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Designing eco-industrial parks: a synthesis of some experiences

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Abstract

Sustainability requires a consideration of the social or community dimension as well as ecological integrity and economic efficiency. Further, ecological systems emphasize interaction and interdependence. Definitions of eco-industrial parks have begun to address this by referring to them as communities of business. The paper describes a number of initiatives, particularly in the United States and Canada. The types of interactions among businesses and between businesses and the community are described and initiatives are categorized as engineering or self-designing. The paper lists 11 characteristics of eco-industrial parks which are emerging from the existing projects.

Keywords: Definitions; Rites; United States; Canada; PALME; UNEP; Interactions; Framework; Community; Engineered; Self-designing; Characteristics

1. Introduction

Although still in its infancy as a field of study, industrial ecology is emerging as an exciting approach to the application of environmentally sustainable economic development. Debate since the release of the World Conservation Strategy in 1980, "Our Common Future" the report of the World Commission On Environment and Development in 1987 and Agenda 21 in 1992 has resulted in gradual acceptance that sustainability must integrate ecological integrity, economic efficiency and social equity. Much of the effort of government and industry since 1987 has emphasized the linkage between economy and environment with much less attention being paid to the social or community dimension of sustainability. Since industry is a human creation and humans are social animals, we need an approach which brings industry and environment together with a social or community perspective.

Ecology is the study of the interrelationships among species and between species and their physical-chemical environments. Key features of ecology are the *habitats* on which species depend, *communities* described as a grouping of species occurring in a particular area and *ecosystems* which are spatially defined assemblages of species, communities and physical and chemical components interacting to form a more or less stable system. What is significant about the three features of ecological systems is that they emphasize *interaction and interdependence*. The stability of an ecosystem depends to a large degree on the interconnectedness of the species within the system. These connections expand as the system matures. Humans are part of and interact with other species in ecosystems as well as influencing the physical and chemical character of the ecosystems.

In contrast, industrial systems have tended to emphasize the independence and competitiveness of enterprises. Yet companies are embedded in chains or webs of suppliers and customers, similar to those *chains* and *webs* which occur in indigenous or natural ecosystems. In addition, industries are dependent on resources available in the environment to ensure their productivity. These include the land on which the facility is constructed, the building materials, the hydrocarbons for their energy supply, the water which may be required for processing or cooling and air used by both workers and process equipment. In other words, individual companies and corporations are parts of systems. They are dependent on others and must cooperate with them to survive.

In this sense, we can discuss whether industrial ecosystems are simply analogies of natural ecosystems and investigated with that in mind or, the metabolism of industrial production and consumption systems are firmly embedded in the biosphere and industrial ecosystems are simply another form of ecosystem with humans

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as the dominant species. Industrial parks or estates, of which there are several types, have been suggested as one grouping of ecosystems, in essence, an ecotype.

This paper will review some of the definitions of eco-industrial parks, discuss their characteristics and present examples of guidelines which have been developed for the establishment of industrial parks as ecosystems, based on these characteristics. The paper will discuss some of the North American, European and Japanese experience in establishing eco-industrial parks. Finally, the authors will present their thoughts on the essential characteristics of eco-industrial parks emerging from this experience.

2. Definitions

An industrial park is defined as "a large tract of land, sub-divided and developed for the use of several firms simultaneously, distinguished by its shareable infrastructure and close proximity of firms" [1]. Types and synonyms of industrial parks include industrial estates, industrial districts, export processing zones, industrial clusters, business parks, office parks, science and research parks, and bio-technology parks. Eco-industrial parks have now been added to this list. As is the case with industrial ecology itself, there are several definitions of the term eco-industrial park.

In 1995, Côté and Hall [2] proposed this definition:

> An eco-industrial park is an industrial system which conserves natural and economic resources; reduces production, material, energy, insurance and treatments costs and liabilities; improves operating efficiency, quality, worker health and public image; and provides opportunities for income generation from use and sale of wasted materials.

