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Eco-Industrial Parks: A Case Study and Analysis of Economic, Environmental, Technical, and Regulatory Issues

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Final Report

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Disclaimer

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Executive Summary

Despite a growing interest in and awareness of applications of industrial ecology (IE), such as eco-industrial parks (EIPs), little information is available about the potential economic and environmental benefits of EIPs, the process for successful EIP development, the important regulatory issues surrounding EIPs, or the technologies needed to support them.

This report contains the results of a body of research intended to investigate and support the development of EIPs—communities of companies modeled after industrial ecosystems. EIPs can exist within defined boundaries and broader industrial ecosystems in a region. These communities consciously collaborate to enhance their economic performance through improved environmental performance. Their design is based, in part, on an understanding of the dynamics of natural systems and includes features such as conversion of wastes into valuable inputs, cogeneration of energy, shared environmental infrastructure, and the minimization of material throughput.

E.1 INTRODUCTION

The purpose of this project is to expand on the information available about EIPs. As noted above, little information is available regarding EIPs. Thus, this project aims to

- demonstrate the potential economic and environmental benefits of an EIP through a case study in Brownsville, TX/Matamoros, Mexico;
- articulate a process for successful EIP development;

- examine the regulatory issues surrounding successful EIPs; and
- identify technologies that are important to the success of the EIP concept.

The project offers insights and tools for those parties developing broader industrial ecosystems or redeveloping existing industrial parks.

E.1.1 Background

An EIP is a community of manufacturing and service businesses seeking enhanced environmental and economic performance by collaborating in the management of environmental and resource issues. By working together, the community of businesses seeks a collective benefit that is greater than the sum of the individual benefits each company would realize if it optimized its individual performance only.

Some developers and communities have used the term EIP in a relatively loose fashion. We encourage applying this term to developments that are more than

- a single byproduct exchange pattern or network of exchanges;
- a recycling business cluster (e.g., resource recovery, recycling companies);
- a collection of environmental technology companies;
- a collection of companies making “green” products;
- an industrial park designed around a single environmental theme (i.e., a solar energy-driven park);
- a park with environmentally friendly infrastructure or construction; and
- a mixed use development (i.e., industrial, commercial, and residential).

An EIP may include any of these features. But the critical element in defining an EIP is the interactions among its member businesses and between them and their natural environment.

EIPs may provide benefits to the companies that participate, to the to the local community, and to the wider community. EIPs also pose some formidable challenges and significant risks.

E.1.2 Previous Research

Prior to commencing this study, the EIP was virtually unexplored. We were unsure whether and under what conditions the EIP concept could be applied with economic and environmental success. We had little information about the specialized technologies required to support EIPs; we did not know what the most appropriate role of government might be. Finally, since few EIPs had been developed purposefully, few people could describe an appropriate process for designing and developing EIPs.

E.1.3 Study Objectives and Research Approach

This project addressed four primary research questions:

R1: How do we determine the potential economic and environmental benefits that may be realized by applying the concepts of IE to current and planned U.S. and Mexican commercial and industrial developments, and what might these benefits be for a prototype EIP in Brownsville/Matamoros?

R2: What is the range of government's appropriate role (federal, state, and local) in facilitating the development and management of EIPs, and how might this role vary in alternative EIP venues?

R3: How do we identify the environmental technologies needed to fully apply IE principles and concepts, and which specific technologies will be needed for the prototype EIP in Brownsville/Matamoros?

R4: How applicable are the results of the Brownsville/Matamoros case study to other venues, particularly other border-area industrial parks?

> The companion to this document, *Fieldbook for the Development of Eco-Industrial Parks*, expands on the issues identified in this document by discussing each issue, providing potential solutions to problems, and illustrating how solutions have been implemented in other EIPs. It also guides the reader to other sources of information about each issue.

Our approach to answering these questions was to develop a case study of a potential EIP in Brownsville, TX, and Matamoros, Mexico and to write a "fieldbook" for planning, developing, and managing EIPs. We use the case study to uncover and illustrate important EIP issues related to each of the four research questions. The *Fieldbook* addresses the issues raised by the case study. It identifies the problems, discusses potential solutions, provides examples of how actual EIPs have handled each issue, and provides sources of information and other resources for addressing these issues. In doing so, it synthesizes all of the elements involved in developing and operating an EIP. The *Fieldbook* addresses each of the elements of the definition provided in Section 1.1.1.

We took a five-step approach to our EIP case study:

1. Develop methodology.
2. Build a prototype.
3. Define scenarios.
4. Collect data.
5. Calculate results.

Following the simulation of the economic and environmental impacts of the EIP, we take a closer look at research questions 2 and 3 by examining the regulatory issues involved in the case study and the technologies that are important to the EIP scenarios. We also examine the specific assumptions behind our analysis to assess the transportability of our results. Finally, we identify the challenges to EIP development that surfaced during our investigation.

E.2 EIP IMPACTS ON FIRMS AND COMMUNITIES

One of the most pertinent issues related to EIPs and other applications of IE is the size of the potential economic and environmental benefits. Although we can identify isolated and immature examples of the application of IE in an industrial park setting, very little has been written about the magnitude of benefits to expect from participation in an EIP, and a systematic framework for measuring these benefits does not exist.

We also need to understand the circumstances under which the potential benefits might be greatest. The magnitude of the benefits of forming an EIP is likely to vary greatly depending on the specific circumstances. Success of an EIP might depend on the industries involved, the location of the EIP, the economic profile of the region, the openness of local developers to a new development strategy, the local political and regulatory environment, and the willingness of the business community to work together.

E.2.1 EIP Stakeholders

EIPs might affect the companies that participate in them, the managers of EIPs, the members of the communities that host them, and the wider community.

EIP members are the building blocks of the EIP's economic and environmental systems. Each EIP member exchanges inputs (labor, capital, and materials) with other EIP members, members of the community, and suppliers and customers from outside the community. EIP members seek to maximize their profitability.

The EIP management unit adds value to the production and service functions of EIP members by performing the roles that in some way support improvements in the EIP's efficiency.

The EIP's community is the local social, environmental, and economic system in which the EIP resides. The local community, which includes community government, households, and community businesses that are not members of the EIP, is the area in which the EIP has the greatest economic, environmental, and sociological impact.

E.2.2 Sources of EIP Benefits and Risks

Each of the stakeholders identified above can potentially benefit from the EIP as an alternative form of business organization. However, the EIP also poses risks.

Membership in an EIP can potentially bring economic benefits to companies by improving their efficiency, reducing their infrastructure requirements, providing access to better information about their customers and suppliers, and reducing their costs for regulatory compliance. However, the EIP may also require that each member form relationships with other EIP members that might bring greater risk than traditional customer/supplier relationships. Furthermore, because the EIP is an emerging form of organization, members face regulatory and technological uncertainties that pose additional risk.

Perhaps the most significant challenge to EIP development is designing it with the flexibility required for longevity.

EIPs have the potential to bring economic and environmental benefits to the communities in which they locate. The EIP can provide a basis for industrial recruitment, diversify the industrial base, encourage the development of new industries, and improve the competitiveness of existing companies. The EIP can also reduce the environmental burden of existing industrial activities and mitigate the environmental impact of new firms. However, communities face a number of challenges in developing and supporting an EIP. Finding a source of development funding, determining what organization should manage the EIP, attracting a viable combination of companies, and gaining the cooperation of regulatory agencies all pose significant challenges to making EIPs viable and successful. Perhaps the most significant challenge to EIP development is designing it with the flexibility required for longevity.

E.2.3 Quantifying Impacts

The economic benefits to EIP members can be measured in terms of several indicators of profitability and investment return:

- change in annual profit
- change in the cost of production per unit
- change in productivity
- return on investment (ROI)
- payback period

Economic benefits to communities can be measured in terms of the EIP's contribution to

- value added by manufacture;
- total number of production workers;
- total production worker wages;
- average wage;
- tax revenues; and
- public expenditures for sewerage and sanitation, as a percentage of value added or tax revenues.

These statistics can be compared for the EIP and for other types of development.

