Chapter 3

Sustainable Development and Industrial Ecology

3.1 Introduction

Concerning environmental issues, there is a common misconception that environmental protection comes at the expense of economic development or vice versa. This is clearly portrayed when communities faced with economic crises settle for alternatives that sacrifice environmental integrity such as incineration, treatment, or the construction of landfills even though these solutions in fact are extremely important but are not sustainable and economically expensive.

Sustainable development is formally defined by the World Commission on Environment and Development (WECD) as "development that meets the needs of the people today without compromising the ability of future generations to meet their own needs". Therefore, sustainable development refers to a shared commitment towards steady economic growth, given that this economic growth does not compromise the satisfactory management of available environmental resources. Resource allocation, financial investments, and social change are directed in a sound manner that guarantees their sustainability or continuation with time and thus they are made consistent with both future and present needs. Another notable definition for sustainable development by Sustainable Seattle is "economic and social changes that promote human prosperity and quality of life without causing ecological or social damage" (Redefining Progress 2002). Industries are therefore encouraged to flourish but also to realize their impacts on the environment and society around them. Thus, it can be concluded that sustainable development is a concept that is not only exclusive to policy makers and environmentalists, but should be a matter of concern to industries, the business community, and society.

The practice of sustainable development is not a new one. This is a concept which has been repeatedly used over time in an effort to sustain and/or preserve resources of any type. However, formal attention and labeling of this concept began during the 1970s. In 1972, the global community came together in Stockholm to discuss international environmental and development issues for the first time in "the United Nations Conference on Human Environment". This conference was the first significant link between business and environment to take responsibility for the environmental problem that uncontrolled industrial development was causing. The conference resulted in the creation of United Nations Environment Program (UNEP) to adopt a global action plan for protecting the environment. From its creation until now it tried to develop guidelines and tools for the above cause. In 1986, the "World Commission on Environment and Development WCED" was established. This commission's report is what first spread the term "sustainable development" and it became the benchmark for thinking about global environmental and development issues. The crest of global attention towards sustainability was during the United Nations Conference on Environment and Development in 1992 held in Rio de Janeiro. During this conference an action agenda was produced. This Agenda 21 was a comprehensive global plan of action for local, national, and global sustainable development. An equally comprehensive summit was the Johannesburg Summit in 2002 which was more focused on eradication of poverty as it also revived the commitment towards global sustainable development. These summits, augmented with vast global efforts, have aided in increasing awareness as well as multilateral agreements concerning various sustainability issues and critical environments.

The concept of sustainable development is a methodology that attempts to encompass social, technological, economic, and environmental aspects. Thus, focus is on the interactions and impacts of these four factors on each other rather than the fallacy that they are independent of one another. The elements of Environmental, technological, social, and economic growth are seen to reinforce each other thus attaining "win–win" solutions that do not compromise any aspect. In order to develop a methodology for sustainable development, a number of tools are required. The main tools necessary for implementing sustainable development are cleaner production (CP), environmental management system (EMS), 7Rs Golden Rule, industrial ecology (IE), environmental impact assessment (EIA), and information technologies (IT) as will be explained in detail in Chapter 4.

3.2 Industrial Ecology

Since the beginning of human history, industry has been an open system of materials flow. People transformed natural materials; plant, animal and minerals into tools, clothing and other products. When these materials were worn out they were discarded or dumped, and when the refuse buildup became a problem, the habitants changed their location, which was easy to do at that time due to the small number of habitants and the vast areas of land.

The goals of industry must be the preservation and improvement of the environment. With increasing industrial activity all over the world new ways have to be developed to make large improvements to industrial interactions with the environment.

An open industrial system – one that takes in materials and energy, creates products, and waste materials and then throws most of these away – will probably not continue indefinitely and will have to be replaced by a different system. This system would involve, among other things, paying more attention to where materials end up, and choosing materials and manufacturing processes to generate a more circular flow. Until quite recently, industrial societies have attempted to deal with pollution and other forms of waste largely through regulation. Although this strategy has been partially successful, it has not really gotten to the root of the problem. To do so will require a new paradigm for our industrial system – an industrial ecology whose processes resemble those of a natural ecosystem (Frosch, 1994).

Industrial ecology (IE) is the study of industrial systems that operate more like natural ecosystems. A natural ecosystem tends to evolve in such a way that any available source of useful material or energy will be used by some organism in the system. Animals and plants live on each other's waste matter. Materials and energy tend to circulate in a complex web of interactions: animal wastes and dead plant material are metabolized by microorganisms and turned into forms that are useful nutrients for plants. The plants in turn may be eaten by animals or die, decay and go around the cycle again. These systems do, of course, leave some waste materials; otherwise we would have no fossil fuels. But on the whole the system regulates itself and consumes what it produces (Frosch, 1994).

Industrial ecology is a new approach to the analysis and design of sustainable political economies (Frosch, 1995). Allenby (1999) calls industrial ecology the science of sustainability. Several other characteristics of stable ecosystems also suggest new norms to pursue in thinking about sustainability. Prigogine (1955) observed several very interesting features about steady state biological systems. One is that they are in a state of minimum entropy production, that is, the system is functioning with the least degree of dissipation of energy (and materials) thermodynamically possible in a real situation. These systems also exhibit a high degree of material loop closing. Materials are circulated through a web of interconnection with scavengers located at the bottom of the food web turning wastes into food. Even long-lived biological systems eventually succumb to environmental and internal stresses. They are not ideal models for a concept that implies flourishing forever. Ayres (1989) coined the term industrial metabolism as the web of flows of energy and material. When modeling an industrial economy consisting of an interconnected system of energy, material, and money flows such a system will supply an analytic means to repair the break in both the economic and environmental sciences. Daly (1977), and others have stressed the importance of including material flows in economic flows analysis, noting the fundamental connections of economics to natural resources. Daly (1977), and earlier Georgescu-Roegen (1971), developed a steady state framework for describing modern economic systems and for designing policy, invoking basic laws of thermodynamics and ecological systems behavior as part of the grounding. Expanding the typically sectoral or firm-level models used by policy analysts and corporate planners to material and energy flows during the entire life cycles of economic goods, in theory should reduce the probability of suboptimal solutions and of the appearance of unintended consequences. To convert part of these ideas into an industrial design context, a set of design rules has to be established for the innovation of more environment friendly and sustainable products and services. A few of these rules were developed by Ehrenfeld (1997):

- Close material loops.
- Use energy in a thermodynamically efficient manner; employ energy cascades.
- Avoid upsetting the system's metabolism; eliminate materials or wastes that upset living or inanimate components of the system.
- Dematerialize; deliver the function with fewer materials.

Industrial ecology as the "normal" science of sustainability (modifying slightly the phrase) as used by Allenby (1999) promises much in improving the efficiency of humans' use of the ecosystem. Technological improvements are not always better in the full sense of sustainability without taking the environment into consideration, where zero pollution is a must for industrial ecology. Cooperation and community are also important parts of the ecological metaphor of sustainability. Industrial ecology is the net resultant of interactions among zero pollution, cleaner production, and life cycle analysis according to the cradle-to-cradle concept.

3.3 Industrial Ecology Barriers

Even the industrial ecology concept has a lot of advantages from economical, environmental, and social points of view; there are still some barriers for implementation. The barriers to industrial ecology fall into five categories (Wernick and Ausubel, 1997) namely technical, market and information, business and financial, regulatory and regional strategies.

Technical barriers

Technical issues are one of the main challenges for industrial ecology to approach a cradle-to-cradle concept. It requires a lot of innovation to convert waste into money or prevent it at the source. Overcoming the technical barriers associated with recovering materials from waste streams is necessary but an insufficient step for stimulating the greater use of wastes in the economy.

Technology making recovery cheap (or expensive) and assuring high quality input streams must be followed by encouraging regulations and easy informational access. Finally a ready market must be present.

Market and informational barriers

These are inseparable from institutional and social strategies. Due to the absence of direct governmental interference, the markets for waste materials will ultimately rise or fall based on their economic vitality. Markets are sophisticated information processing machines whose strength resides in a large part on the richness of the informational feedback available. One option for waste markets is dedicated "waste exchanges" where brokers trade industrial wastes like other commodities. By using "Internet technology" to facilitate the flow of information, the need for centralized physical locations for either the waste itself or for the traders in waste may be minimal. Research is needed on waste information systems that could form the basis for waste exchanges. A stock market can be developed based on waste material. Systems would need to list available industrial wastes as well as the means for buyers and sellers to access the information and conduct transactions. The degree to which such arrangements would allow direct trading or rely on the brokers to mediate transactions presents a further question. As part of the market analysis for waste materials, research is needed to understand past trends regarding the effect of price disparities between virgin and recovered materials, and to assess the effect of other economic factors associated with waste markets, such as additional processing and transportation costs. A further matter for investigation concerns whether some threshold level of industrial agglomeration is necessary to make such markets economically viable. Progress is already being made on this front.

The Chicago Board of Trade (CBOT), working with several government agencies and trade associations, has begun a financial exchange for trading scrap materials. Other exchanges such as the National Materials Exchange Network (NMEN) and the Global Recycling Network (GRN) facilitate the exchange of both materials recovered from municipal waste streams and industrial wastes. Analysts might propose ideas for improving or facilitating the development of these exchanges. The value of such exchanges as a means of improving the flow of information depends on the deficiency of the current information flow, and how much this particular aspect of recycling plays in its success or failure. The CBOT is different from the other exchanges in that it is a financial market – starting as a cash exchange with hopes that it will evolve into a forward and/or futures market.

A simple waste exchange is premised on the notion that opportunities for exchange are going unrealized. A cash exchange has a related premise that there is a need for what economists call price discovery. Finally, a futures or forward market exists to allow the risk associated with price volatility to be traded independently of the commodity.

Business and financial barriers

Private firms are the basic economic units that generate innovative ideas which, among other goals, serve to enhance environmental quality. Corporations employ a spectrum of organizational approaches to handle environmental matters. In some cases the environment division of a corporation concerns itself exclusively with regulatory compliance and the avoidance of civil liability for environmental matters. For other firms the environment plays a more strategic role in corporate decision making. Decisions made at the executive level strongly determine whether or not companies adopt new technologies and practices that will affect their environmental performance. Also, the manner in which corporations integrate environmental costs into their accounting systems, for instance how to assign disposal costs, bears heavily on its ability to make both short- and long-term environmentally responsible decisions.

Research is needed to better understand the role of corporate organization and accounting practices in improving environmental performance and the incentives to which corporations respond for adopting new practices and technologies. Such studies would examine the learning process in corporate environments as well as investigate how corporate culture influences the ultimate adoption or rejection of environmentally innovative practices.