Yet another definition was put forward by Lowe et al. [3]:

> An eco-industrial park is a community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaboration in managing environmental and resources issues including energy, water and materials. By working together, the community of businesses seeks a collective benefit that is greater than the sum of the individual benefits each company would have realized if it optimized its individual interests.

At an October 1996 workshop hosted by the United States President's Council on Sustainable Development [4], two definitions received serious consideration. The first was:

> 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 and environmental quality gains, and equitable enhancement of human resources for the business and local community.

The second definition considered by the participants was:

> An industrial system of planned materials and energy exchanges that seeks to minimize energy and raw materials use, minimize waste, and build sustainable economic, ecological and social relationships.

In describing what an eco-industrial park is, it may be worthwhile to consider what some proponents have suggested eco-industrial parks are not. In 1994, Research Triangle Institute and Indigo Development International [5] suggested that the term applied to developments that are more than

- "a single by-product exchange pattern or network of exchanges;
- a recycling business cluster (resource recovery, recycling companies, etc.);
- a collection of environmental technology companies;
- a collection of companies making 'green' products;
- an industrial park designed around a single theme;
- a park with environmentally infrastructure or construction;
- a mixed use development (industrial, commercial and residential)."

Ayres [6] suggested that an industrial ecosystem would involve at least one major firm exporting raw or processed materials, connected to one of more firms capable of utilizing significant portions of the major waste streams of the "anchor" industries. In turn, these would be linked to several "satellite" enterprises converting wastes into usable products. Cooperation would be facilitated by a coordination mechanism and information sharing.

Lowe and Warren [7] indicate that an eco-industrial park may include many of these features but the essential feature is the interactions among businesses and between the businesses and the natural environment. As is the case with the field of industrial ecology, the definition of an eco-industrial park is still evolving. Some have argued that we are discussing transformations of industrial symbioses or by-products exchanges within a continuum of different levels of complexity. These can range from symbioses involving two or more materials to virtual eco-industrial parks such as proposed in Brownsville, Texas and Matamoros, Mexico across the international border from each other [8], or regional industrial networks such as described for Styria in Austria [9]. Some of the key descriptors of an eco-industrial park appear to be community, cooperation, interaction, efficiency, resources and system. It may well be that these are most effectively achieved in a traditional industrial park but this has not yet been evaluated.

3. Current experience

Although there are many examples of symbiosis involving the exchange of material and the cascading of energy and water and of cycles in which material is recovered and recycled, multi-faceted industrial ecosystems are few and far between. However, planning and design of these ecosystems is underway in many countries. In the United States, a number of initiatives have been taken pursuant to support from the United States Environmental Protection Agency and the President's Council on Sustainable Development. As can be seen in Table 1, a range of sites have been identified and various characteristics apply.

Canada has a few industrial projects underway embodying ecological characteristics with the potential for many more across the country. The "Industrial Park as an Ecosystem" project in Burnside Industrial Park began in 1992 as a multi-disciplinary research initiative investigating the possible application and interpretation of ecological characteristics and functions to an industrial park. The expected outcome of the research guidance was first, on the transformation of Burnside itself and second, for the establishment of future industrial parks. This is a "work in progress", a "living experiment" which will continue for some time. As this project has been described in detail elsewhere, we will not dwell on it in this paper [2,11].

A similar study has been underway in the Portlands Industrial District in Toronto, Ontario since 1995. This industrial area also involves enterprises in a variety of sectors in manufacturing and services with the potential for waste and energy exchanges. A recent study of the potential for integrated eco-industrial parks with co-generation, energy cascading and recycling across Canada identified 40 sites of which nine were deemed to have excellent possibilities for eco-industrial development [12]. Table 2 provides additional details on these potential eco-industrial park sites.

There are a number of sites in Canada where limited industrial ecosystems are in operation. In Sarnia, Ontario, some symbioses exist between oil refineries, a synthetic rubber plant, petrochemical facilities and a steam electrical generating station and more linkages are possible. At the Bruce Energy Centre, also in Ontario, the "park" is organized around Ontario Hydro's nuclear power station to take advantage of its waste heat and steam generation capacity. The industries that have co-located use this capacity for processes such as dehydration, concentration, distillation, hydrolysis and space heating [13]. Four of the facilities also take advantage of the proximity of agricultural production. In Nova Scotia, one corporate entity has linked several industries under their control in wood/paper fiber and hydrocarbon cycles which feature the recycling of waste paper, cardboard and oils. Other possibilities exist within the corporation but these are limited in part because the companies are not co-located.