The EIP cannot be considered successful unless it fully complies with all applicable environmental regulations. Beyond compliance, the environmental impact of the EIP can be determined by examining the resource use and emissions of groups of companies in a with-EIP versus without-EIP scenario. A weighting scheme could be used, if necessary, to place all discharges on a risk-based metric and to convert quantities of resource use to a single metric of resource efficiency. Other weighting schemes can be developed that account for a community's special environmental concerns. Other environmental factors, such as the EIP's impact on community aesthetics and wildlife habitat, can also be considered.

Our approach to simulating the economic and environmental impacts of the EIP is to compare the without-EIP scenario (baseline) to each of the with-EIP scenarios. We examine the impact of each scenario on the profitability, resource use, and solid waste of the EIP companies as a group.

E.3 A PROTOTYPE EIP FOR BROWNSVILLE, TX/MATAMOROS, MEXICO

The prototype EIP for Brownsville/Matamoros comprises a group of EIP member relationships that we think are feasible for the area, given the community's resources, the existing economic structure, and the available technology. We focus on the Brownsville/Matamoros area to take advantage of the richness of the issues that might be explored there, including border issues, environmental challenges to economic development, the importance of the support of a local champion, and the influence of incoming industry.

E.3.1 Building the Prototype EIP

To develop the prototype EIP and the EIP scenarios, we used information we collected from many companies operating in the area, as well as one company that operates in another location, but which we believe would fit well with the economic and environmental conditions of the proposed EIP.

Choosing a Site

Some of the relationships among these companies and their potential economic and environmental impacts depend on details specific to a site. After considering several potential sites, we chose to assume that the prototype EIP is centered at the Port of Brownsville (Port).[1] The Port provides excellent infrastructure and access to industry, and several of the anchor members of the prototype EIP are currently located at the Port.

[1] A brief description of the Port of Brownsville is provided in Appendix B.

Choosing the Members of the Prototype EIP

> To choose members for our prototype EIP, we looked for companies that presented opportunities for symbiotic linkages with other companies in the area and were willing to participate in the exercise. The *Fieldbook for the Development of Eco-Industrial Parks* describes a procedure for analyzing potential byproduct exchanges among EIP members.

With the help of the Brownsville Economic Development Council we identified a subset of the businesses in Brownsville and Matamoros as potential candidates for the prototype EIP. We screened these companies and identified companies that were willing to participate and provided opportunities for symbiotic links with other companies. Then we visited the companies to collect information about the inputs and outputs of each company, the potential for using recycled material where virgin material is currently used, and the potential for marketing byproducts that the company currently processes as waste. We summarized these site visits and prepared a chart detailing the inputs and outputs of each company. From this chart, we identified several opportunities for symbiotic byproduct exchange. The prototype EIP contains 12 members.

EIP Port Members

1. Refinery—The refinery produces three products: naphtha, diesel, and residual oil.
2. 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.
3. 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.[2]
4. 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.

Remote Partners

5. Discrete parts manufacturer—This company produces plastic and metal parts using screw machines, automated roll feed punch presses, and injection molding.
6. Textile plant—This company assembles garments.
7. Auto parts manufacturer—This company uses plastic injection molding, metal stamping, and powdered metal forming to make small parts for assembly at a maquiladora facility.

[2] Currently, the asphalt plant actually imports its oil from outside the community. When the refinery is operating, it will use residual oil from the refinery. We assume this at baseline.

8. Plastic recycler—This recycler accepts 12 types of plastic, grinds it, and sells the grind overseas. The company also manufactures plastic pellets from scrap.
9. Seafood processor and cold storage warehouse—This company processes seafood and acts as a cold storage warehouse.
10. Chemical plant—This plant manufactures anhydrous hydrogen fluoride. The major byproduct is $CaSO_4$ (gypsum).
11. Manufacturer of magnetic ballasts—This company produces electronic and magnetic ballasts.
12. Gypsum wallboard company—This EIP member, located in Houston, is the only member not located in the Brownsville/Matamoros area.

E.3.2 EIP Scenarios

Although many other potential analysis scenarios are probably possible, we investigated five EIP scenarios (see Figure E-1) described below because they appeared to have the greatest potential for economic and environmental benefits.

Figure E-1. Five Scenarios for the Prototype EIP Analysis
The five EIP scenarios build on each other as new symbiotic relationships are added in each step.

Scenario 1 *Baseline*	Baseline EIP members and production activities.
Scenario 2 *Pollution Prevention*	Members implement noncooperative pollution prevention activities.
Scenario 3 *Pollution Prevention plus Industrial Symbiosis*	EIP members develop symbiotic relationships with other EIP members and remote partners.
Scenario 4 *New EIP Members*	New symbiotic relationships develop as a result of new EIP members.
Scenario 5 *Collocation and Joint Services*	Remote partners locate within the EIP. EIP provides environmental services.

Scenario 1: Baseline Production and Trade Activities

Figure E-2 provides a graphical representation of the baseline scenario.[3] At baseline, very few symbiotic relationships exist between these companies:

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

Scenario 2: Pollution Prevention

This scenario describes some pollution prevention (P2) and recycling opportunities that can provide economic and environmental benefits to the companies acting independently of other EIP members. We qualitatively analyze the following opportunities, which are relevant comparisons for later scenarios:

- ➤ The discrete parts manufacturer introduces an aqueous cleaning system and an oil–water separation system.
- ➤ The textiles company recycles cutting room clippings.
- ➤ The automobile parts manufacturer purchases a ringer system for absorbent socks and rags.
- ➤ The seafood processor uses brownwater for noncritical cleaning processes.

Scenario 3: Industrial Symbiosis

The first development stage of the EIP is fairly limited (Figure E-3).

- ➤ The discrete parts manufacturer sells scrap plastic, which is currently landfilled, to the recycler. He also purchases plastic pellets, which he currently purchases from a more distant source, from the plastic recycler. 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.

[3]Each of these descriptions is based on the operations of companies in the Brownsville/Matamoros area. However, we have also made assumptions about operation data where the actual data were not available.

Figure E-2. Scenario 1: Baseline Activities
These companies form the baseline scenario for the Brownsville/Matamoros EIP.