Regulatory barrier

Environmental regulation strongly induces companies to appreciate the environmental dimensions of their operations. Businesses must respond to local, national, and international regulatory structures established to protect environmental quality.

Although few question that regulations have helped to improve environmental quality, many argue that wiser, less commanding regulations would improve quality further at less cost. Agreements on hazardous waste tightly regulate the transport of these wastes across state and national boundaries, perhaps reducing opportunities for reuse and encouraging greater extraction of virgin stocks. Elements of the national regulatory apparatus for wastes, heavily control the storage and transport of wastes and dictate waste treatment methods that also serve to dissuade later efforts at materials recovery.

Regional strategies barrier

Often geographic regions may provide a sensible basis for implementing IE. Industries tend to form spatial clusters in specific geographic regions based on factors such as access to raw materials, convenient transportation, technical expertise, and markets. This is particularly true for "heavy" industries requiring large resource inputs and generating extensive waste quantities. Furthermore, the industries supporting large industrial complexes tend to be located within reasonable proximity to their principal customers. Due to the unique character of different regions this work could proceed in the form of case studies of regions containing a concentration of industries in a particular sector.

3.4 Eco-Industrial Parks

As noted in Chapter 2 from the definition of cleaner production, there are three stages during the life cycle of any item for consumption. Evans and Stevenson (2000) have illustrated these three stages as follows:

- Production processes: Conserving raw materials and energy, eliminating toxic raw materials, and reducing the quantity and toxicity of all emissions and wastes.
- Products: Reducing negative impacts along the life cycle of a product.
- Services: Incorporating environmental concerns into designing and delivering services.

Brewster (2001) has implied from the cleaner production definition that CP focuses only on individual activities or a single production process rather than focusing on the environmental impacts of the entire range of industrial activity. With the evolvement of CP, many decision makers, scientists, and engineers begin to break our dependence on single use of the finite natural sources that will lead to the ultimate depletion of these sources. As an alternative, biological ecosystems should be our model guidance to establish the industrial system with no "waste" but only residual materials that could be consumed by another process in the same industry or a different one. This preceding recognition is the main concept for the industrial ecology as explained before. Therefore industrial ecology seeks strategies to increase eco-efficiency and protect the environment by minimizing the environmental impacts to be within the allowable limits. In other words, industrial ecology seeks to move our industrial and economic systems toward a similar relationship with the Earth's natural systems or "artificial ecology". IE seeks to discover how industrial processes can become part of an essentially closed cycle of resource use and reuse in concert with the natural environmental systems in which we live. There are some similarities between IE and CP, but CP puts more emphasis on the sustainability of industrial practices over time and more frequently looks beyond individual firms and their existing processes, products, and services.

One of the most important goals of industrial ecology (Frosch, 1994) – making one industry's waste another's raw materials – can be accomplished in different ways. The most ideal way for IE is the eco-industrial park (EIP). These are industrial facilities clustered to minimize both energy and material wastes through the internal bartering and external sales of wastes. Robert Frosch – an executive at General Motors – put the question in 1989 "Why would not our industrial system behave like an ecosystem where the waste of a species may be the resource to another species?" (Wikipedia, 2006). One industrial park located in Kalundborg, Denmark, has established a prototype for efficient reuse of bulk materials and energy wastes among industrial facilities. The park houses a petroleum refinery, power plant, pharmaceutical plant, wallboard manufacturer, and fish farm that have established dedicated streams of processing wastes (including heat) between facilities in the park. The gypsum from neutralization ("scrubbing") of the sulfuric acid produced by a power plant is used by a wallboard manufacturer; spent fermentation mash from a biological plant is being used as a fertilizer, and so on. For more detail regarding Kalundborg, see case study on p. 100. The success of the EIP depends on the ability to innovate, access to talent, markets, and the ability to meet profit conditions or cost constraints and on achieving close cooperation between different companies and industrial facilities.

Nemerow (1995) defines EIP as "a selective collection of compatible industrial plants located together in one area (complex) to minimize both environmental impact and industrial production costs. These goals are accomplished by utilizing the waste materials of one plant as the raw materials for another with a minimum of transportation, storage and raw material preparation." There are a lot of definitions regarding EIP but all of them have taken into consideration the three main criteria for sustainable development namely, environmental, economic and social dimension and they emphasize the main role of eco-industrial parks as a tool for industrial ecology and for achieving the objectives of sustainable development.

From the above discussions, one can defend EIP as "a community of manufacturing and service businesses seeking conservation of natural and economic resources in order to reduce production cost and protect the environment as well as public and occupational health". The word community can be defined as a local community within the same facility or surrounding community within the industrial estate or nearby community or global community across a broader region. The global community is not yet realized because of distances. This could be done between two industrial estates where some wastes might match different industries in two different communities, especially if the industrial communities were not designed initially to act as an EIP.

EIP aims at achieving economic, environmental, social, and government benefits as follow:

- Economic: Reduce raw material and energy cost, waste management cost, treatment cost, and regulatory burden, and increase competitiveness in the world market as well as the image of the companies.
- Environmental: Reduce demand on finite resources and make natural resources renewable. Reduce waste and emissions to comply with environmental regulations. Make the environment and development sustainable.

- Social: Create new job opportunities through local utilization and management of natural resources. Develop business opportunities and increase cooperation and participation among different industries.
- Government: Reduce cost of environmental degradation, demand on natural resources, and demand on municipal infrastructure, and increase government tax revenue.

3.5 Recycling Economy/Circular Economy Initiatives

Developing an eco-industrial park is a complex process because it requires integration among information technologies, innovation, extended producer responsibility, design for environment, and decision making. Several models with slight differences are encountered in many countries. One of the models is the 1996 Act of the German Federal Government of the recycling economy (RE). After a short period of time, the Japanese Government established a program to achieve the RE concept by implementing a good product design and a comprehensive resources recovery. The circular economy (CE) initiative is then undertaken by the Chinese Government. The circular economy approach to resource-use efficiency integrates cleaner production and industrial ecology in a broader system encompassing industrial firms, networks or chains of firms, eco-industrial parks, and regional infrastructure to support resource optimization. Different initiatives were undertaken in other countries such as the USA and Canada.

Germany: The German Government passed a new Act in 1996 to move Germany toward a recycling economy using a closed loop economy law. This law traces the life cycle of production, consumption, and recovery or disposal in order to minimize the amount of waste generated in the manufacturing processes and encourage the product design that can be easily reused or recycled according to the principle of "extended producer and consumer responsibilities" discussed in Chapter 1 (Dietmar, 2003).

Upstream strategy for waste prevention and enhancing recyclables is the main key behind the German recycling economy legislation. Germany has started a number of EIPs and waste exchange projects to support implementation of the recycling economy law. The German institutes and consulting firms supporting implementation of the German legislation provided guidelines in the use of cleaner production, life cycle analysis and design for environment tools in the industrial sectors.

Japan: According to the Japan Environmental Agency (1998), Japan currently consumes 1,950 million ton/y of natural resources and imports 700 million ton/y from overseas. In the same time, a total of 450 million tons of waste (industrial and municipal) are generated per year. Over 60% of this waste is either incinerated or landfilled. Current estimates predict that remaining landfill capacity will be exhausted by 2007. As a result, Japan's government has created a comprehensive program for achieving a recycling economy through a series of laws such as the Basic Law for Promoting the Creation of a Recycling Oriented Society and the law for the Promotion of Effective Utilization of Recycled Resources. The foundation for the basic recycling law was a report by the Industrial Structure Council (July 1999). Other supporting legislations were issued to support the recycling law such as the Law Concerning Promotion of Separate Collection and Recycling of Containers and Packaging (2000), which accounts for more than 25% of general waste.

China: The Government of China introduced a circular economy as the outcome of over a decade's efforts to practice sustainable development by the international communities, and is the detailed approach towards sustainable development (Xiaofei, 2006). Sun Youhai, a law-drafting official with the Environment and Resources Committee of the Standing Committee of the National People's Congress, stated that "China has chosen a circular economy as the major means to combat environmental degradation and pursue sustainable development, but the development of the economy still lacks strong legal support and therefore it is necessary to draft such a law in time to help build a sound material-recycling society" (China Internet Information Center, 2005).

Since circular economy is a new concept in China, there are no clear mandates of each ministry on circular economy to date, and this problem may be solved by the end of 2006 after the issuance of the Guiding Principle of Promoting the Development of Circular Economy which the National Development and Reform Committee (NDRC) is now preparing for the State Council, yet Xiaofei presumes their mandates according to the existing ones (2006).

The circular economy (CE) initiative has been developed in China as a strategy for reducing the demand of its economy upon natural resources as well as the damage it causes to natural environments. The CE concept calls for very high eco-efficiency of using natural resources as a way of improving the quality of life within natural and economic constraints for sustainable development. China's planned economy is a top-down approach, which is similar to the economy model in most developing countries.

The circular economy model encompasses both the cleaner production techniques and industrial ecology strategy in a broad system that aims at industrial establishments, eco-industrial parks, and services in order to optimize the use of natural resources. The whole community has to play a role in achieving the CE concept, from the government to the firms all the way to the public. The fundamental actions that should be applied are stated below (Circular Economy, Xiaofei 2006).

- The first action within the individual firm, the managers must seek to apply the cleaner production hierarchy discussed in Chapter 2.

- The second action is to reuse and recycle resources within the established industrial parks. This will ensure that the resources will be circulated within the local industrial area.
- The third action is to integrate different production and consumption systems in such a way that resources circulate between industries and the community.

The circular economy initiative is meant to widen the opportunities and chances for local and foreign investments to take place. This is accomplished through the three actions stated above, and they all include development of resource recovery, cleaner production enterprises, and public facilities to achieve the concept of the circular economic industry. Another addition to the third regional level would be integrating management of material flow among suburban, urban, and rural areas (Circular Economy Xiaofei, 2006).

The circular economy concept joins the two basic approaches of cleaner production and industrial ecology with its application as eco-industrial development. The central strategies should revolve around establishing eco-industrial parks and networks within the borders of the country. On the other hand, eco-industrial parks confine themselves to the basic idea that one company utilizes the wastes of another, which goes against the understanding of how such established parks can meet the goal of a circular economy in a region. Countries must focus on meeting the demands of a circular economy and not just the establishment of eco-industrial parks by the actions stated earlier (Circular Economy Xiaofei, 2006).

Circular economy plans in some regions in China have been able to link eco-industrial development with cleaner production as the main strategies for applying a circular economy. This proves that eco-industrial parks form a link to the success of a circular economy; however, the parks should not be perceived as companies that use each other's wastes, but to look at the broader view.