4. Guidelines

Guidelines for the implementation of industrial parks or eco-systems have been developing slowly as pro-

Table 1
Some eco-industrial park projects in the United States [4,10]

Site	Characteristics
Port of Cape Charles, Virginia	Sustainable technologies, natural coastal features
Fairfield, Baltimore, Maryland	Transformation of an existing industrial area, co-generation, waste re-use, environmental technology
Brownsville, Texas	Regional or virtual approach to waste materials exchange, marketing
Riverside, Burlington, Vermont	Agricultural industrial park in urban setting, bio-energy, waste treatment
Chattanooga, Tennessee	Redevelopment of inner city and former military manufacturing facilities, green areas, environmental technology
Green Institute, Minneapolis, Minnesota	Inner city, small scale green business incubator, waste material re-use
Plattsburgh, New York	Redevelopment of a large military base, resource and waste management, EMS
East Shore, Oakland, California	Resource recovery based-park, landscaping, energy efficiency
Londonderry, New Hampshire	Small scale, community-based park
Trenton, New Jersey	Redevelopment of an existing industrial area, clean industries
Civano, Tucson, Arizona	A new development integrating commercial and residential, environmental businesses, natural features
Franklin, Youngsville, North Carolina	A commercial complex with renewable energy and environmental technologies
Raymond, Washington	A new park within a second growth forest, recycling of solid and liquid wastes
Skagit County, Washington	A new park with support systems and centers, environmental industries
Shady Side, Maryland	Renovation of existing facility, maintaining jobs, small scale environmental and technological businesses

Table 2
Some potential eco-industrial park sites in Canada [12]

Province	Key industries
Vancouver, British Columbia	Steam generator, paper mills, packaging, industrial park
Fort Saskatchewan, Sask.	Chemicals, power generation, styrene, PVC, biofuels
Sault Ste.Marie, Ontario	Power generation, steel, paper mill, flakeboard mill, industrial park
Nanticoke, Ontario	Thermal generating station, oil refinery, steel mill, cement, industrial park
Cornwall, Ontario	Power and steam generation, paper mill, chemical, food, electrical equipment, plastics and concrete products
Becancour, Quebec	Co-generation plant, chemical plants (H^2O^2, HCL, Cl, NaOH, Alkylbenzene) magnesium, aluminum
Montreal East, Quebec	Co-generation plant, petrochemicals, refineries, compressed air, gypsum board, metal refinery, asphalt
Saint John, New Brunswick	Power plant, paper mill, oil refinery, brewery, sugar refinery industrial parks
Point Tupper, Nova Scotia	Generating station, pulp and paper, building board, oil refinery

ponents explore the features of these systems. In some cases guidelines have been developed on the basis of applied research projects [3,14] and in others, using design charettes as has been the case in several U.S. projects [10]. In the former, the guidelines reflect the perspectives of a multi-disciplinary team of researchers. In the latter, a multi-stakeholder group of people with varying interests provides guidance.

The United Nations Environment Programme's Industry and Environment Office has just released a technical report on Environmental Management of Industrial Estates [15]. The UNEP has noted that "industrial estates have become common features of the global landscape". There are in excess of 12,000 industrial parks and export processing zones around the world concentrating hundreds of thousands of industries and millions of workers into relatively compact areas. On the one hand, this concentration can increase environmental health and safety risks, while on the other, this co-location can facilitate management of materials, energy and wastes. The report provides guidelines for the design of new parks and the operation of existing parks based on experiences in park management around the world. The technical report addresses a wide range of environmental issues and strategies for preventing or remediating them. It is not a guide to establishing industrial parks as ecosystems but it suggests that such systems may represent the ultimate integration of economic, ecological and social dimensions of sustainable industrial development.