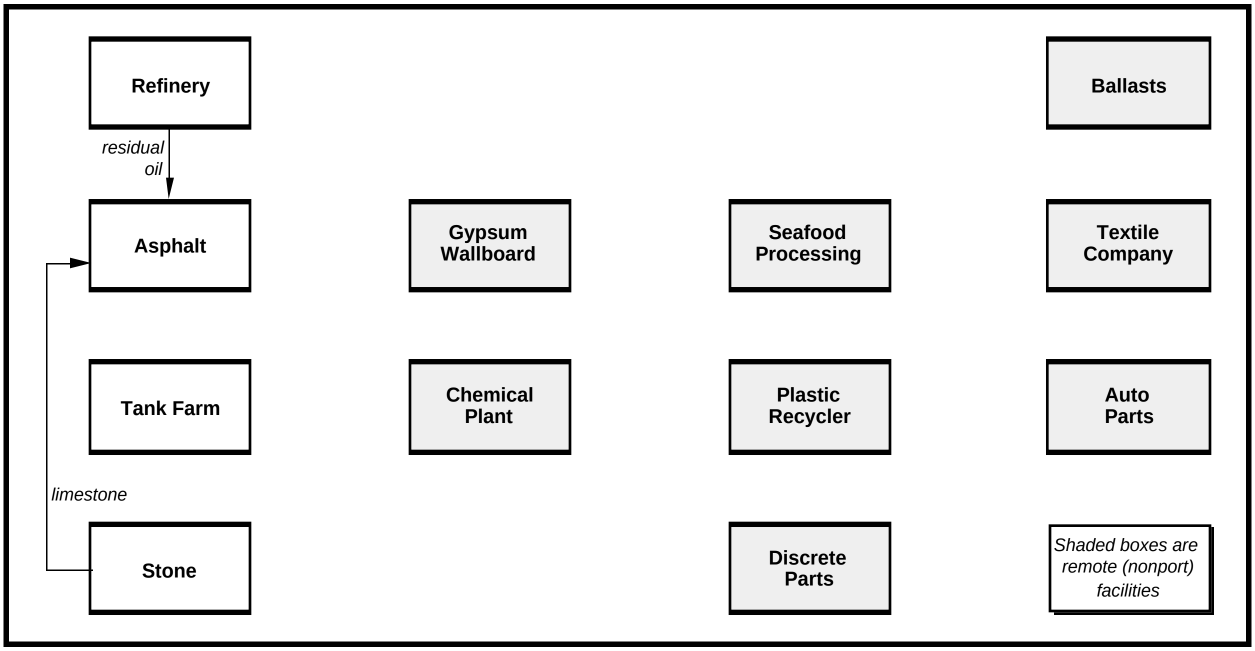
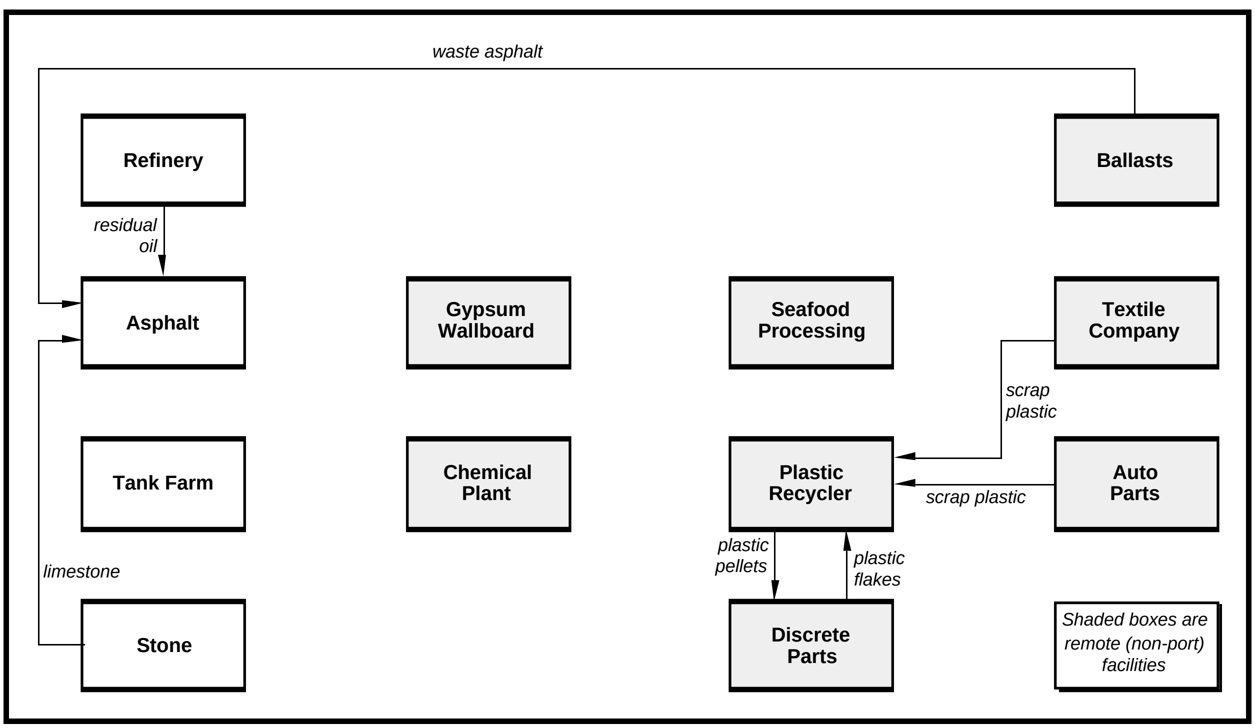


Figure E-3. Scenario 3: Industrial Symbiosis
The exchange of scrap plastic and waste asphalt among noncollocated companies characterizes this scenario.



Scenario 4: New EIP Members

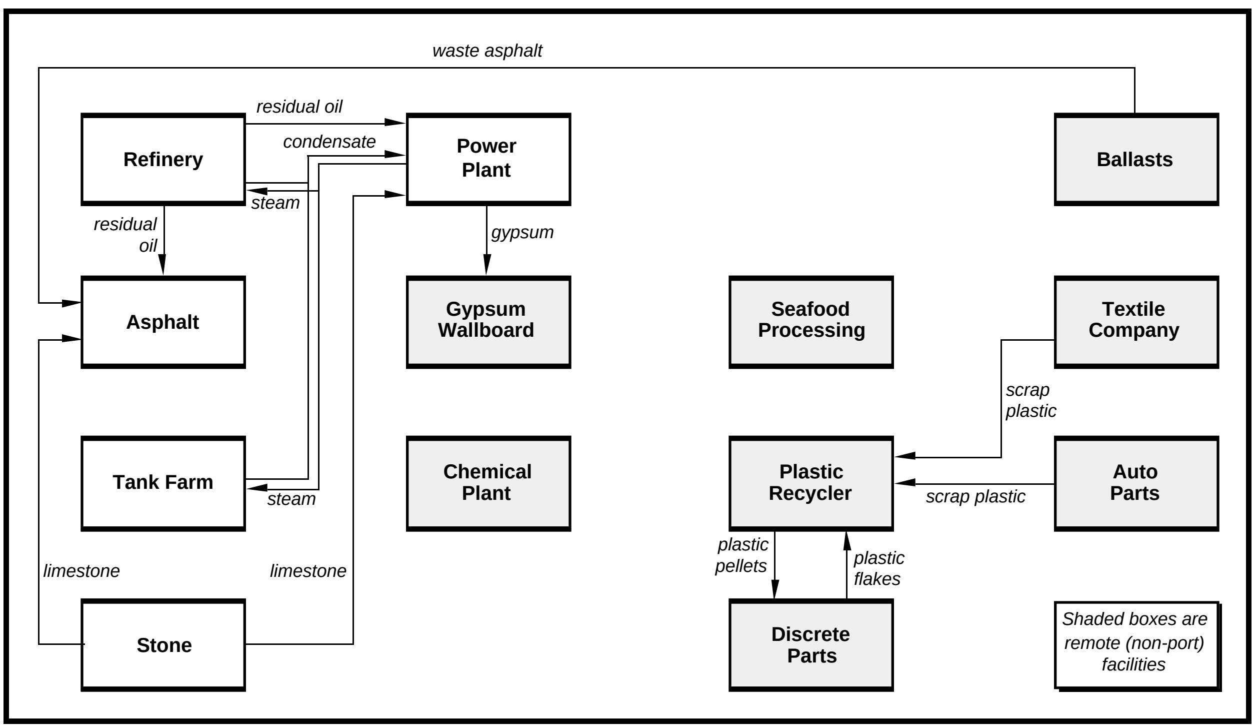
In this stage, we examine the environmental and economic benefits of creating new businesses within the EIP (Figure E-4). The new members include the following:

- a power plant burning *Orimulsion*™, a heavy bitumen emulsified with water equipped with a steam pipeline to distribute process steam to other EIP members and
- 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 E-4. Scenario 4: New EIP Members
A power plant and a remote gypsum wallboard company are added to the EIP.



Scenario 5: Pollution Prevention, Industrial Symbiosis, and Collocation; Joint EIP Services

In this stage, we assume that the remote partners are collocated with the remainder of the EIP members. We *do not* analyze their decision to move into the park from their current location; we only show the additional benefits that could be derived from collocation. We also analyze 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 takes place with lower transportation costs.
- The water pretreatment plant provides clean water to the power plant.
- The solvent and waste oil recyclers are used by several EIP members.

Figure E-5 also shows the seafood processor providing brownwater to the textile company. In our prototype, this brownwater is used to provide a rooftop sprinkling system to cool the textile company. Although we do not quantify the benefits of this relationship in Chapter 4, we include it in Figure E-5 because it demonstrates one important method for conserving water—water cascading, which we discuss in Chapter 6.