United States: Reviewing the experience of the United States shows that a variety of stakeholders have important roles to play in promoting the development of eco-industrial parks and networks. Yet due to the stringent health, safety, and environmental regulations (Martin *et al.*, 1996), combinations of top-down and bottom-up approaches are required.

The US has been actively involved in the promotion of EIPs since 1994 when a major contract was granted to Research Triangle Institute in South Carolina and Indigo Development in California to assess the potential application of industrial ecology to economic development with the Environmental Protection Agency (EPA) being the primary federal agency interested in the concept at the time, which resulted in new White House initiatives to "reinvent regulation" and promote community economic development (Peck *et al.*, 1997). Ms Suzanne Giannini-Spohn, US-EPA, Office of Policy, Planning and

Evaluation, stated that the policies and programs that are needed to promote EIP development are those that promote resource efficiency, recycling, pollution prevention, and environmental management systems (Peck *et al.*, 1997). In 1995, EPA took up the challenge, looking at ways to improve the efficiency of its regulatory programs and reduce the burden on all concerned through cutting red tape, partnerships, flexibility, and facilitating compliance, which resulted in some projects and initiatives to promote the concept of EIP.

Also, research conducted by the US-EPA on EIPs has resulted in the identification of a number of regulatory strategies for encouraging the development of industrial ecosystems and the implementation of pollution prevention in the context of EIPs that could be summarized as follows (Peck *et al.*, 1997):

- Modifying existing regulations.
- Reforming existing permitting and reporting processes.
- Moving toward performance-based regulations.
- Promoting the use of facility-wide permitting.
- Promoting the use of multimedia permitting.
- Utilizing market-based approaches, such as emissions trading.
- Utilizing voluntary agreements such as covenants.
- Implementing manufacture extended waste liability regulations, which will impact on the design, production, use, reuse, and recycling of products.
- Promoting technology diffusion within and between industrial sectors.
- Providing opportunities for technology development and commercialization.
- Providing technology development grants specific to industrial ecology applications.

University and research institutes have also supported the development of EIP extensively in cooperation with local and federal governments. It is very important to develop a partnership among different stakeholders with universities and research institutes to develop innovative techniques and guidelines for industrial parks to follow. EIP concept, methodology, and strategies should also be included with the educational system within colleges and universities.

Canada: The strategic and policy framework exists at the federal and provincial levels to support activities that promote EIPs in Canada as discussed by Peck *et al.* (1997) and falls under the following five main guidelines:

- Securing Our Future Together Plan
- Business Plan and Sustainable Development Strategy
- Sustainable Development Strategy
- Renewed Canadian Environmental Protection Act and Toxics Management
- Pollution Prevention Federal Strategy

The outcome of main guidelines developed by Canada to move toward sustainable development was reflected in several programs and action plans with no programs specifically designed to support EIP development in Canada, yet programs that may be applicable to EIP have been identified by Peck *et al.* (1997) with their incentives, objectives, and outcome mechanisms.

Several federal strategies, programs, initiatives, and tools have been developed to help implement EIPs. Although these programs are not intended specifically for EIP, they are generally directed to material and energy saving, and innovation which fit the criteria of EIP. Legislation and incentive mechanisms to encourage EIP in Canada were developed such as:

- Overcome traditional fragmentation by collaboration among public agencies, design professions, project contractors, and companies.
- Developers may need to make a strong case for banks to finance a project with a longer payback period.
- Get contracts with major companies to locate in EIP; this will help prove the concept to financiers.
- Public development authorities may be better prepared to bear the possible increase in development costs than private developers. Or the public sector may fund some aspects of the development of an EIP with strong public benefits.
- Companies using each other's residual products as inputs face the risk of losing a critical supply or market if a plant closes down. To some extent, this can be managed as with any supplier or customer relationship (i.e. keeping alternatives in mind and writing contracts that ensure reliability of supply).
- Exchange of byproducts could lock in continued reliance on toxic materials. The cleaner production solutions of materials substitution or process redesign should take priority over trading toxics within an EIP site.

3.6 Eco-Industrial Park Case Studies

Based on previous discussion, a well-designed eco-industrial park (EIP) will close the material flows and energy cascading within an industrial community. In other words, eco-industrial parks can be considered an "Industrial community of manufacturing and service companies to enhance their eco-efficiency through improving their economic and environmental performance by collaboration among each other in the management of the natural resources." EIPs proved that it is the most valuable approach in the industrial zone from the economical, social, and environmental points of view. One famous model for eco-industrial parks is Kalundborg industrial estate located in Kalundborg town (harbor town) at the north west of Denmark, 75 km west of Copenhagen. It will be discussed in detail in the following case study to demonstrate the benefits of and approach to EIP. New EIPs have been designed and engineered by researchers, companies, and developers in different parts of the world such as the Netherlands, Austria, Canada, USA, Denmark, Spain, Costa Rica, Australia, Finland, etc. The world marches to adopting EIP concept, and thus more and more EIP is introduced all over the world every day such as:

- Crewe Business Park, UK
- Knowsley Park, UK
- Londonderry Eco-Industrial Park, UK
- Trafford Park, UK
- Emscher, Germany
- Value Park, Germany
- Environmental Park, Italy
- Hartberg Ecopark, Austria
- Styria, Austria
- Herning-Ikast Industrial Park, Denmark
- Vreten, Solna, Sweden
- Sphere Ecoindustrie D'alsace, France
- Parc Industriel Plaine de l'Ain (Pipa), France
- Burnside Industrial Park in Dartmouth, Canada
- New Eco-Industrial Park in Hinton, Alberta, Canada
- Brownsville, Texas, USA
- Chattanooga, Tennessee, USA
- Baltimore, Maryland, USA
- Cape Charles, Virginia, USA, etc

The concept of Eco-Industrial Parks (EIP) was first developed by Indigo Development (Indigo Development 2006). In the early 1990s, innovators at Dalhousie University (Nova Scotia, Canada) and Cornell University (Ithaca, New York, USA) conceived related frameworks for industrial park development (Côté and Cohen-Rosenthal, 1998). Indigo introduced this concept to staff at the US-EPA in 1993. The EPA then included an EIP project in an Environmental Technology Initiative and recommended that the President's Council on Sustainable Development adopts EIPs as demonstration projects in 1995. From 1994 to 1995 Indigo collaborated with Research Triangle Institute in a major US-EPA cooperative research grant focused on EIPs.

An eco-industrial park or estate is a community of manufacturing and service businesses located together on a common property. Member businesses seek enhanced environmental, economic, and social performance through collaboration in managing environmental and resource issues. By working together, the community of businesses seeks a collective benefit that is greater than the sum of individual benefits each company would realize by only optimizing its individual performance.

TABLE 3.1
EIP in USA and Developer Organization (Gibbs and Deutz, 2004)

EIP	*Developer*
Devens Planned Community, MA	Public Agency
Philips Eco Enterprise Center, MN	Community non-profit
Port of Cape Charles Sustainable Technology Park, VA	Public agency
Gulf-Coast By-product Synergy Project, Freeport, TX	Private companies
Londonderry Eco-Industrial Park, NH	Private sector
Redhills Ecoplex, MS	Public agency
Dallas Eco-Industrial Park, TX	Local authority
Ecolibrium, Computer and Electronic Disposition, Austin, TX	Public sector consortium
Front Royal Eco-Office Park, VA	Public agency
Basset Creek, MN	Consultants/Local Authority

The main goal of an EIP is to improve the economic performance of the participating companies while minimizing their environmental impacts and complying with environmental regulations. Components of this approach include environmentally friendly design of park infrastructure and plants (new or retrofitted), cleaner production, pollution prevention; energy efficiency; and intercompany partnering. An EIP also seeks benefits for neighboring communities to assure that the net impact of its development is positive.

There is no one single model or methodology to follow for developing EIP and accordingly there cannot be a single Act or strategy to be addressed. It seems that in Canada the development of EIP is still more of a top-bottom approach, unlike the US where many private companies are taking the lead as shown in Table 3.1. A combination of the Canadian system and American system might be the best: to develop strategy and awareness programs and seek benefits and compliance with environmental regulations according to a bottom-up system. The development of a circular economy still lacks strong legal support and therefore it is necessary to draft such a law in order to achieve the desired objectives.

These experiences showed some important support tools that have been developed in the process of EIP development. These tools include a mechanism to make the park work, financial tools, and model codes among the members of EIP. An information management system to facilitate the interconnectedness is identified as a major tool (Peck, 1998; Peck *et al.*, 1998; El Haggar, 2005) with more research needed in this area.

The following case studies will illustrate some ideas and history behind each EIP to help readers or researchers to develop their own methodology to approach EIP in their country/industrial estate. The methodology might change from one industrial estate to another and from one country to another according to the awareness level, type of industry, and industrial estate and accordingly type of raw material/waste generated, culture, available information, etc. Some case studies will be handled in some detail and others will be handled very briefly for the sake of demonstrating different ideas, methodologies, concepts, criteria, etc.

Kalundborg Eco-Industrial Park, Denmark (Indigo Development 2006)

Kalundborg is a typical example to demonstrate the benefits and methodology of implementing industrial ecology within an existing industrial estate toward an eco-industrial park (EIP). The example of Kalundborg is often quoted because it is simple enough to demonstrate the idea of an industrial ecosystem. Moreover, it helps to visualize the benefits of industrial ecology and the main criteria for the implementation of such ecosystems as well as the way the methodology of industrial ecology was structured.

As discussed in this chapter, industrial ecology can be defined as "a manmade artificial ecosystem that follows the natural ecosystem". The main point behind this definition is to eliminate the words waste/pollution from manmade systems, and replace them with raw material or byproduct. If this is applied, then this definition will be more accurate, leading to an overall increase in efficiency – "eco-efficiency".

Kalundborg was not planned to be an eco-industrial network in the first place. Gradually, a network of industries has slowly developed over 30 years resulting in the formation of an industrial ecosystem or symbiosis. The case of Kalundborg started in 1961 with an idea to reduce the limited supplies of underground water usage and replace it with surface water from Lake Tisso. The first company to start this idea was an oil refinery called Statoil. The first partnership was between the city of Kalundborg which took the responsibility of constructing the pipelines and the oil refinery which financed the project. Building on this first project were other projects where the parties concerned started to realize the benefits from this partnership. Nowadays, Kalundborg is one of the largest complexes in which a mutual exchange of input and output is applied between different industrial organizations. The main partners in this industrial complex are the following (Saikkuu, 2006):

- Asnaes Power Station, Denmark's largest coal fired power plant, producing electricity with a capacity of 1,500 MW – it produces heat for the town of Kalundborg (4,500 households) and other industries in the estate.
- Statoil refinery, Denmark's largest oil refinery, with a capacity of 3.2 million tons/yr and expanded to 4.8 million tons/yr recently.
- Gyproc, a Swedish company producing 14 million square meters of gypsum wallboard (plasterboard) annually.