Another approach has emerged in France. DSA Environment [16], a French consulting group linking private and public organizations has proposed the "Programme d'actions labelise pour la maitrise de l'environnement" (PALME). Palme is an eco-label for industrial parks and provides a slightly different interpretation of the term eco-industrial park. PALME does not emphasize cycles, webs and networks. As noted in Table 3, the elements are very similar to the guidelines developed by Côté et al. [14] and others, although they emphasize environmental management of a park rather than cooperation and interaction between industries. The PALME requirements are very demanding. At least two

Table 3
Some elements of the PALME label for industrial parks [15]

1. Prepare a site development plan, and have available the relevant regulations and guidelines
2. Prepare an initial baseline "State of Environment" report for the site
3. Establish a landscaping plan and architectural requirements for buildings
4. Ensure compliance with (environmental) regulations and by-laws, and adherence to operational guidelines
5. Establish and implement a plan for natural flora and fauna to maintain or re-establish the ecological balance of the site
6. Implement a public awareness and information programme concerning natural environmental and conservation
7. Establish an advisory service for clean technologies
8. Develop and implement a "clean construction site" programme
9. Establish a plan for solid waste management
10. Establish a plan for industrial wastes and effluents
11. Establish a plan for management of rainwater and surface runoff, and construction of any necessary installations
12. Advise enterprises on noise reduction measures and materials for buildings and machinery
13. Monitor site air quality and noise
14. Establish an energy management plan for the site
15. Investigate alternative energy sources
16. Establish a liaison mechanism with relevant local authorities
17. Establish a monitoring and coordination unit for the above

industrial sites in France have already signed the Palme charter and others are under consideration. An effort is underway to establish a national PALME association.

One of the most exciting eco-industrial park projects under development has been initiated by the EBARA Corporation of Japan with the cooperation of the Zero Emissions Research Initiative (ZERI) at the United Nations University and the Japanese Ministry of International Trade and Industry. The Fujisawa Factory eco-industrial park will combine industrial, commercial, agricultural, residential and recreational components into a multi-faceted community. The Fujisawa Factory park will include technologies and features in energy conservation and cascading, renewable energy, conversion of waste into energy, solar greenhouses, waste water treatment using wetlands, reuse of treated waste water, conversion of ash and other wastes into cement and ceramics, reuse and recycling of materials, etc. The park will be supported by a zero emission center, an environmental clinic and a logistics center. The park will be completed in 2000 [17].

Eco-industrial parks are being considered in a number of other countries including Thailand, Indonesia, the Philippines, Namibia and South Africa.

5. Discussion

Eco-industrial park analysis occurs in at least three domains. The problem with adequate analysis of this emerging area is that these domains stretch across three different disciplinary sets that rarely interact. At one level, industrial ecology describes a set of interactions within a physical realm of chemical and energy transactions and the associated technologies with those transactions. At a second level, industrial ecology exists within an economic or business framework where exchanges and relationships of a different sort occur. Last, and certainly not least, there is a connection between the network of businesses and the surrounding community, in both its social and ecological dimensions, that shapes the character of industrial ecology applications such as eco-industrial parks.

In the opening of this paper, we discussed the similarities between natural eco-systems and eco-industrial development. One of the unique characteristics of the current range of eco-industrial park experiments is their differentiation—further proof of the inherent nature of the ecological shaping of industrial systems which seeks adaptive variation. Indeed the assumption that there is a single right way to engineer an industrial eco-system is a fiction—yet an attractive one. The lesson of Kalundborg is not found in mapping its pipes but in the unfolding of the existing relationships. What makes Kalundborg a model is that its participants allowed and continue to encourage interaction, not that it had a particularly spectacular technical breakthrough. Too often the focus has been on copying the connections, not learning from the connecting. The Kalundborg may provide lessons for future developments in other settings where other configurations of companies, materials, culture and personalities provide other variations on the theme that Kalundborg so elegantly demonstrates.

