Technology in *China Newsletter*. 2:3.

Smart Growth Network. “Designing Industrial Ecosystems Tool (DIET).” Available at http://www.smartgrowth.org/library/DIET.html.

Smith, Chester. “Red Hills EcoPlex.” Presentation to the Eco-Industrial Development Roundtable, Washington, DC, October 1999.

Smith, L., J. Means, and E. Barth. 1995. *Recycling and Reuse of Industrial Waste.* Columbus OH: Battelle Press.

Smolenaars, T. 1996. “Industrial Ecology and the Role of the Cleaner Production Centre.” *Industry and Environment Review*, United Nations Environment Programme - Industry and Environment, Paris. (Oct.-Dec.).

Socolow, R., C. Andrews, F. Berkhout, and V. Thomas. 1994. *Industrial Ecology and Global Change.* New York: Cambridge University Press.

Spurlock, J. M., Ward, H. C. 1980. *Systems-Integration Requirements for the Synergistic Co-Siting of Industrial Activities.* Washington, DC: US Department of Commerce, National Technical Information Service publication PB81-150294.

Stahel, W. R. 1998. “The Product-Life Factor.” in: Robert U. Ayres, Kenneth J. Button, and Peter Nijkamp, Peter (eds.). *Global Aspects of the Environment*. Cheltenham, UK: Edward Elgar Publishing.

Steinhilper, R. 1998. *Remanufacturing: The Ultimate Form of Recycling*. Stuttgart: Fraunhofer IBC Verlag.

Stuber, U. H., N. V. Schaefer, and B. Sharma, B., (eds.). 1996. *Business Networks: Prospects for Regional Development*. Berlin: Walter de Gruyter.

SWIX. 2000. *Southern Waste Information eXchange, Inc. Catalogue*. Tallahassee, FL: Southern Waste Information eXchange, Inc. 19:3. (October-November).

Talbot, Frederick A. 1920. *Millions from Waste.* Philadelphia, PA: J. B. Lippincott Company.

Tibbs, Hardin. 1992. “Industrial Ecology: An Environmental Agenda for Industry,” *Whole Earth Review*. (Winter).

United Nations Environment Programme (UNEP). 1996. “Environmental Management of Industrial Estates,” *Industry and Environment*. 19:4. (October-December).

UNEP. *The Environmental Management of Industrial Estates*, UNEP IE Technical Report No. 39. Paris: United National Environment Programme, Industry and Environment.

UNEP. 1996. “Life Cycle Assessment: what is it and how to do it.” Paris: UNEP Industry and Environment Programme.

U.S. Environmental Protection Agency. 2001. “Superfund Redevelopment Initiative.” Washington, DC: U.S. EPA. Available at http://www.epa.gov/superfund/programs/recycle/recycle.htm.

U.S. Environmental Protection Agency. 1999. Tools for Eco-Industrial Development Planning, Version 1.3. Industrial Economics, Inc.

Van Der Ryn, Sim and Stuart Cowan. 1996. *Ecological Design.* Washington, D.C.: Island Press.

Von Hauff, Michael and Martin Z. Wilderer. 2000. “Eco Industrial Networking: A practicable approach for sustainable development in developing countries.” Presentation at the Helsinki Symposium on Industrial Ecology and Material Flows, Helsinki, August 31st - September 3rd 2000.

Von Weizacker, E., A. Lovins, and L. H. Lovins. 1998. *Factor Four: Doubling Wealth, Halving Resource Use.* London: Earthscan Publications.

Wallace, David. 1995. *Environmental Policy and Industrial Innovation: Strategies in Europe, the US and Japan.* London: Royal Institute of International Affairs.

Wallace, David. 1996. *Sustainable Industrialization.* London: Royal Institute of International Affairs.

Wallner, H.P. 1997. "Regional Embeddedness of Industrial Parks--Strategies for Sustainable Production Systems at the Regional Level." *Journal of Cleaner Production.* 4:4.

Weitz, Keith A. and Shelia A. Martin. 1995. “Regulatory Issues and Approaches for Encouraging Eco-Industrial Park Development.” [draft] Designing, Financing and Building the industrial Park of the Future: An International Workshop on Applications of Industrial Ecology to Economic Development Institute of the Americas, University of California, San Diego, May 4-5, 1995.

Wernick, Iddo K. and Jesse H. Ausubel. 1995. “National Material Metrics for Industrial Ecology.” *Resources Policy*, 21:3:189-198.

Wernick, I. K., R. Herman, S. Govind, and J. H. Ausubel. 1996. “Materialization and Dematerialization: Measures and Trends.” *Daedelus.* 125:3.

Work and Environment Initiative (WEI). 1997. “Targeted Recruitment and Eco-Industrial Development for the Eastern Shore of Virginia.” Ithaca, NY: Work and Environment Initiative, Cornell University.