- Novo Nordisk, a multinational biotechnological company producing pharmaceuticals including 40% of the world's supply of insulin and industrial enzymes with annual sales over $2 billion.
- The Municipality of Kalundborg supplies district heating to the 20,000 residents, as well as water to the homes and industries.

Other partners joined the symbiosis based on the waste of the core partners as a byproduct. They ended up with the following added partners as will be explained later in detail:

- Bioteknisk Jordrens Soilrem – a soil remediation company that joined the symbiosis in 1998.
- Fish farm – consists of 57 fish ponds.
- Fertilizer farm.
- Cement company – Aalborg Portland and road paving.
- Kemira – a sulfuric acid producer.

The history of structuring Kalundborg

The history of structuring Kalundborg as an eco-industrial park was based mainly on individual and independent agreements according to the following time history and as shown in Figures 3.1, 3.2 and 3.3:

- In 1959 the Asnaes power station commissioned.
- In 1961 the Statoil refinery commissioned. The oil refinery started to utilize water from Lake Tisso through a pipeline that was financed by the refinery and built by Kalundborg city.
  - Saving the underground water resources.
  - *Driving force*: Enforcing community regulation/requirement.

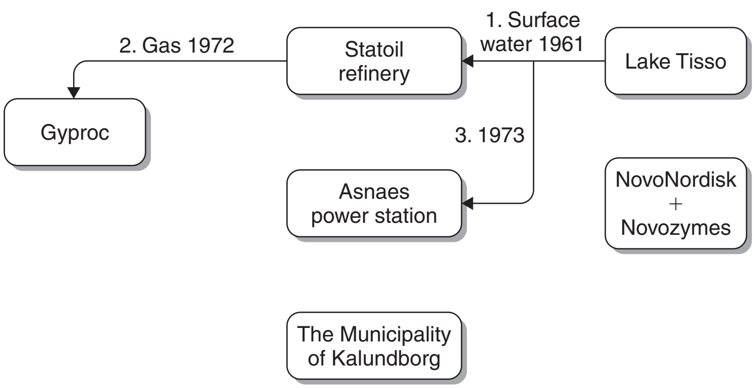

FIGURE 3.1 Kalundborg industrial symbiosis in 1975 (Saikkuu, 2006)

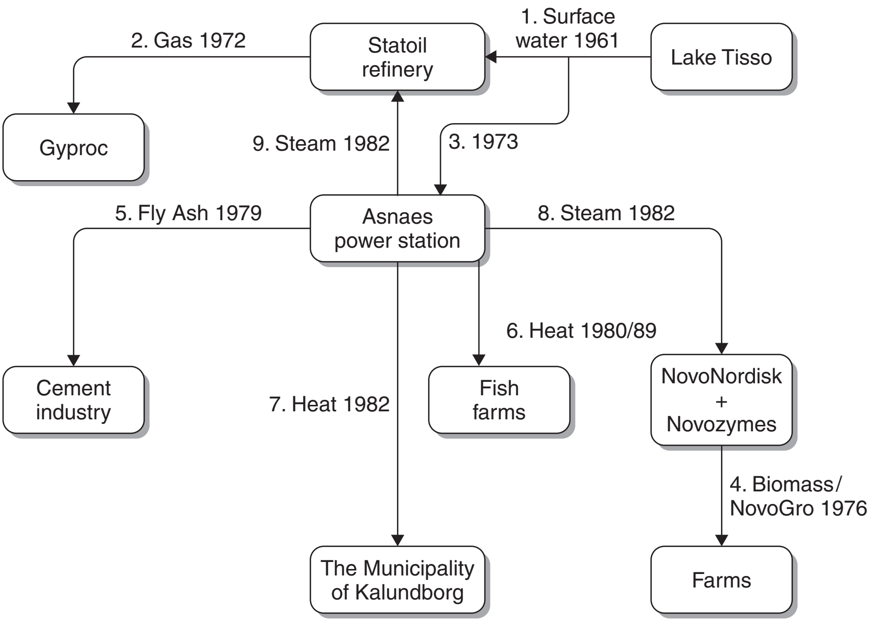

FIGURE 3.2 Kalundborg industrial symbiosis in 1985 (Saikkuu, 2006)

- In 1972, Gyproc was established. Gas for Gyproc plant was piped from the refinery after the refinery removed the sulfur from the gas.
  - Statoil gas is cheaper for Gyproc plant than using oil.
  - *Driving force*: Economic benefits.
- In 1973, the Asnaes power station expanded drawing water from Lake Tisso.
  - Saving the underground water resources.
  - *Driving force*: Enforcing community regulation/requirement.
- In 1976, regulation placed significant restriction on the discharge of organics into the sea. Since Novo Nordisk used to mix the industrial sludge with wastewater and discharge it to the sea, it found that the most cost effective way for sludge disposal/utilization was to give it for free to farmers as fertilizer. This was done by pipeline and trucks.
  - *Driving force*: Enforcing regulation as well as economic benefits.
- In 1979, the Asnaes power station started to sell fly ash to cement factories. Asnaes built an ash silo with an unloading facility to accomplish this duty.
  - Saving money by not landfilling fly ash.
  - Making money out of selling fly ash.
  - Less cost for cement producers.
  - *Driving force*: Economic benefits.

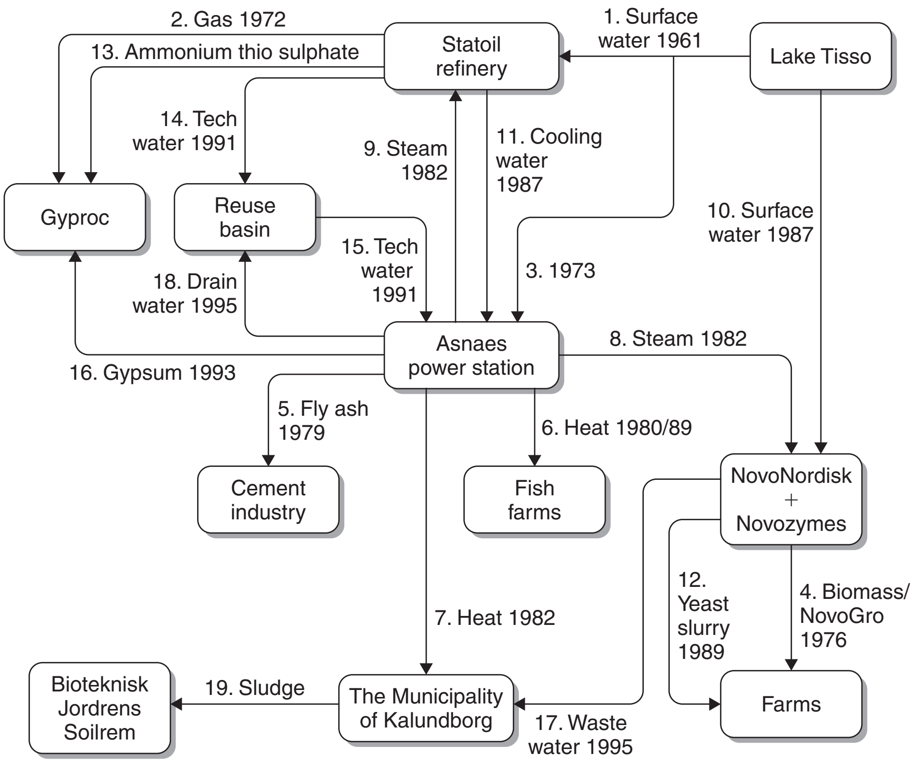

FIGURE 3.3 Kalundborg industrial symbiosis in 2000 (Saikkuu, 2006)

- In 1981, Asnaes started to supply heat to the Kalundborg community. There was an oil crisis in the late 1970s due to the 6th of October war in the Middle East. Oil prices increased and heating security was in question. The Kalundborg city was mostly heated by oil. There was a need to restrict the use of the oil heating system. Asnaes took care of this by supplying steam/hot water to the city.
  - *Driving force*: Security and economic reasons.
- In 1982, Asnaes delivered steam to Statoil and Novo Nordisk. Novo need to renovate and upgrade their boilers to get the required heat. The construction of a pipeline was more cost effective than an upgrade. For Statoil, it was much cheaper to get steam from Asnaes.
  - *Driving force*: Economic benefits.
- In 1987, Statoil piped cooling water to Asnaes power station. Considering the rare water resources there, and knowing that thermal pollution was being criticized at Asnaes, the most cost-effective solution was to utilize the waste cooling water from Statoil in Asnaes.
  - *Driving force*: Economic benefits.

- In 1989, Novo Nordisk switched from Lake Tisso to well water.
- In 1989 Asnaes power station started fish farming to solve the problem of thermal pollution. The sea water used to cool the condenser of the thermal power plant was utilized to develop an artificial fish farm that makes the fish grow faster in such a warm temperature.
  - *Driving force*: Economic benefits.
- In 1990, Statoil began selling molten sulfur to Kemira in Jutland. Excess gas from the operations at the Statoil refinery was treated to remove sulfur, which was sold as raw material for the manufacturing of sulfuric acid at Kemira, and the clean gas was then supplied to Asnaes power station and to Gyproc as an energy source.
  - *Driving force*: Economic benefits.
- In 1991, Statoil sent treated wastewater to Asnaes for utility use. Due to community pressure as well as related regulations, Statoil invested in a wastewater biological treatment plant to supply clean water to Asnaes.
  - *Driving force*: Enforcing regulation and economic benefits.
- In 1992, Statoil sent desulfurized waste gas to Asnaes.
- In 1993, Asnaes supplied gypsum to Gyproc. Asnaes power station installed a desulfurization unit to remove sulfur from its flue gases, which allowed it to produce calcium sulfate (gypsum). This is the main raw material in the manufacture of plasterboard at Gyproc. By purchasing synthetic "waste" gypsum from Asnaes power station, Gyproc were able to replace the natural gypsum imported from Spain.
  - *Driving force*: Enforcing regulation and economic benefits.

In summary, materials and energy are being exchanged in the city of Kalundborg among different companies and with the community in a closed loop such that the waste or byproduct of one company is taken as the raw material for another. It all started in 1961 with the need to use the surface water from Lake Tisso for a new oil refinery (Statoil) to save groundwater. Originally, there was no planning of the overall network; it just evolved as a collection of one-on-one deals between different industries that resulted in economic benefits for both partners in each deal. Figures 3.1 to 3.3 illustrate the network of companies in the symbiosis, showing the extent of the material and energy exchanges.