In the field work on eco-industrial parks at present there is a tug between two basic polarities: engineered systems or self-organizing systems. We describe it as a polarity rather than oppositional because each recognizes the value of the other perspective but there is a difference of opinion on what should be the primary driver and to what degree.

One group's understanding is the notion that adequate data analysis and excellent engineering can result in "zero emission" or measurably convincing connections. The UN University's ZERI efforts, the Bechtel model as applied in Brownsville Texas and the "Smart Park" proposed in Tennessee rely heavily on pre-engineered descriptions. These studies emphasize local and regional resource and energy flows and seeks maximal efficiency in their interaction. Having demonstrated such a possibility, it assumes that intelligent, profit-maximizing firms will seek to operate in that manner. We describe above some of the operational characteristics of the pipe-to-pipe model.

Eco-industrial parks have been primarily described in the industrial ecology literature as a means of managing material and energy flows with attention to the possibility of particular chemical linkages [18]. Further, environmentalists have been intrigued with the fit as a means for waste minimization. By creating specific connections, solid waste disposal can be reduced while input and transport costs can be lowered both in dollar value and environmental damage. There are possibilities of shared steam systems, beneficial use of toxic wastes and aggregated collection of materials to produce sufficient quantities for use elsewhere. There are difficult issues associated with this approach about timeliness, volume, quality, transport and reliability that need to be worked out. Further, direct pipe to pipe connections are a possible but improbable outcome. In most cases intermediary processes are required that would expand the possible interface between outputs and inputs to meet the issues previously mentioned. Regardless of one's perspective, research is needed on improving the usable connectability of resources from one source to another. Yet there is an alternative approach to the same set of concerns that looks primarily on the set of organizations as a business relationship.

A second approach appears to believe that organic growth of connections among companies which is facilitated leads to a larger range of connections, greater ownership over the process and higher results over a broader range of measures. Structures and specific material and energy connections emerge from the network of companies becoming an organism and developing its own character. The Burnside activity emerges from the companies which comprise the set of tenants. The Baltimore EIP and the Trenton Eco-Industrial Complex are proposed as being built on and largely by the businesses in the area. Trusting in a theory of emergent systems [10] optimization, its proponents seem to substitute vision and process for uncertain outcome targets. Other approaches seem to straddle some of these beliefs such as Cornell's approach to seeing maximum probable connection within upstream and downstream materials domain such as organics, metals, energy cascades. etc. Lowe and Warren [7] use the concept of an anchor tenant as a means to help to create a more definable set of possible connections.

Eco-industrial parks also exist within an economic and socio-organizational framework which has a considerable literature and experience of its own. What is often described in chemical metabolism of a healthy organism has its organizational analogue in the business world of resource efficiency. Examples of business process re-engineering are ways to assure that internal processes are aligned in ways that lead to maximum output. In accounting terms, this is expressed as Return on Assets (ROA). ROA is an appropriate measure of EIP performance for several reasons. The primary effect of an EIP on a business has to be asset maximization—the highest possible yield for the least possible set of inputs. Those inputs can be technological, raw materials, capital, labor, energy, transaction, marketing, etc. The chemical/energy ecology is only one of the possible levels of efficiency and should be vigorously pursued, especially when it leads to higher productivity or less pollution and toxicity. A complete approach also devises strategies for the other components of business success.

There is a dimension of eco-industrial parks that the fascination with internal efficiencies tends to ignore. The success of an eco-industrial park will not be simply a function of its environmental record but its ability to compete in the marketplace. According to Cornell's model when examining an eco-industrial opportunity, the market issues are the primary factors that go into the analysis for a location. Environmental improvements are designed subsequently. If the market viability of a location is in question, then the success or failure of classical industrial ecology issues cannot be judged adequately since the organization will shortly disappear and thus mask a true evaluation of industrial ecology effects. Hence, superior environmental *and* business performance is a means to assure cost competitiveness and drive up revenues for one company and thus drive out of business more wasteful competitors. It leads to superior business opportunities and environmental performance by designing in both quality and ecological awareness.