E.4 RESULTS OF THE EIP PROTOTYPE SIMULATION

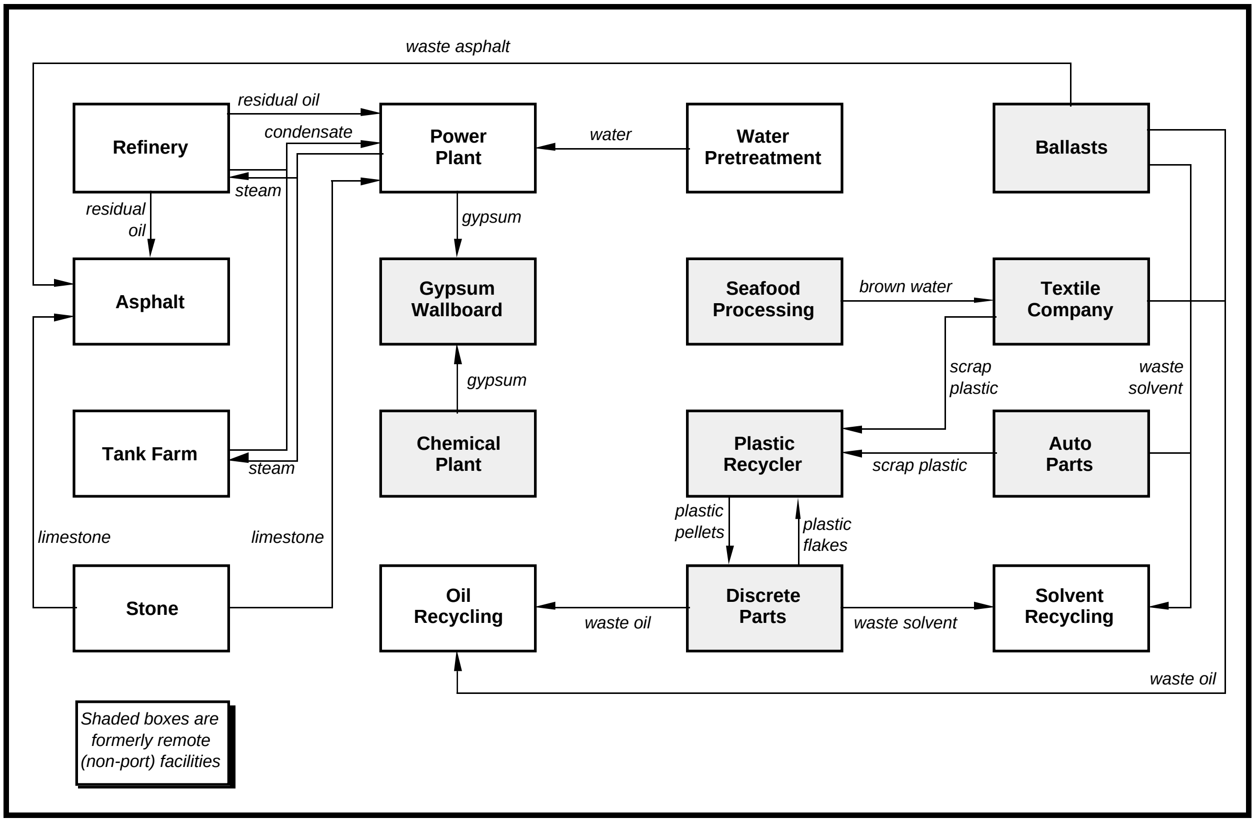
In this section, we review the results of our economic and environmental analysis of each EIP scenario.

E.4.1 Analysis Approach

The analysis procedures and spreadsheet model used to simulate changes in economic and environmental performance can provide three basic types of information for each EIP scenario:

- net changes in their materials flows
- changes in their net annual revenues
- their incremental annualized fixed costs

Figure E-5. Collocation and EIP Services
All previously remote facilities are assumed to be located at the Port and solvent and oil recycling facilities serve the EIP.



From this information, we calculated changes in annual profit, ROI, and payback periods. These measures refer exclusively to the profitability of the EIP relationships we describe, rather than to the overall profitability of an EIP member, which would require complete knowledge of each company's baseline operations and finances. Net changes in materials flows represent the expected environmental impact of each EIP scenario.

Data Sources

The facilities described in this case study are model plants that are based on information obtained from representatives of the companies operating similar plants in the Brownsville/Matamoros area. We call this analysis a simulation, rather than an estimate, because, although we used actual engineering and economic data wherever possible, we encountered difficulty obtaining the level of detail and accuracy necessary for credible estimates of the impact of the simulated symbioses.

Net Benefit, Payback Period, and ROI

In our case study, we refer to the net benefit, rather than the annual change in profit, of a symbiosis. This is the combined annual change in revenue for all EIP companies minus the combined annualized investment and O&M costs required to facilitate the symbiosis. Although this is basically the same as profit for all companies combined, we do not know how these benefits will be distributed among the EIP members; thus we refrain from calling these benefits profits.

The net benefit of an EIP relationship is the change in annual net revenue minus the annualized investment required to move from baseline to each EIP scenario. Because we cannot realistically predict how these changes in net revenue would be distributed among the companies, we compare the combined annual change in revenue for all EIP companies to the combined annualized investment and operation and maintenance (O&M) costs required to facilitate each new level of symbiosis. We call this the net benefit of the symbiosis, because it is not really appropriate to speak of profit when discussing the joint benefits of the EIP.

We calculated an ROI for each relationship. ROI is

$$\sum_{i=0}^{n} \frac{\Delta\pi_{t+1}}{(1+r)^{i}} = 0$$

where $\Delta\pi_{t+i}$ is the net benefit (benefit minus cost) of the investment; t is the amount of time over which the investment provides benefits (or costs), and solving for r provides the ROI. We calculated the payback period for each scenario as the total investment divided by annual net revenue.

E.4.2 Simulation of Economic and Environmental Benefits

Table E-1 summarizes the results of the quantitative analysis of the EIP, comparing a number of economic and environmental indicators from the baseline.

The benefits of an EIP expand as companies take on greater investment, greater risk, and a greater level of cooperation among each other.

Our case study demonstrates that the benefits of an EIP expand as companies take on greater investment, greater risk, and a greater level of cooperation. In Scenario 2, we described some efficiencies that companies capture on their own by engaging in waste reduction activities. In many cases, they gain concrete economic and environmental benefits with little investment and little risk. These opportunities require no cooperation or dependence on other companies.

In Scenario 3, we demonstrated that the opportunities to improve economic and environmental performance expand when companies are informed about how they might work together to improve the "industrial ecosystem" in their community. For this scenario, the economic benefits were small, but the risk and investment required

Table E-1. Summary of Simulation of EIP Benefits Over Baseline
The economic and environmental benefits of the EIP grow as the symbiosis expands to include more partners and as those partners locate closer to each other.

Indicator	Scenario 3	Scenario 4	Scenario 5
Net annual economic benefit	$107,384	$4,658,786	$8,180,869
ROI	359%[a]	38%	59%
Payback period (years)	0.28	2.64	1.69
Reduction in landfill waste			
Plastic (lbs)	131,227	131,227	131,227
Asphalt (lbs)	730,831	730,831	730,831
Gypsum (tons)		121,545	121,545
Change in resource use			
Orimulsion (bbls)		163,142	163,142
Residual oil (bbls)		-273,750	-273,750
Water (gals)		15,768,000	15,768,000

[a]This reflects only changes in net revenue from asphalt, since the plastics exchange required no investment.

were also small, since the relationships between the companies involved operations that were peripheral to their main production activities.

In Scenario 4, we found that a single new member of an industrial ecosystem can have an important impact on the opportunities available to the EIP. We also saw the dramatic increase in potential EIP benefits derived from increasing dependence of the EIP members on each other. These increased benefits were accompanied by increases in investment and risk.

In Scenario 5, we demonstrated that collocation of EIP members can increase the opportunities and benefits of an industrial symbiosis. Although many profitable opportunities for symbiosis do not require collocation, these benefits can expand if EIP members locate in a single physical location, under a single management structure that includes shared infrastructure, regulatory structure, and joint services. This implies, of course, an even greater level of dependence of companies on each other and on the EIP management.

E.4.3 Lessons and Limitations of the Case Study Analysis

Our case study was based on a number of assumptions and much conjecture. However, it served to demonstrate some important points about the elements required for a successful EIP:

1. The first and most essential input to the EIP is information about members' operations.
2. The success of the EIP requires that members are open to depending on each other.
3. To achieve the greatest economic benefits, the EIP will require substantial investment in infrastructure.
4. 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. Retrofitting existing plants, while possible, decreases the economic benefits.

Our analysis was limited in several ways. First, within the scenarios we examined, we did not consider the influence of the changes in operations on several important factors that may affect the EIP's economic and environmental impact:

- the risk to companies of investing in symbiotic relationships with suppliers and customers
- the risk to companies that they may be liable for the environmental impacts of other EIP members' operations
- the implications of the operations changes depicted by the scenarios for the regulatory costs faced by each EIP member

The second way in which our analysis was limited was that we did not examine whether the EIP member would rather locate at the EIP than at alternative locations. That is, we assumed that everything else about the baseline scenarios and the with-EIP scenarios was the same except for the byproduct exchanges. This would certainly not be true if a company was trying to decide whether becoming a member of an EIP would be more profitable than some alternatives.