Material and energy flow analysis

Material and energy exchanges and savings started in Kalundborg in 1961 as the Statoil refinery began using water from Lake Tisso instead of groundwater, saving around 2 million cubic meters of water per year. Then Gyproc located its facility in Kalundborg to take advantage of the fuel gas available from Statoil. By the early 1970s, Statoil refinery agreed to provide its excess gas (byproduct) to Gyproc instead of burning it, which has been considered by Gyproc to be a source of low cost fuel. Later on as Statoil supplied both its purified wastewater as well as its cooling water to the Asnaes power station, it thereby saved a total of 3 million cubic meters of water per year (instead of 2 million) as the same water was being "used twice". In 1976, the Novo Nordisk plant started materials flows by supplying sludge from its processes as well as from the fish farm's water treatment plant to be used as a fertilizer for a nearby farm. This sludge exchange totalled over 1 million tons per year. In addition, surplus yeast from the produced insulin was sent to farmers as animal food.

Enzyme production is based on fermentation of raw materials such as potato flour and cornstarch. The fermentation process generates about 150,000 cubic meters of solid biomass as well as 90,000 cubic meters of liquid biomass. Through proper repositioning of this waste, farmers have been using it as fertilizer, thus reducing the consumption of commercial fertilizers.

Another waste transformation is the yeast which is used in the production of insulin. Through the addition of sugar water and lactic acid it is converted into animal food. The insulin production builds on a fermentation process in which some of the main ingredients are sugar and salt, which are converted into insulin by adding yeast. After a heating process, the yeast, a residual product in this production, is converted into a much appreciated feed: yeast slurry. Sugar water and lactic acid bacteria are added to the yeast, making the product more attractive to animals (800,000 pigs).

The Asnaes power station is coal fired and operates at about 40% thermal efficiency producing huge amounts of energy. It uses salty seawater for its cooling needs saving the Lake Tisso water, and at the same time supplies the heated seawater to the 57 nearby fish ponds producing 200 tons of trout and salmon on a yearly basis.

In 1981, Asnaes began to supply the districts with steam for heating which replaced about 3,500 oil furnaces and significantly reduced air pollution. In addition, it provided steam to both Novo Nordisk and Statoil for their heating processes. After Statoil treated its excess gas by removing sulfur to comply with regulations on sulfur emission, it became possible to use the gas at the Asnaes power plant. Statoil's desulfurization plant reduces the sulfur content of the refinery gas whereby SO_2 emissions are reduced significantly. The byproduct is ammonium thiosulphate, which is used in the production of approximately 20,000 tons of liquid fertilizer roughly corresponding to the annual Danish consumption.

In 1992, the Asnaes power plant began using the treated gas from Statoil in place of coal. Statoil also supplies gas to Gyproc as its source of energy. In addition, the removed sulfur is sold as a raw material for the manufacture of sulfuric acid at Kamira. In 1993, the Asnaes power station added a desulfurization unit that removes sulfur from its gases and produces calcium sulfate as waste which is known as synthetic gypsum. The desulfurized fly ash is used by a cement company while gypsum is supplied to Gyproc as the main raw material for the manufacture of plasterboard instead of importing natural gypsum from Spain. In 1998, approximately 190,000 tons per year of synthetic gypsum were available from the power station.

Other types of wastes were also generated such as 13,000 tons of newspaper/cardboard which after a quality check are sold to cardboard and paper consuming industries in Denmark, Sweden, and Germany producing new paper, new cardboard, egg boxes and trays. Another 7,000 tons of rubble and concrete were used for different surfaces after crushing and sorting, and 15,000 tons of garden/park refuse were delivered as soil amelioration in the area as well as 4,000 tons of bio-waste from households and company canteens. The bio-waste is used in compost and biogas production. Four thousand tons of iron and metal were resold after cleaning for recycling as well as 1,800 tons of glass and bottles sold to producers of new glass.

In ecological terms, Kalundborg exhibits the characteristics of a simple food web: organisms consume each other's waste materials and energy, thereby becoming interdependent with each other. The exchange of reused and recycled materials and energy from the industries' byproducts resulted in large amounts of profit and cost savings. Through 1993, the $60 million investment in infrastructure (to transport energy and materials) has produced $120 million in revenues and cost savings. In 1998, the capital cost for this project was around $75 million. The savings were estimated to be $160 millions for a payback period less than 5 years. At the same time, tens of thousands of tons of water, fuel and other products are saved annually. The reductions in consumption of natural resources are as follows: 45,000 tons of oil/y, 15,000 tons of coal/y, and 600,000 m^3 of water/y. The amounts of reduced wastes and pollution are also significant: 175,000 tons of carbon dioxide/yr; 10,200 tons of sulfur dioxide/y; 4,500 tons of sulfur/y; 90,000 tons of calcium sulfate (gypsum)/y; and 130,000 tons of fly ash/y.

Although the industrial symbiosis of Kalundborg was developed due to business interactions between companies seeking to make economic use of their byproducts and waste material, it ended up with both economic as well as environmental benefits. Materials are being exchanged in a closed loop, companies are gaining profits, and the environment is protected by the reduced air, water and land pollution.

The Kalundborg case study proved that sustainability through industrial ecology can be profitable. The main obstacle to implementing industrial ecology methodology is the absence of an industrial ecology leadership. Industrial ecology leadership is a must to initiate and maintain the methodology. Industrial ecology leadership should be done on a voluntary basis. Socializing the top management of the industrial activities will enhance the communication skill and will develop mutual trust between partners and help people talk to each other and initiate eco-industrial systems.

Criteria for symbiosis

From the above analysis, one can develop the following criteria for successful implementing of an eco-industrial park:

- Database for wastes quantity and quality (analysis).
- Environmental and economical awareness.

- Possibility of mutual benefits between companies.
- Proximity between the locations of the companies forming the network.
- Communication between companies.
- Developing well-structured legislation and incentive mechanism to encourage such networking.
- Providing technical know-how through CP/IE experts.
- Providing facilities for partnership.
- Developing confidence between different establishments of the network.
- Developing trust between stakeholders including companies and government.

Administration

The Kalundborg center for industrial symbiosis was established and financed by symbiosis partners with the following objectives:

- Follow-up on the current Kalundborg symbiosis.
- Developing a database for Kalundborg symbiosis and other successful case studies.
- Developing an internal and external communication system to disseminate information and experience.
- Coordinating studies on the industrial symbiosis according to demand and need.
- Organizing of visits and study tours on the symbiosis.
- Consultation on new symbiosis projects.
- Contributing to forming new symbiosis projects.

Brownsville Eco-Industrial Park (Martin *et al.*, 1996)

This case study is a prototype developed by a group of researchers for the existing Brownsville eco-industrial park located in Texas, USA. The main reason for selecting this case study in particular is that the group of researchers who studied this EIP has developed five different scenarios based on the level of interaction and the extent to which wastes and resources are exchanged between members of the park. Not all of the EIP members participate in each scenario. In scenario 1, very few of the companies are working together. As we move from one scenario to the next, the level of cooperation and interactions among members of the park increases. In scenario 5, each EIP member interacts with the others in some way. This means that in one case study we will be able to trace the development of EIP and how this will be reflected on the economical and environmental benefits.

To develop the EIP prototype and its different scenarios, the researchers have collected data regarding the inputs and outputs of each company operating in the area of Brownsville, their willingness for using recycled material instead of virgin material that is currently used, and the potential for selling their byproducts instead of disposing of them as wastes. Finally, they summarized this data and prepared a flow diagram illustrating the inputs and outputs of each company. From this diagram, they identified several opportunities for symbiotic byproduct exchange.

EIP members

The prototype EIP contains 12 members; some of them are within the area of Brownsville, while others are located at remote sites. Therefore, this eco-industrial park is referred to in many literatures as a "virtual" eco-industrial park.

EIP port members

- Refinery: The refinery produces three products: naphtha, diesel, and residual oil. It expects to be producing approximately 8,300 barrels per day of each of these products. Its main input materials are light crude oil and energy.
- Stone company: The stone company brings limestone into the port and distributes it to companies in the area. At baseline, it sells stone to the asphalt company.
- Asphalt company: The asphalt company uses limestone from the stone company and residual oil from the refinery to produce asphalt for use on roads in the area.
- Tank farms: Clusters of tanks belonging to a variety of companies offload a variety of fluids brought into the port by ship and store them until they are delivered to their destinations by tanker trucks. The tanks sit in the port and frequently contain materials that must be kept warm to remain fluid. At baseline, they burn natural gas to generate the steam required to keep the materials warm.

Remote partners

- Discrete parts manufacturer: This company produces plastic and metal parts using screw machines, automated roll feed punch presses, and injection molding. At baseline, this company gives away used oil (about 100 gallons per month) to a recycler; it also landfills about 75% of its scrap plastics.
- Textile plant: This company assembles garments. It uses a small amount of solvents to wash parts. An outside party treats and disposes of compressor oil waste. A large quantity of high density polyethylene is landfilled.
- Auto parts manufacturer: This company uses plastic injection molding, metal stamping, and powdered metal forming to make small parts for assembly at a facility. A distant recycler buys the company's plastic scrap. The company also pays for disposal of several types of oil.

- Plastic recycler: This recycler accepts 12 types of plastic, grinds it, and sells the grind overseas. The company also manufactures plastic pellets from scrap.
- Seafood processor and cold storage warehouse: This company processes seafood and acts as a cold storage warehouse. It uses a great deal of water and electricity.
- Chemical plant: This plant manufactures anhydrous hydrogen fluoride. The major byproduct is $CaSO_4$ (gypsum). The company currently gives away gypsum to the Mexican Department of Transportation for use as road base. The gypsum is very pure and probably could be used in other applications (e.g. wallboard, concrete, tiles).
- Manufacturer of magnetic ballasts: This company produces electronic and magnetic ballasts. It currently landfills about 332 tons of waste asphalt per year.
- Gypsum wallboard company: This EIP member, located in Houston, is the only member not located in the Brownsville area. This wallboard producer relies exclusively on synthetic gypsum as an input to its wallboard production process.

EIP scenarios

In this section each of the five scenarios will be elaborated. The level of interactions between companies will increase gradually as we go from one scenario to the other until reaching a maximum level of interaction at scenario 5.

Scenario 1

At baseline, very few symbiotic relationships exist between these companies as shown in Figure 3.4 and as follows:

- The refinery sells its residual oil to the asphalt company.
- The stone company sells limestone to the asphalt company.

Scenario 2

In this scenario, the existing EIP members implemented pollution prevention activities independently from one another. This scenario is useful because it helps in revealing the benefits and limitations of individual pollution prevention efforts compared with the gains achievable by looking outside the plant boundaries for waste reduction opportunities.

This scenario describes some pollution prevention and recycling opportunities that can provide economic and environmental benefits to the companies acting independently. Experts in cleaner production techniques identified some of these opportunities during brief site visits to the companies.