The degree that materials/energy industrial ecology can have an impact on the success of the business depends on the percentage of costs and revenues attributable to materials or energy. A large improvement in a modest part of the cost structure may not make a significant difference. A narrow approach on materials limits industrial ecology's appeal to heavy manufacturing when its lessons can have a much broader impact on shaping organizations. Further, extraordinary resource efficiencies have no impact if there is market rejection of the product or service provided by the organization. Too few industrial ecology advocates understand this basic fact. It is not just how well the internal machinery is engineered but whether the system fits into the larger ecology of its market.

Hence, effective eco-industrial strategies provide a clear link to the marketplace. One can for environmental reasons focus more closely on the bio-regional economy to assure more considered choices of materials and to minimize transportation environmental loadings. Such an approach can adapt to water and air shed based issues and policies to link systemic eco-industrial development to similar efforts in the environment. In the Cornell Plattsburgh study, one of the options examined was the Lake Champlain Basin as a market focus for their eco-industrial park.

For the last 30 years there has been considerable study of regional self-organizing manufacturing and enterprise networks [19–21]; these have been successful in many parts of the world. Those in the Emilio Romagna region of Italy have been particularly well studied, as well as others in Denmark, Finland, Australia, Austria and in parts of North America. As a whole they have been shown to be effective at the use of resources and adaptability in the marketplace with superior performance. These networks come together as needed to meet certain internal and customer needs as independent entities who choose mutually advantageous interdependent activity. Their connections are not random but based on a series of understandings among those who comprise the network. Their flexibility and capability are enhanced without having to carry excessive overhead burden. Their behavior mirrors the experience in natural self-organizing eco-systems. Not all organisms can overcome their environmental challenges but most are better able to withstand strains than isolated organisms. Wetlands also display the same capability to cleanse diverse influences and make the water fit for later use. Van der Ryn and Cowan [22] write:

> Self designing systems like these present a rich possibility. If they are seeded with sufficient diversity, they can design their own solutions to the problems they are presented with. At first, this seems rather disconcerting. We are used to working out all the details. In highly complex situations, however, our limited knowledge may render such a level of control impossible. Letting go, trusting the capacities of a self-designing system, may be a better way of working constructively with complexity than attempting to oversimplify it [22] (p. 123).

Similarly current practice on internal management practices has shown that self-managing team based systems with redundant capabilities, adequate information and adequate resources are able to produce at a higher quality level, adapt to change faster and meet or exceed traditional command-and-control work places. Again at the socio-organizational level, self-organizing systems exhibit more robust, adaptive, resource enhancing behavior. The results of these studies have been higher productivity, greater satisfaction and greater customer responsiveness Hence, internal organizational systems that respect and use human resources in new and different ways are a corollary requirement of internally consistent and maximally effective industrial ecology applications. These results have also been shown clearly to have higher environmental results as well [23–25].

The third domain for the eco-industrial park concept is one that stretches beyond the boundaries of either a physically connected or a virtual eco-park—its relationship to its surrounding community. While EIP enthusiasts promise to have a lower impact than traditional development on the local ecosystem, there remains an impact of some sort even if is only the truck and car traffic that goes to and from the new development activity. Materials and energy will be used in the EIP and while cycling may be more common, an understanding of basic physics requires at least some dissipation. Further, tightly connected systems require at least one level of backup contingencies in case some part(s) of the system fail to do their intended functions in the designed industrial ecology.

A responsible approach to any new development in an area—especially one with an overburdened eco-system—is to identify ways in which the total impact on the local ecosystem is reduced. In essence that requires community interaction which involves other businesses and people in the community actively working to make sure that aggregate impact on the environment is lowered while new economic opportunity is developed. By linking to existing businesses and absorbing some of their waste stream or helping them to manage their businesses in a more resource effective way their impact can be diminished. By connecting with local residents and encouraging community and home based environmental responsibility, the impact can be lowered further. This also removes EIPs from being islands of environmental correctness sinking in a larger sea of pollution.