The third way in which our analysis was limited was the exclusion of aspects of the EIP aside from the symbiotic relationships between companies, shared infrastructure, and shared EIP services. EIPs may differ from traditional industrial parks in other ways that affect the magnitude of the environmental and economic benefits.

Finally, we did not consider the costs of managing the EIP.

E.5 REGULATORY ISSUES AND APPROACHES FOR ENCOURAGING EIP DEVELOPMENT

The second research question we addressed with this project was, "What is the range of government's appropriate role in facilitating the development and management of EIPs, and how might this role vary in alternative EIP venues?" We address this question in Chapter 5 by describing how environmental regulations affect EIPs.

E.5.1 Regulatory Issues Surrounding EIP Development

Environmental regulations often create disincentives for industry to develop and implement P2 programs or to exchange potentially useful byproduct materials for other applications. Several regulatory issues are particularly germane to companies trying to participate in an EIP.

- **Definition of waste:** The lack of distinction between solid and hazardous wastes and secondary materials in the language of Resource Conservation and Recovery Act (RCRA) leaves little room for generators to reuse, recycle, or reclaim the waste to recover any beneficial constituent or use any property of the waste.
- **Definition of source:** The term "source" can apply to an entire industrial facility or to each point at which emissions are released. However, it is most appropriate to view the EIP as a single source for some pollutants, because the sum of discharges from each company may be greater than the net discharges of the EIP. Furthermore, the current definition of source poses a significant administrative burden on many industrial facilities.
- **Liability:** Two liability concerns are
  - ✓ the use of potentially hazardous secondary materials in other applications subject to liability under RCRA's "derived from" rule and
  - ✓ the liability of separate companies when regulated with other members of industrial parks or regions under single regulatory umbrellas.
- **Single-medium permitting:** A multimedia approach to regulation will be necessary to encourage EIP members to take a systemic view at reducing their wastes, rather than to shifting waste from one form (and medium) to another, without significantly reducing the totals.
- **Brownfield versus greenfield issues:** To prevent EIP development from encroaching on green spaces, a company needs incentives such as those included in EPA's (1995) *Brownfields Action Agenda* will contribute to clarifying.
- **U.S–Mexico border issues:** Regulation of EIPs along the border will be complicated by different sets (U.S., Mexico, and bilateral) of environmental regulations. Some progress has been made toward establishing binational "border-area" permits that cover facilities located in border areas with both

U.S.' and Mexico's environmental protection laws under a single piece of legislation.

E.5.2 Prototype EIP Regulatory Case Study

The Brownsville/Matamoros prototype EIP scenarios provide a backdrop for analyzing regulatory issues surrounding each scenario and possible regulatory approaches for encouraging EIP development. Because we did not consider changes in regulatory requirements in our case study analysis, we felt it was important to provide some idea of the regulatory considerations and costs that might face the companies in the prototype EIP. We provide highlights of this analysis for each scenario.

- **Scenario 1:** The petroleum refinery and possibly the asphalt company must apply for a new source review permit, permit variance, or flexible permit to comply with 40CRF262 (standards for generators of hazardous waste) and 40CFR279 (used oil management standards).
- **Scenario 2:** The discrete parts manufacturer and the automobile parts manufacturer must obtain a new source review permit, permit variance, or flexible permit.
- **Scenario 3:** The auto parts manufacturer, because it is a maquiladora firm, may be required to report to its governing body that the scrap is being shipped to another U.S. site. The ballast manufacturer may need to modify its RCRA permit to comply with 40CFR262 (standards for generators of hazardous waste) and 40CFR268 (land disposal regulations).
- **Scenario 4:** The power plant may need a new source review permit for generating steam.
- **Scenario 5:** All companies using the solvent recycler or the oil recycler would be required to submit an application for variance or flexibility to 40CFR262 (standards for generators of hazardous wastes), 40CFR264-265 (tanks and containers), and/or 40CFR279 (used oil management standards). The recycler would be required to obtain new source permits for all major federal and state statutes.

The re-permitting process or application for a permit variance would cost the manufacturer from $450 to $75,000, depending on the type of permit sought and details of the proposed modification.

E.5.3 Regulatory Strategies for Supporting EIP Development

The challenge over the coming years will be to balance the tradeoffs between regulatory strategies that meet aggressive environmental goals and those that allow and encourage innovative approaches, such as EIP development, to meet those goals. Generic regulatory strategies for encouraging P2 and IE in the context of EIP development include the following:

- modifying existing regulations
- streamlining existing permitting and reporting processes
- moving from technology-based to performance-based regulations
- promoting facilitywide permitting
- promoting multimedia permitting
- market-based approaches
- voluntary agreements
- manufacturer "take-back" regulations
- technology transfer
- opportunities for technology development and commercialization
- IE technology development grants

E.5.4 Current Regulatory Initiatives Encouraging EIP Development

Recognition of the benefits of P2 and IE already is driving some regulatory initiatives to promote not only source reduction but also the reuse and recycling of waste and secondary materials. These current regulatory initiatives include the following:

- EPA's P2 Policy Statement, which eliminated some of the confusion surrounding the terms P2, waste reduction, waste minimization, and recycling and established a hierarchy of waste management by placing P2 (source reduction and environmentally sound recycling) above waste treatment, control, and disposal
- EPA's Solid Waste Task Force, which is revising the rules governing hazardous waste recycling in an effort to give industry more flexibility for recycling
- EPA's Permits Improvement Team, which is working in the following areas:
  - ✓ alternatives to individual permits
  - ✓ administrative streamlining
  - ✓ enhanced public participation
  - ✓ P2 incentives

- ✓ training
- ✓ performance measures

➤ Brownfields Economic Redevelopment Initiative, which is establishing pilot sites; clarifying liability and cleanup issues; building partnerships with states, clients and community representatives; and fostering job development and training

➤ Technology Transfer Initiatives to advance environmental technology development and transfer

E.5.5 Regulatory Policy Recommendations

One of government's roles in supporting EIP development is to increase the flexibility of the regulatory structure so that it functions to encourage greater innovation. Changing the regulatory structure to more flexible, more resilient, systemic solutions will require environmental regulations that are less focused on single-medium and single-source controls. This type of flexibility will allow EIPs to respond to environmental issues of greatest concern in their communities.

Optimal regulatory solutions for future EIP developments will require the following:

➤ clearly defining regulatory problems associated with EIPs to reduce the uncertainty of potential EIP members

➤ allowing industry maximum flexibility consistent with solving environmental problems

➤ encouraging open communication and cooperation among key stakeholders

➤ encouraging a systems approach to regulation

E.6 TECHNOLOGIES SUPPORTING EIPS

The appropriate technologies can improve the sustainability of the EIP. Although we cannot identify specific technologies that are important to all EIPs, we can provide a framework for identifying them. Clearly, the technologies contributing to the success of each EIP are specific to the EIP's particular industrial activities, the characteristics of the industrial symbiosis, the geophysical characteristics of the location, the available resources, and many other factors.

E.6.1 Technological Challenges for EIPs

Technology's role in the EIP is to help communities, EIP members, regulators, designers, and managers solve potential problems and meet challenges. Technologies can help an EIP meet challenges in the following ways:

- **Improving the EIP's economic efficiency.** Technology can improve the economic efficiency of EIPs by helping members reduce transaction costs and take advantage of economies of scale and scope.
- **Improving the technical and cultural feasibility of symbiotic relationships.** Technologies can lead to symbioses compatible with existing production systems and the skills of existing workers and managers.
- **Reducing risk and improving flexibility for the symbiosis.** Technologies that improve process flexibility will reduce the risk that a member of the industrial symbiosis cannot purchase or supply a material in the required quantities or of the required quality.
- **Reducing the environmental burden of the production and consumption of EIP goods and service.** Many, but not all, of the technologies that take advantage of economic efficiencies will also provide environmental benefits to the EIP.
- **Reducing the costs of regulatory compliance.** Any technology that reduces the cost of reducing air emissions, water discharges, hazardous wastes, and solid waste will reduce the cost of complying with the associated regulations. Other technologies are more specific to meeting the demands of the regulatory process.