- The discrete parts manufacturer introduces an aqueous cleaning system and an oil/water separation system.

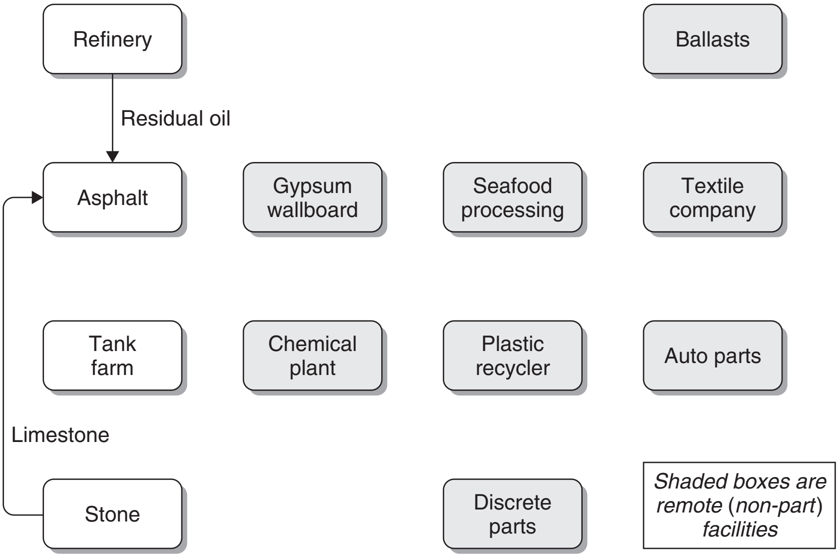

FIGURE 3.4 Scenario 1 – Baseline activities (Martin *et al.*, 1996)

- The textiles company recycles cutting room clippings.
- The automobile parts manufacturer purchases a ringer system for absorbent socks and rags.
- The seafood processor uses brown water for non-critical cleaning processes.

Scenario 3
This scenario represents the first development stage of the EIP as shown in Figure 3.5. This stage takes advantage of potential exchange opportunities that can take place with little or no additional investment.

- The discrete parts manufacturer sells scrap plastic, which is currently landfilled, to the recycler. He also purchases plastic pellets from the plastic recycler instead of from a remote source. The benefits arise from conducting both transactions with a local broker.
- The textile company sells plastic, which is currently landfilled, to the plastic recycler.
- The auto parts manufacturer begins selling scrap plastic to the local recycler, rather than the current recycler he uses in Chicago.
- The ballast manufacturer sells scrap asphalt to the asphalt company for mixing with its virgin materials.

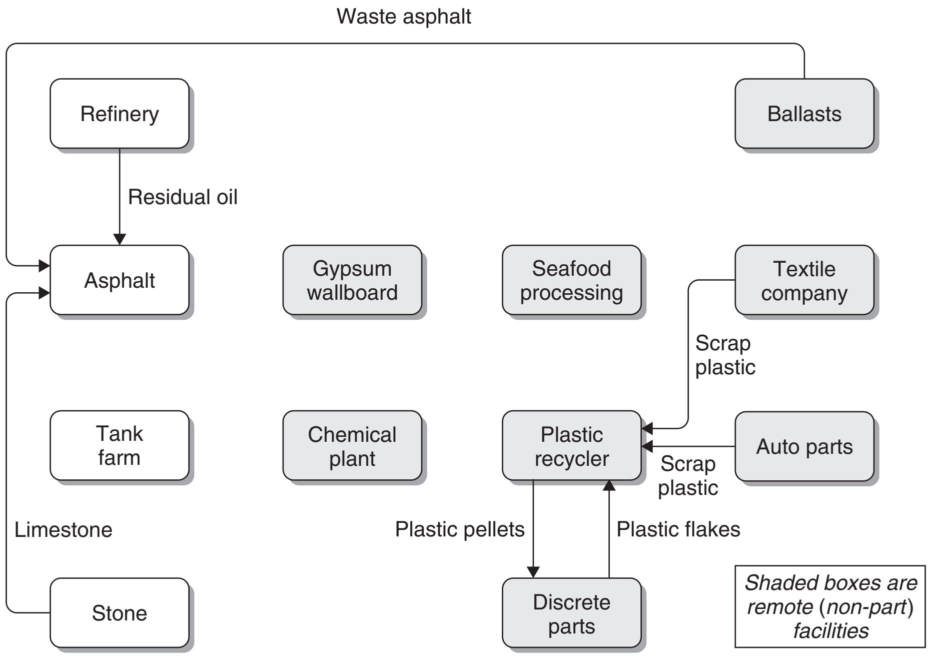

FIGURE 3.5 Scenario 3 – industrial symbiosis (Martin *et al.*, 1996)

Scenario 4

In this stage, the environmental and economic benefits of creating new businesses within the EIP will be demonstrated as shown in Figure 3.6.

- A power plant burning Orimulsion™, a heavy bitumen emulsified with water equipped with a steam pipeline to distribute process steam to other EIP members.
- A remotely located gypsum wallboard company.

These projects will require investment but will result in the following set of symbiotic relationships:

- The power plant delivers waste steam, through the pipeline, to the refinery and the tank farm. Once the energy in the steam is spent, the condensate is returned to the power plant and recycled to make more steam.
- The stone company delivers stone to the power plant for use in the scrubbers in the power plant's air pollution control system.
- The wallboard company receives waste gypsum from the power plant.

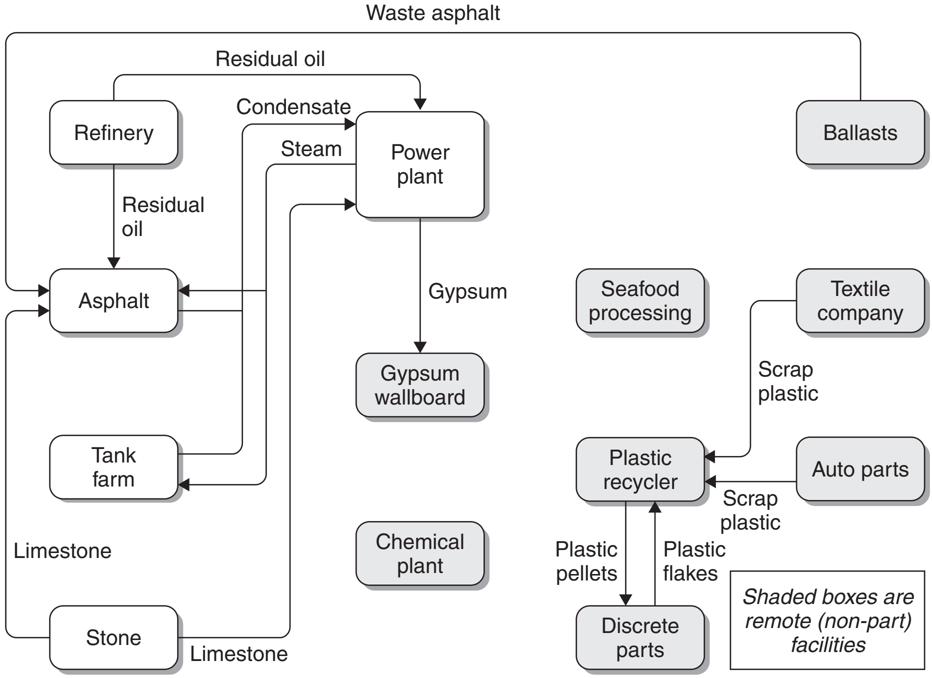

FIGURE 3.6 Scenario 4 – new EIP members (Martin *et al.*, 1996)

Scenario 5

In this stage, the researches assume that the remote partners are co-located with the remainder of the EIP members to study the additional benefits that could be derived from co-location. They also analyzed the provision of several joint services, which we assume the port can provide once the EIP has enough members to make these activities economically feasible. These joint services include a solvent recycler, an oil recycling operation, and a water pre-treatment plant. These changes produce the following opportunities:

- Each of the exchanges described in scenario 3 take place with lower transportation costs.
- The water pre-treatment plant provides clean water to the power plant.
- The solvent and waste oil recyclers are used by the discrete parts manufacturer, ballast manufacturer, auto parts manufacturer, and textiles company.

Comments and analysis

This study has demonstrated the development of different levels of interactions between Brownsville park's members starting from minimum interactions taking place at scenario 1 and increasing gradually until reaching

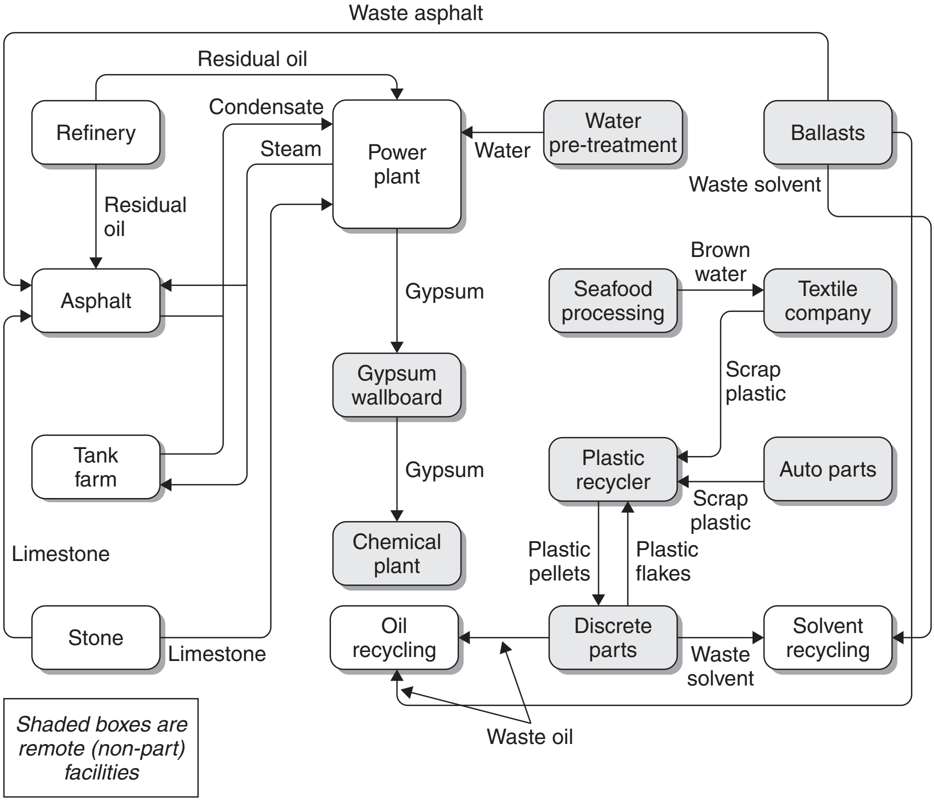

FIGURE 3.7 Collocation and EIP services (Martin *et al.*, 1996)

TABLE 3.2
Economic Indicator for Each EIP Scenario

Economic indicator	*Scenario 3*	*Scenario 4*	*Scenario 5*
Net annual economic benefit	$107,384	$4,658,786	$8,180,869
Return on investment	359%*	38%	59%
Payback period (year)	0.28	2.64	1.69

* This figure reflects only changes in net revenue from asphalt, since the plastics exchange required no initial investment.

maximum level of interaction and co-location at scenario 5. This breakdown in the level of interactions between the companies has allowed the researchers to trace the development and extent of the economic benefits resulting from each scenario alone. Thus, allowing them to know different circumstances at which industrial symbiosis might be more beneficial. Table 3.2 illustrates some economic indicators for each EIP scenario.