Multi-media measurement systems designed and administered in conjunction with the community helps to assure better performance and credibility. In our experience, communities do not care which media is responsible for pollution, but instead want to know what is the cumulative impact and how can dangerous activity be stopped. Hence, area level monitoring that looks at water, air and solid waste issues simultaneously and in an aggregate over the companies with community impact provides the kind of assurance of public health a community desires. For EIP companies, a common environmental management approach can provide flexibility in meeting compliance goals, assistance in remediation efforts and by collective monitoring lower costs of environmental reporting.

In some ways, we hope that an EIP will make its mark on a local community. It should provide jobs for people in the area, contribute to the education of the children and college students in the area, actively engage the community in emergency preparedness, integrate EIP services with the community including recreation, wellness, transport and day care facilities. The existence of an EIP in a locality should add value to quality of life as well as jobs or indirect economic benefit to an area.

In the American experience, most of the communities exploring eco-industrial parks have high percentages of low income and/or minority residents. Local residents find it very appealing that they are no longer a dumping ground but a proving ground for excellence in environmental and business performance. Very often these groups are subject to environmental dumping where the worst jobs and the worst impacts on the local environment are the only options made available to them. They see EIPs as a viable and desirable strategy for restoring economic and public health. Good jobs and a good environment are not an esoteric concept but very real concerns.

Community based planning techniques have been used frequently as a means for the design of eco-industrial parks. In Baltimore, a search conference with about 200 participants from all diverse constituencies participated in setting the vision and the parameters of the effort. The social technology was intentionally a mirror of the operational philosophy desired for the eventual park. The Search Conference was followed by a participatory design charrette to plan the next steps and inclusive task forces. In Minneapolis, in a section with the highest concentration of Native Americans in the city, a participatory charrette was also held to help design the Green Institute's initiative. Similarly, Chattanooga, Cape Charles and Civano all worked with active community engagement processes, especially working with William McDonough, Dean of the University of Virginia School of Architecture, to use design charrette techniques [8]. The social shaping of the economic and environmental confluence was a key defining element of each activity.

6. Conclusion

The evolution of industrial parks into ecosystems is still at a very early stage. Kalundborg has had its critics but it has clearly inspired a wide range of projects in a number of countries. Although some research and design projects have attempted to identify the essential characteristics of eco-industrial parks, there is as yet no agreement. There does appear to be some consensus emerging from the French, Japanese, American and Canadian work and the UNEP technical report in industrial parks.

The essential characteristics of eco-industrial parks have been proposed by a number of authors including Research Triangle Institute [26], Côté et al. [14], Lowe and Warren [7], the President's Council on Sustainable Development [8] and Peck and Associates [13], among others. Compared to a traditional industrial park, an eco-industrial park would:

1. Define the community of interests and involve that community in the design of the park.
2. Reduce environmental impact or ecological footprint through substitution of toxic materials, absorption of carbon dioxide, material exchanges and integrated treatment of wastes.
3. Maximize energy efficiency through facility design and construction, co-generation, and cascading.
4. Conserve materials through facility design and construction, reuse, recovery and recycling.
5. Link or network companies with suppliers and customers in the wider community in which the eco-industrial park is situated.
6. Continuously improve the environmental performance by the individual businesses and the community as a whole.
7. Have a regulatory system which permits some flexibility while encouraging companies to meet performance goals.
8. Use economic instruments which discourage waste and pollution.
9. Employ an information management system which facilitates the flow of energy and materials within a more or less closed-loop.
10. Create a mechanism which seeks to train and educate managers and workers about new strategies, tools and technologies to improve the system.
11. Orient its marketing to attract companies which fill niches and complement other businesses.

Other characteristics may emerge as eco-industrial parks are planned, designed and operated. Clearly an eco-industrial park requires a systems-approach involving an understanding of the quantities, as well as the physical and chemical characteristics, of materials and energy flowing in, within and out of the park, in addition to the regulatory, economic and managerial aspects of the park. The literature has emphasized waste exchanges and to a lesser degree, energy cascading as dominant features. These are important elements but in our view, they are limited perspectives. If the goal is sustainability of the industrial community and ecosystem, a more comprehensive perspective involving ecological, economic and social aspects is necessary.

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