E.6.2 Technologies Meeting EIP Challenges

Because each EIP will have a unique set of companies and symbiotic relationships, identifying a list of technologies that might be important to its sustainability is difficult. However, certain categories of technologies help capture the efficiencies available to an EIP and meet the technical, cultural, and environmental criteria discussed above:

- transportation technologies
- recovery, recycling, reuse, and substitution technologies
- environmental monitoring technologies
- information technologies
- energy and energy-efficient technologies
- water treatment and cascading technologies

E.6.3 Technological Challenges in the Brownsville/Matamoros Case Study

Some technologies of interest to the Brownsville/ Matamoros EIP are

- *plastics separation,*
- *solvent recycling and recovery,*
- *recovery of byproducts,*
- *cogeneration, and*
- *water treatment and cascading.*

The Brownsville/Matamoros case study examined applications of some of the technology types listed in Section E.6.2. Our report provides details about the following technologies:

- **Recovery, Recycling, Reuse, and Substitution:** The case study explored the feasibility of several types of plastics separation in Scenario 3, reuse of synthetic gypsum that is a byproduct of power plants and chemical manufacturers in Scenario 4, and solvent recycling and recovery in Scenario 5.
- **Energy Technologies—Cogeneration:** Scenario 4 of our EIP case study included a simulation of a cogeneration relationship between a power plant and other members of the EIP.
- **Water Treatment and Cascading:** Scenario 5 of the EIP case study included a discussion of an exchange of brownwater between the seafood processing plant, which produced it as a byproduct of seafood processing, and the textile company, which could use it to cools its roof. We also investigated the feasibility of applying several types of water treatment and cascading schemes in the prototype EIP in Brownsville/Matamoros. Joint treatment of segregated waste streams allows companies to achieve economies of scale not possible if they operated independent wastewater treatment plants.

E.7 SUMMARY AND CONCLUSIONS

In this section, we address the final research question, "How applicable are the results of the Brownsville/Matamoros case study to other venues, particularly other border-area industrial parks?" First, we note the assumptions and conditions that were specific to our case study and scenarios and explain how our results might be more or less applicable in other circumstances. Second, we summarize the challenges to EIP development that we identified while building the EIP prototype, developing the simulations, calculating the case study results, exploring regulatory roles, and investigating the potential impact of technology.

The transportability of the results of the EIP case study depends on the ability of communities, EIP members, regulators, EIP designers and engineers, and EIP managers to meet these challenges. The EIP *Fieldbook* (Lowe et al., 1996) further investigates these challenges, provides potential solutions, and examples of cases in which the solutions have been successful.

E.7.1 Transferring Results to Other EIPs

Our case study and the analysis of regulatory and technological changes needed to support an EIP were driven to a certain extent by the specific conditions found in Brownsville/Matamoros. Not all potential EIPs will have these same elements.

Our scenarios were motivated largely by a cogeneration situation. In Brownsville, we found a situation in which the community's power needs suggested a new power plant with cogeneration. However, cogeneration is not profitable in all cases and therefore may not be appropriate for all EIPs.

However, usually an anchor tenant provides rich opportunities for converting byproducts into useful intermediate goods. In Brownsville/Matamoros, the anchor tenants are an oil refinery and a power plant. In other cases, it could be a chemical plant, a large food processor, or some other company that produces byproducts that have a low ratio of value to weight. This low ratio implies that, to be valuable, these byproducts must be processed nearby to decrease transportation costs.

Other issues that are likely to affect the success of an EIP are the following:

- resource scarcity
- community industrial structure
- industry dynamics
- environmental considerations

Our simulation of the potential economic and environmental effects of an EIP has demonstrated that success is possible under the right conditions. Ultimately, the success of an EIP depends on the specific local context for EIP development. However, communities can apply an analysis framework similar to the one we developed in this report to assess their chances for success. Communities also must consider whether they can meet the considerable challenges to EIP development.

E.7.2 EIP Challenges

Developing a successful EIP presents challenges to each of the EIP stakeholders.

Challenges to community organizations and local government include the following:

- building local support
- setting EIP performance objectives
- sharing ownership, development, and costs
- developing EIP financing strategies
- recruiting industry
- reducing administrative red tape

Potential EIP members face the following challenges:

- estimating EIP benefits and costs
- determining the right mix of partners
- finding appropriate technologies
- reducing regulatory uncertainty and liability
- marketing EIP membership to customers

Local, state, and federal regulatory agencies are challenged to

- streamline zoning, permitting, and other development regulations;
- add flexibility to environmental regulations;
- develop appropriate technology, promote technology transfer, and provide technical training; and
- encourage the exchange of information among EIPs.

Those who develop, design, and build EIPs are challenged to improve the success of the EIP by

- choosing a site that will maximize the economic and environmental benefits of an EIP,
- designing park infrastructure that incorporates the needs of the EIP members for specialized services,
- designing industrial facilities that build in the flexibility that allows the EIP to grow and evolve,
- designing buildings that maximize the efficiency of energy and materials, and
- using construction practices that are consistent with the EIP vision.

The challenges to EIP managers include the following:

- managing the design and development process
- maintaining relationships between companies
- managing EIP property and shared support services
- ensuring the future viability of the EIP

1 Introduction

Although interest in and awareness of industrial ecology applications are growing, little information is available about the potential economic and environmental benefits, the process for successful eco-industrial park (EIP) development, the important regulatory issues surrounding EIPs, or the technologies needed to support them.

Traditionally, business, the economy, and the environment have been viewed as separate systems, operating independent of—and sometimes in opposition to—one another. However, awareness of the actual interdependence between these systems is increasing, highlighting the need for a business framework that protects the natural environment while improving business performance. A new approach—industrial ecology (IE)—is evolving to unite the requirements of industrial and natural systems. Just as ecology studies the interrelations between organisms and their environment, IE studies the relationships among members of an industrial system and the relationships between industrial and natural systems. A major premise of IE is that industrial systems can achieve higher efficiencies and lower pollution by better exhibiting the circular flows of materials and energy demonstrated by natural ecosystems.

This report contains the results of a body of research intended to investigate and support the development of communities of companies modeled after industrial ecosystems. Such communities include eco-industrial parks (EIPs) within defined boundaries and broader industrial ecosystems in a region. These communities consciously collaborate to enhance their economic performance through improved environmental performance. Their design is based, in part, on an understanding of the dynamics of natural systems and includes features such as conversion of wastes into valuable inputs, cogeneration of energy, shared environmental infrastructure, and the minimization of material throughput.

The purpose of this project is to expand on the information available about EIPs. Although isolated and emerging examples of the applications of the EIP concept exist, little information is available regarding EIPs' potential economic and environmental benefits. Finding information about the process by which successful EIPs are developed, the regulatory issues surrounding them, or the technologies needed to support them is also difficult. Thus, this project aims to

- demonstrate the potential economic and environmental benefits of an EIP through a case study in Brownsville, Texas/Matamoros, Mexico;
- articulate a process for successful EIP development;
- examine the regulatory issues surrounding successful EIPs; and
- identify technologies that are important to the success of the EIP concept.

The project offers insights and tools for those parties developing broader industrial ecosystems or redeveloping existing industrial parks.

This introduction provides a brief overview of the background for this project, previous research in the field, and the questions explored in this project. A companion document, *Fieldbook for the Development of Eco-Industrial Parks* (Lowe, Moran, and Holmes, 1996), was also produced for this project. The *Fieldbook* shows how tools and concepts from many fields are integrated into the design, construction, and management of EIPs.

1.1 BACKGROUND

Before discussing the research issues and methodology employed in this project, we define EIPs and summarize their potential benefits.

1.1.1 Definition of EIP

An EIP is a community of manufacturing and service businesses seeking enhanced environmental and economic performance through collaborating in the management of environmental and resource issues. By working together, the community of businesses seeks a collective benefit that is greater than the sum of the individual benefits each company would realize if it optimized its individual performance only.

The goal of an EIP is to improve the economic performance of the participating companies through a systems approach to improved environmental performance. Using the principles of IE, the community of companies collaborates to become an "industrial ecosystem."