The researchers have concluded that the benefits of an EIP expand when companies are engaged in greater levels of cooperation as well as when they are located at a closer proximity to one another. Meanwhile, the opportunities to improve economic and environmental performance expand when an effective communication is established between members of the park so that companies are informed about how they might work together to improve the "industrial ecosystem" in their community.

Also, the researchers have noticed that in scenario 2, companies can achieve economic and environmental benefits through pollution prevention techniques that can be implemented with little or no investment. These opportunities require no cooperation or dependency between companies and they can be done at the unit level. In fact, this finding supports the vision that the industrial ecology approach is the net result of interaction among zero pollution, cleaner production, life cycle analysis, and eco-industrial parks (Peck, 1998; El Haggar, 2005).

From the previous analysis, some elements that play an important role in the success of any EIP project have been identified by the group of researchers and these elements are:

- The first and most essential input to the EIP is information about members' operations.
- The success of the EIP requires that members are open to depending on each other.
- To achieve the greatest economic benefits, the EIP will require substantial investment in infrastructure.
- The economic and environmental benefits to the EIP and the community are greater if the potential symbiosis opportunities are recognized during the planning stages of a park or plant.

Naroda Eco-Industrial Park, Ahmedabad, India

This case study is presented by UNEP. Naroda industrial estate is located in Ahmedabad in the northwest of India. Ahmedabad is the largest city in the state of Gujarat and has played an important industrial role in the estate because of its important textile industries. However, in the 1980s many of the textile industries in Ahmedabad closed. The city promoted other industries such as chemical, plastics, engineering, and pesticides industries. In the 1980s lots of textile chemical dyestuffs manufacturing was transferred from Europe and North America to India and other countries in Asia. Today almost 60% of dyestuffs exports from India are manufactured in Gujarat with approximately half coming from three industrial estates in Ahmedabad: Vatwa, Odhav, and Naroda.

Naroda industrial estate was established in 1964 by the Gujarat Industrial Development Corporation. Today there are approximately 900 industries located in Naroda industrial estate. They employ nearly 30,000 employees

TABLE 3.3
Industrial Sectors in Naroda Industrial Estate

Industrial sector	*% of industries*
Chemicals: dyestuffs and dye-intermediates	26
Engineering	24
Trading companies	9
Plastics	5
Textiles	5
Pharmaceuticals	3
Pesticides	1
Other industries	27

while 40,000 people depend indirectly on the industrial estate for their livelihood. Table 3.3 shows the significant industrial sectors in the Naroda industrial estate.

The estate provides services like water, power, and communications, in addition to infrastructure such as roads, schools, hospitals, post offices, banks, and a police station.

Administration/developer

EIP in Naroda was administered by Naroda Industries Association (NIA). NIA is an association made up of the owners of companies located within the estate. It achieved a number of projects in the areas of infrastructure, services, and environment. For example, NIA established Naroda Environmental Projects Ltd (NEPL) as a separate company to operate a landfill for the estate's hazardous wastes starting in 1997. NEPL also was responsible for the construction and operation of a common effluent treatment plant (CETP) which started in 1999. The CETP treats the wastewater for more than 200 companies. NIA also provides opportunities for its members to share information and learn about environmental approaches. The involvement of NIA in the estate activities is important for promoting environmental awareness for a large number of firms.

The eco-industrial network

The firms in the estate needed to enhance their environmental performance beyond mere compliance to regulations. They investigated more proactive approaches such as cleaner production to be promoted within the estate. The establishment of the CEPT led to a better understanding of the waste material flows within the estate thereby providing information on possible links between processes. Finally, the environmental and economic pressures had led firms in Naroda to improve their processes in order to improve their resource efficiency and their profitability. They started to achieve this improvement through applying cleaner production techniques. This helped to enhance individual environmental performance. After that they wanted to enlarge the scope of their activities and to cooperate with different companies to look for resource recovery opportunities.

The eco-industrial networking project described in this study was carried out by NIA and the University of Kaiserslautern (Germany). The project started as a sponsored "workshop on industry and environment" held at the Indian Institute of Management in Ahmedabad in 1999. The first step was to understand the main types and quantities of wastes generated by the firms in the estate. A survey of 500 companies was carried out. As a result of the survey, the most important waste materials were:

- Chemical gypsum
- Biodegradable waste
- Mild steel scrap
- Waste acids in particular sulfuric and hydrochloric acids
- Chemical iron sludge

Chemical gypsum is generated by 19 chemical industries as a result of neutralization of their acidic wastewater with lime. This gypsum can be used by cement manufacturing companies provided that it meets certain specifications. An analysis for the process of recovering the gypsum as a raw material confirmed that it is economically viable.

Biodegradable waste is produced from a total amount of 10,000 kg of solid material and 90,000 liters of liquid wastes per year. This type of waste could be used to generate biogas as an energy resource for the industrial estate or for a housing development located nearby. An economic analysis showed that this energy recovery process is extremely favorable.

Sulfuric acid and mild steel scrap can be used as raw materials to make ferrous sulfate, a chemical used in primary wastewater treatment at the CETP.

Several of the partnerships described above are now being put in place with the support of NIA. Other possible partnerships that have been identified in the industrial estate are:

- Using sulfuric acid in the manufacture of phosphate for fertilizer.
- Using iron sludge to prepare synthetic red iron oxide.
- An alternative application for chemical gypsum in the production of plaster board.
- Reduction in raw material and energy use in the ceramic sector.

In conclusion, the use of a resource recovery project in the Naroda industrial estate has enhanced the interest of the firms in environmental management activities and has encouraged the industries in the estate to focus not only on their individual environmental aspects but also on the effect resulting from the large number of companies concentrated within the estate.

Analysis and comments

- Establishing an EIP takes time and happens in stages. Starting in 1964 Naroda began by increasing the awareness of business leaders by presenting them with past experiences of the industries that joined the industrial complex. Today, there are 900 plants in the Naroda industrial estate.
- The Naroda Industries Association (NIA) played a major role in establishing the EIP. It acted as a steering organization and managed the project. It keeps on looking for opportunities for partnerships, and creates opportunities for its members to exchange information and learn about various environmental approaches. The involvement of NIA is helping to sustain progress in the Naroda industrial estate.
- The firms in the estate were willing to establish the eco-industrial network as a result of environmental and economic pressures. They wanted to enlarge the scope of their activities beyond just complying with the regulations. They wanted to recover their resources to increase their profitability. This mature vision evolved from an awareness of the meaning of EIP.

Burnside Eco-Industrial Park, Canada

The Burnside park is located in Halifax Regional Municipality, Nova Scotia, Canada, in an area of 1,200 hectares of which three-quarters is currently developed, and it is operated by a municipality. The main aim is to protect water, air, and land because this was the demand of the Canadian Government. There are approximately 1,300 companies and 17,000 employees in those businesses. The park is one of the five largest in Canada (UNEP 2001). It has a solid waste management system which is considered the most highly sophisticated in Canada.

The success behind this eco-industrial park lies in the fact that municipalities in Canada such as Halifax Regional Municipality have "implemented a solid waste management system, which is widely viewed as the most sophisticated in Canada" (UNEP 2001). This system includes diversion of glass, some plastics, paper, and cardboard and aluminum, organic wastes, and construction and demolition debris from the landfill. The municipality has adopted a sewer use by-law which will limit discharges of certain materials into the sewers and a pesticide use by-law which will, within four years, ban the use of pesticides for aesthetic purposes within the city (UNEP 2001).

Burnside is designated primarily for light manufacturing, distribution, and commercial activities as shown in Table 3.4. One section of the park is designated as a business park and attracts computer, health, and technology companies. Although not specifically designated as such, another section has attracted many large trucking companies and their maintenance facilities. There is no "worker housing" at this time but there are two hotels in

TABLE 3.4
Sectors Represented in Burnside Industrial Park (UNEP 2001)

Accommodations	*Distribution*
Adhesives	Door and window manufacturing
Air conditioning	Electrical equipment
Automotive repair	Environmental services
Beverage products	Furniture manufacturing
Building materials	Food equipment
Business centers	Industrial equipment
Business firms	Steel fabrication
Carpeting and flooring	Machine shops
Chemicals processing	Medical equipment
Commercial cleaners	Paint recycling
Clothing manufacturers	Paper/Cardboard products
Communications equipment	Printing
Computer assembly and repair	Metal plating
Construction	Refrigeration
Containers and packaging	Transportation
Dairy products	Warehousing

the park and a third is being considered. Housing is an option that is under consideration for park expansion.

Businesses in the park must satisfy the federal, provincial, and municipal regulations that apply to them. These include requirements to prevent the discharge of pollutants that may be "hazardous to fish, restrictions of specified toxic chemicals such as PCBs and ozone depleting substances, and separation of solid wastes that can be composted or recycled for diversion from the landfill". These requirements are enforced through regulation or encouraged through fees such as tipping fees and sewer use fees. All of these requirements, whether regulation or economic instruments, along with the increasing environmental awareness of people in Canada, have created an atmosphere which is conducive to enhanced networking and the application of new environmental management strategies based in industrial ecology (UNEP).

All of the functions that were identified have been put into place. The Eco-Efficiency Centre is primarily an information clearinghouse and networking mechanism. According to UNEP:

> The Centre conducts environmental reviews and encourages companies to join an Eco-Business program adopting an environmental code or policy, setting objectives and targets and, competing for reduction or conservation awards. Recently, the Centre has begun testing the Efficient Entrepreneur calendar and assistant developed jointly by the Wuppertal Institute and UNEP-DTIE to encourage companies to track their performance.

Moreover UNEP stated that

> Both Dalhousie University and the Eco-Efficiency Centre act as educators in this endeavor. For the past seven years, we have written The Burnside Ecosystem column in the monthly park newspaper. The Centre prepares and publishes a series of fact sheets on various generic and sector specific topics which are distributed to businesses in the park. In addition, we have just concluded an agreement with the Metropolitan Chamber of Commerce which will result in the publication of 3 or 4 articles per year in their monthly magazine. Under the supervision of their professors, students undertake projects with companies in the park. For example, during the past five years, papers on the implications of environmental management systems with a gap analysis have been written and presented to 25 businesses in the park. The Centre encourages materials exchange and symbiotic relationships between companies and supports Clean Nova Scotia in the province-wide waste materials exchange. There is a possibility that the Centre will be taking this function over in the next few months. Finally, the project and the Centre encourage professors and students to collaborate with companies or sectors on applied research projects. One such study involves the integration of an environmental management system and the Natural Step into a furniture manufacturer owned by a multi-national corporation. Another project is a demonstration of an engineered wetland for the treatment of landfill leachate and runoff.

Analysis and comments

According to Mr Raymond Cote, the contact person in the park, what constitutes success in the park is as follows (Smart Growth 2000):

- Commitment from park owners;
- Flexibility in implementation of environmental regulations;
- Participation by capital owners;
- Appropriate economic instruments;
- Active information, education and interpretation; and
- A technical extension service.

With the following linkages:

- System Definition [Surveys and Database]; Industrial, social, brainpower inventories;
- Food Web [Materials Flow Database];
- Energy Conservation [Energy Audits];
- Resource Conservation [Waste Audits and Materials Exchange];
- Scavengers and Decomposers [Recyclers and Waste Managers];
- Information Exchange [Cleaner Production Centre Business Leaders Forum, Newspaper Column].

The park key features are:

- Six year multi-disciplinary, multi-institutional study of requirements;
- Cooperative partnership among academic, 3 levels of government, owners, developers and tenants;
- Phases/retrofitting and planning.

Burnside Eco-Industrial Park reflects an example of what an eco-industrial park should be like. The idea of having such parks requires a lot of study and analysis through university professors and students in cooperation with municipalities and owners.

The Bruce Energy Centre in Tiverton, Canada

Developing an eco-industrial park focused mainly around energy cascading is the objective of this case study (The Cardinal Group 2005). In this park, six companies are organized around Ontario Hydro's Bruce Nuclear Power Development (BNPD) to take advantage of its waste heat and steam generation capacity (steam serves as a potential source of heat energy for a broad range of industrial and agricultural processes such as dehydration, concentration, distillation, hydrolysis, and space heating). The main industries currently located in the park include:

- Bruce Tropical Produce Tomato: Which grows 2.3 million pounds of tomatoes each year in a hydroponic greenhouse; an amount equivalent to a 100 acre field. Steam from the BNPD is used to heat the greenhouse. The steam is transported in hot water coils and the condensate is then returned to the BNPD for reuse.
- Bruce Agra: Foods that process fruits and vegetables into concentrates, sauces, and purees. The food processing facilitators use steam energy from the BNPD to concentrate 84,000 gallons of raw products per day.
- Bruce Agra: Dehydrates locally grown crops to produce nutrient rich feeds for livestock and horses. The facility uses steam to run its dehydrators. This firm produces 90,000 tons of feed cubes per annum.
- Commercial Alcohols: The largest manufacturer and distributor of alcohol in Canada, and currently produces 23 million liters of industrial and fuel alcohol from 58,000 tons of locally grown corn. Steam from the BNPD is used in the distillation and ethanol processing of the alcohol.
- BI-AX International: A specialized company that manufactures a special polypropylene film for domestic and international markets. The polypropylene is heated in steam-driven ovens.
- St Lawrence Technologies: A research and development facility that specializes in finding ways to convert renewable resources to develop a wide range of products.

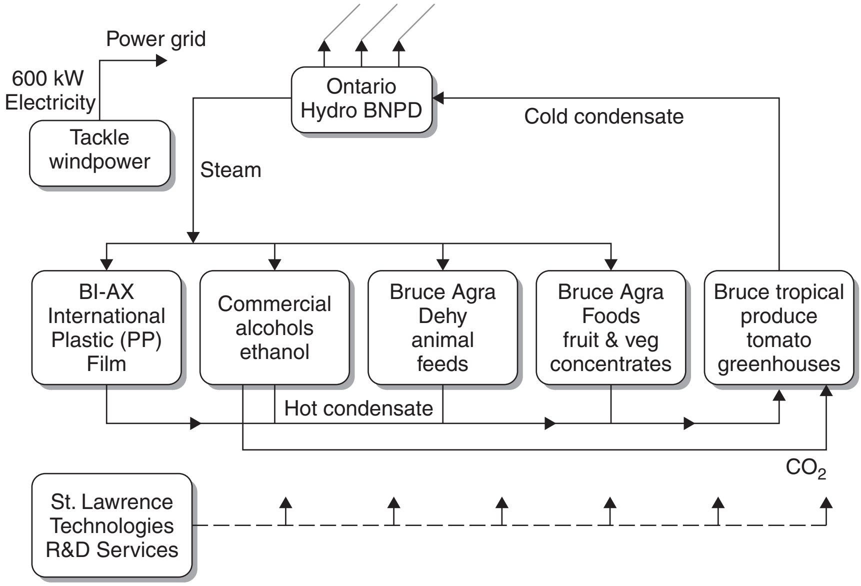

FIGURE 3.8 The Bruce energy linkages (Cardina Group)

The positioning of and interaction occurring between these industries enables the participants in the park to exchange recovered material so that byproducts of one firm serve as a raw material in another. Any residues generated at the Bruce Agra Foods facility, for example, are used either for animal feed or as an input for ethanol by Commercial Alcohols. Another established waste linkage in the park involves the use of carbon dioxide from the fermentation plant by Bruce Tropical Produce in their agricultural process. Figure 3.8 illustrates the types of linkages that exist between the firms in The Bruce Energy Centre. This project has been championed by Integrated Energy Development Corporation, a local industrial firm. It has resulted in substantial savings for the firms involved, an increase in local jobs, and environmental benefits.

Fairfield Ecological Industrial Park, USA

The Fairfield park is located to the Southeast of Baltimore, Maryland, USA. The park deals mainly with heavy Industries such as petroleum firms, chemical plants, trucking depots, asphalt manufacturing facilities, and others. During the last couple of years a lot of effort has been put in by the City of Baltimore, Baltimore Development Cooperation, and Cornwell University, for example, to come up with an outline for an efficient ecological industrial park (Smart Growth 2000).

The Fairfield mission statement is:

> The Fairfield Ecological Industrial Park is an interdependent, partnering, environmentally conscious business/residential district. This district encourages recycling of products and services, and is committed to empowerment through improved employment, profits, education, health, and quality of life. This district cycles resources with minimum export of waste products and maximum export of value added products.

The Fairfield EIP has over 1,300 heavy industrial zoned areas and about 60 operating companies located in the South Baltimore Empowerment Zone. Transportation of raw materials and waste streams will be facilitated by port and rail. All available resources and other newly initiated ones will be used to achieve a closed loop for the production process (Smart Growth 2000).

The current economy of Fairfield is based on carbon-based industries. The major facilities in the area include:

- Oil company marketing sites.
- Asphalt manufacturing and distribution facilities.
- Chemical plants.
- Homologation companies which customize automobiles for export and import.

Other companies were developed to connect primary facilities to Fairfield. For transportation trucks, rail, and ports are used. Environmental companies control tank trucks, storage tanks, and cleanup operations. For manufacturing and distribution tire treading, box making, and materials handling machinery exist. Table 3.5 provides percentages for the current economies in the Fairfield EIP.

The Fairfield EIP is trying to achieve the following:

- Expand cleaner production programs.
- Integrate innovative environmental technologies.
- Expand its business networks.
- Implement an extensive master plan and fiscal impact analyses.

TABLE 3.5
Percentages for the Current Economies in the Fairfield EIP

Industrial classification	*Percentage*
Carbon	77%
Metal manufacturers	10%
Inorganic products	4%
Services	9%

Achievements

- Making plans and getting funds for demolition and site preparation.
- A state sponsored cleaner production monitoring program.
- Implementation of a land swap and ordinance process.
- Construction of new rail and road.
- Reuse of some unused sites by building new buildings and industrial projects.

Main goals

- Fairfield Housing Project: The goal of this project is to reduce the amount of waste that comes from the demolition process of the buildings and especially lead that has hazardous effects as a waste material.
- Hazardous waste: Recycling of waste that will help in using it as potential raw material for different industries.
- To avoid paperwork and duplicated reports.
- Voluntary inspection and maintenance: To ensure operation is at highest levels of efficiency.

Expected results

- Higher rates of solid wastes and hazardous wastes recycling.
- Eliminate illegal dumps.
- Decrease air emissions.
- Improve the quality of the air.
- Improve contaminant of non-point source run-off.

Analysis and comments

Of course there is still a great deal to be done for the completion of the closed loop of the Fairfield EIP but it is still considered as one of the more successful emerging examples. Still new ideas and creativity are being developed to improve the current situation. "By using the creativity of businesses, the desires of local residents, the experience of employees, the knowledge of educators, and the regulatory flexibility, the EIP will become a model of economic and environmental performance" (EPA).

In a study (Heeres *et al.*, 2004) of three designed EIPs from USA and three from the Netherlands, the Dutch parks (INES, RiVu, Moerjdik) were found more successful than the ones in the USA (Fairfield, Brownsville, Cape Charles). The participation in the Dutch companies was more active than the US companies. The presence of an anchor person or champion was found to be very important for the success of an EIP. The champions in Netherlands were local Dutch entrepreneurs. EIP's projects were mainly led by companies receiving local and regional financial and advisory support.

In the US cases, the most crucial point against success was a lack of companies' interest in the project. The US EIPs were initiated by local government and the companies were not interested in the project. In Fairfield and Brownsville, the majority of companies did not want to invest in the project because they saw it as financially risky and because they did not trust the local government. In addition, politicians in those areas saw the project merely as a job creation opportunity, not as economically or environmentally beneficial.

Questions

1. Make a comparison between natural ecosystem and artificial ecology – "industrial ecology".
2. What is the difference between industrial ecology and an eco-industrial park?
3. Make a comparison between industrial ecology and cleaner production.
4. Discuss the top-down approach versus bottom-up approach for administering EIP. Which approach do you prefer for your community? Why?
5. The recycling economy legislation approach will improve the utilization of natural resources. How can you structure such an initiative in your country? What are the benefits of a recycling economy?
6. Develop a strategic framework to initiate EIP in your community.
7. How does EIP relate to a cradle-to-cradle approach? What are the necessary tools to implement a cradle-to-cradle concept in the nearest industrial estate?