Key elements of our definition of an EIP deserve greater attention:

Environmental Performance—We follow the increasingly common view that superior environmental performance transcends the requirements of regulation and legislation to include such ideas as reduced resource use and reduced net negative environmental impact. By adopting this view, businesses may discover new efficiencies in materials and energy use with bottom-line benefits.

IE—This idea is an emerging systems framework for guiding design and decision-making in private and public sectors. IE takes the common-sense view that private and public organizations operate as members of natural ecosystems. All industrial operations (private and public manufacturing, service, and infrastructure) are natural systems that must function as such within the constraints of their local ecosystems and the biosphere. Recognizing this is a fundamental condition for long-term business viability.

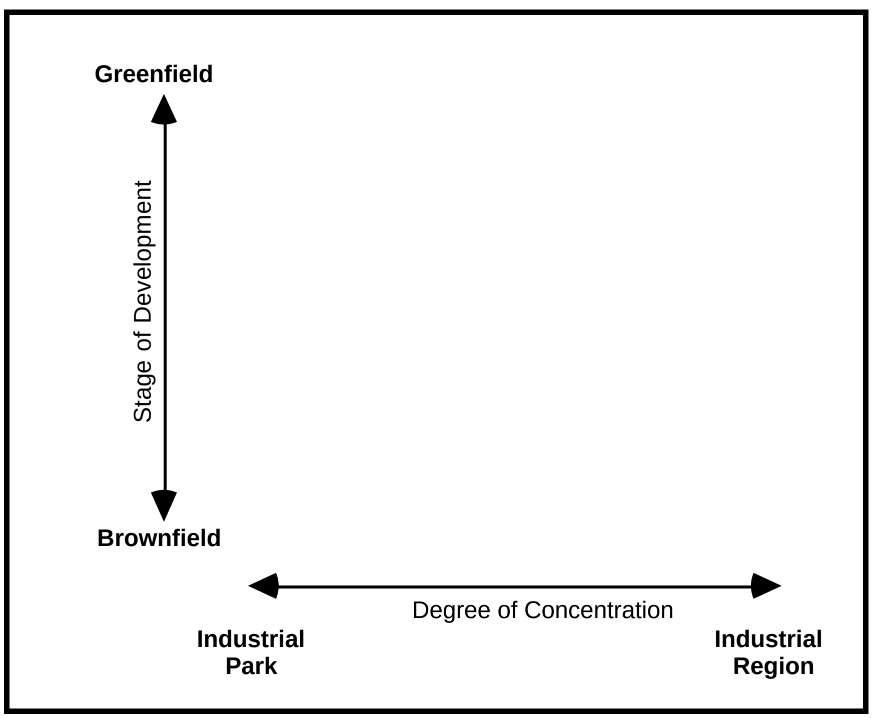
Industrial Ecosystem—Robert Frosch and Nicholas Gallopolous (1989) provide the following definition "… the traditional model of industrial activity—in which individual manufacturing processes take in raw materials and generate products to be sold plus waste to be disposed of—should be transformed into a more integrated model: an industrial ecosystem. In such a system the consumption of energy and materials is optimized, waste generation is minimized and the effluents of one process … serve as the raw material for another process."

An industrial ecosystem demonstrates the systematic approach to business that IE represents. The interactions among companies resemble the dynamics of natural ecosystems, where all materials are continually recycled. IE suggests that the designers of industrial systems can learn from the principles and dynamics of natural systems to better adapt their designs to ecological constraints and needs.

Industrial Park—The term "industrial park" generally has a restricted meaning in terms of geography and (usually) ownership. This project will address industrial parks in the narrow sense but also broader, more diffuse "industrial areas." (See Section 1.1.2 for further discussion.) The Brownsville/Matamoros case study will focus on several industrial parks in the two cities.

IE may be applied to local development initiatives across two dimensions: degrees of concentration of business and stage of development. We consider two critical dimensions for introducing the concept of industrial ecosystems. Greenfield sites are new industrial developments, while Brownfield sites are abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination (EPA, 1995). Either may be in bounded industrial parks or less organized sets of companies in a region. Figure 1-1 illustrates this taxonomy. Although this project focuses on the industrial park side of this chart, much of our analysis also applies to industrial ecosystems that lie anywhere within this taxonomy.

Figure 1-1. Taxonomy for Describing Industrial Ecosystems
Industrial ecosystems can be characterized along two dimensions: stage of development and degree of concentration.



1.1.2 Limits to the Definition

Some developers and communities have used the term EIP in a relatively loose fashion. We encourage applying this term to developments that are more than

- a single byproduct exchange pattern or network of exchanges;
- a recycling business cluster (e.g., resource recovery, recycling companies);
- a collection of environmental technology companies;
- a collection of companies making "green" products;
- an industrial park designed around a single environmental theme (i.e., a solar energy driven park);
- a park with environmentally friendly infrastructure or construction; and
- a mixed use development (i.e., industrial, commercial, and residential).

An EIP may include any of these features. But the critical element in defining an EIP is the interactions among its member businesses and between them and their natural environment.

1.1.3 Examples and Precursors

Existing examples of industrial ecosystems and proposed EIPs reflect the essential characteristics listed above to varying degrees.[1] The industrial symbiosis at Kalundborg, Denmark, is the most celebrated functioning example of a network of companies exchanging byproducts. The large petro-chemical complex on the Houston Ship Channel is a good example of the historical pattern of byproduct utilization in the chemical industry.

The Kalundborg story and the emergence of IE have inspired a number of attempts to consciously create industrial ecosystems. Dalhousie University in Nova Scotia has led the most advanced project in this field. Others are in earlier planning stages.

1.1.4 Potential Benefits of EIPs

EIPs may provide benefits to the companies that participate, to the to the local community, and to the wider community. EIPs also pose some formidable challenges and significant risks.

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[1]Descriptions of several of these can be found in the companion to this report, *Fieldbook for the Development of Eco-Industrial Parks*.

Potential Benefits and Risks to Industry

The EIP offers participants the opportunity to decrease production costs through increased materials and energy efficiency, waste recycling, shared infrastructure costs, and avoidance of regulatory penalties. Companies in an EIP interact in ways that are unfamiliar to many companies in the U.S. and in ways that may pose significant risks.

To the companies involved, the EIP could offer the opportunity to decrease production costs through increased materials and energy efficiency, new revenue streams from former wastes, and reduction of regulatory burden. Increased efficiency could also enable park members to produce products that are more competitive in domestic and global markets.

In addition, some costs once incurred solely by individual businesses may be shared by all member businesses in the park. This cost sharing could include the cost of infrastructure, research and development, training, and the expense of designing and maintaining sophisticated information systems. Such collaboration could help EIP members achieve greater economic efficiency than their stand-alone counterparts. Companies could also use their EIP membership as a solid foundation for green marketing campaigns.

These benefits to participating companies could increase the value of industrial park projects for private or public real estate developers and park management companies.

However, the EIP also poses risks to industry. EIP membership requires a special, dependent relationship among its members that is not common in the U.S. Furthermore, the regulatory status of EIPs is uncertain, and many of the technologies that support EIPs are unproven.

Potential Benefits and Risks to Local Communities

Enhanced economic performance of participating businesses could make EIPs a powerful economic development tool. EIPs can provide communities a focal point for industrial recruitment activity. This activity can diversify the industrial community, stabilizing the community's economy.

EIPs can reduce the environmental burden of existing and new businesses by reducing discharges and the use of locally scarce natural resources.

However, communities also face significant challenges in developing EIPs. These include raising development funds, recruiting appropriate companies, and managing the park for flexibility.

Benefits to the Wider Community

> The wider community can maximize the benefits of EIPs and minimize its risks by carefully examining the potential obstacles to EIPs and determining whether they can be overcome.

EIPs could yield a significant reduction in many sources of pollution and decreased demand for natural resources. The combination of environmental and economic benefits could demonstrate the principles of sustainable development in a real-world setting. The EIP's evolution may also create demand for more innovative approaches to pollution prevention (P2), energy efficiency, resource recovery, product disassembly, and other advanced environmental management technologies. This demand in turn will increase demand for research and development in these areas. Each park will serve as a working model for future eco-parks and other environmentally sound forms of business operation.

EIPs could provide governments at all levels with a laboratory for creating policies and regulations that are more effective for the environment and less burdensome to business.

The risk that the EIP poses to the wider community is the possibility that after spending significant resources developing the EIP concept, it could prove unworkable because of constraints such as regulatory restrictions, standards of business practice, technological limits, or insufficient economic benefits. It is therefore important to carefully examine the potential obstacles to EIPs and determine whether they can be overcome. This can be done by engaging in exploratory case studies, such as this case study of an EIP for Brownsville/Matamoros. It can also be done by carefully studying recent experiments in EIP development.

1.2 PREVIOUS RESEARCH

Before finalizing the objectives for and design of this project, we examined the literature to explore the extent to which the EIP concept had been studied. Appendix A contains a summary of the literature we reviewed and an annotated bibliography. Because of the interdisciplinary nature of the EIP concept and its application, this review was especially difficult. We reviewed literature in fields as diverse as IE, design, architecture, economics, sustainable development, systems science, and accounting. Each of these fields has something to contribute to our research, but few have worked toward integrating these disciplines and applying them toward developing and analyzing an EIP.

Some earlier work on applying IE and other fields to EIPs has been very promising. Of particular note is the work of Ray Côté and his colleagues (1994), who outlined and applied the concepts of IE and industrial ecosystems. The authors used the Burnside Industrial Park in Dartmouth, Nova Scotia, as a test case for developing and applying a set of principles and guidelines for designing and operating EIPs.

Prior to commencing this study, the EIP was, to a large extent, unexplored. We were unsure whether and under what conditions the EIP concept could be applied with economic and environmental success.

Prior to commencing this study, the EIP was virtually unexplored. We were unsure whether and under what conditions the EIP concept could be applied with economic and environmental success. We had little information about the specialized technologies required to support EIPs; we did not know what the most appropriate role of government might be. Finally, since few EIPs had been developed purposefully, few people could describe an appropriate process for designing and developing EIPs.

With this project, we provide information on some of these issues. We certainly do not answer all of the questions relevant to the economic feasibility of EIPs and to their successful development and operation. We do hope to begin a dialogue about these issues, thereby bringing together the many disciplines that can contribute to the debate.

1.3 STUDY OBJECTIVES AND RESEARCH APPROACH

This project addressed four primary research questions. Although IE has been applied in a number of situations outside and, more recently, within the U.S., the U.S. has no mature models of EIPs. Thus, we have no empirical evidence of the size of the economic and environmental benefits that can result from forming an EIP in the U.S. Although these benefits are specific to each situation, providing a model for measuring these benefits and demonstrating the application of that model in a specific situation are important. Thus, the first research question is the following:

R1: How do we determine the potential economic and environmental benefits that may be realized by applying the concepts of IE to current and planned U.S. and Mexican commercial and industrial developments, and what might these benefits be for a prototype EIP in Brownsville/Matamoros?

The existing EIP in Kalundborg, Denmark, and other examples of IE throughout the world have evolved primarily through developing complementary bilateral relationships between companies. In most cases, government has played a minor role or has influenced the development of these relationships only indirectly through regulatory action. However, government clearly has an interest in the successful development of methods for improving industrial competitiveness while protecting environmental resources. The most appropriate role for government is unclear, and this role is likely to differ among different EIP sites. Thus, the second research question is the following:

> R2: What is the range of government's appropriate role (federal, state, and local) in facilitating the development and management of EIPs, and how might this role vary in alternative EIP venues?

Developing and managing EIPs will require applying new and existing technologies. Although many of the enabling technologies for EIPs have been used in different contexts for years (e.g., transportation infrastructure, cogeneration, waste processing and purification technologies), their application to IE is new. Furthermore, applying IE principles will stimulate demand for new technologies for energy, water, and materials exchange and processing. We view the identification of these new and existing technologies and the location of information about their development and transfer as an essential task for facilitating the development of EIPs. Therefore, the third research question is the following:

> R3: How do we identify the environmental technologies needed to fully apply IE principles and concepts, and which specific technologies will be needed for the prototype EIP in Brownsville/Matamoros?

Each of the three research questions noted above must be answered within the context of a specific EIP site with reference to the specific stakeholders; the economic conditions; the ecosystem; and the local social, management, and governmental systems. Although our case study answers these questions for a specific site in Brownsville/Matamoros, we stress the importance of applying the lessons learned in the case study to other venues. Thus, the final research question is the following:

R4: How applicable are the results of the Brownsville/Matamoros case study to other venues, particularly other border-area industrial parks?

> The companion to this document, *Fieldbook for the Development of Eco-Industrial Parks*, expands on the issues identified in this document by discussing each issue, providing potential solutions to problems, and illustrating how solutions have been implemented in other EIPs. It also guides the reader to other sources of information about each issue.

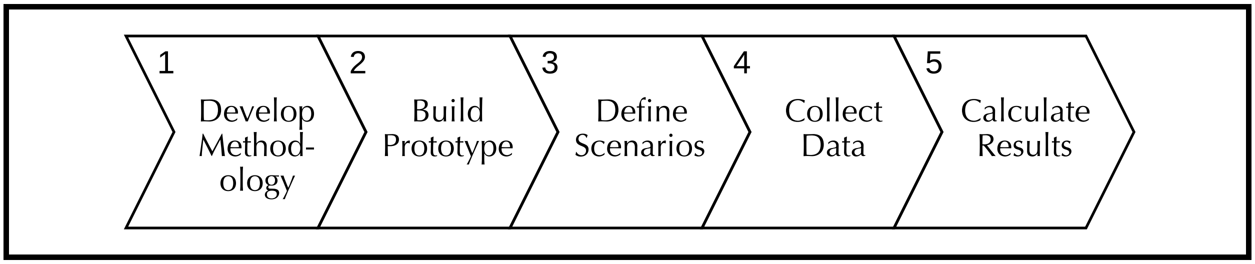
Our approach to answering these questions was to develop a case study of a potential EIP in Brownsville, Texas, and Matamoros, Mexico and to write a "fieldbook" for planning, developing, and managing EIPs. We use the case study to uncover and illustrate important EIP issues related to each of the four research questions. The *Fieldbook* addresses the issues raised by the case study. It identifies the problems, discusses potential solutions, provides examples of how each issue has been handled in actual EIPs, and provides sources of information and other resources for addressing these issues. In doing so, it synthesizes all of the elements involved in developing and operating an EIP. The *Fieldbook* addresses each of the elements of the definition provided in Section 1.1.1.

As shown in Figure 1-2, we took a five-step approach to our EIP case study:

1. **Develop methodology**. We developed a methodology for identifying and quantifying the potential environmental and economic impacts of the EIP.
2. **Build a prototype**. We designed a prototype EIP for Brownsville, Texas/Matamoros, Mexico that consists of a group of companies operating in the area, as well as some companies that operate in other locations but would fit well with the economic and environmental conditions of the proposed EIP.
3. **Define scenarios**. We developed five EIP scenarios that allow us to examine the impact of incrementally changing the relationships among the EIP members.
4. **Collect data.** We collected data from existing companies in the Brownsville/Matamoros area and from pertinent technical literature to apply our methodology for quantifying the economic and environmental impacts of the EIP.
5. **Calculate results**. We used the data to simulate changes in profit, return on investment, and annual changes in solid waste and resource use.

Following the simulation of the economic and environmental impacts of the EIP, we take a closer look at research questions 2 and 3 by examining the regulatory issues involved in the case study and the technologies that are important to the EIP scenarios.

Figure 1-2. The Five-Step Case Study Approach
We followed a five-step approach to the EIP case study.



1.4 ORGANIZATION OF THE REPORT

This report contains seven chapters. In Chapter 2, we lay the groundwork for addressing the first research question. First, we identify each of the stakeholders in the EIP process, describe the potential benefits and risks to each, and describe a method for measuring the potential benefits. Then we describe our approach to quantifying the impacts in the Brownsville/Matamoros case study.

In Chapter 3, we develop a prototype EIP for Brownsville/ Matamoros and describe several scenarios for EIP operation. In Chapter 4, we apply economic and environmental analysis tools to simulate the potential economic and environmental benefits of the prototype EIP for Brownsville/Matamoros. We then discuss the case study's unique characteristics that might affect the feasibility of an EIP under different economic, environmental, and social situations.

In Chapter 5, we address the second research question. We investigate the role of regulations in promoting or discouraging P2 and IE applications and formulate a regulatory framework for EIPs. We summarize the regulatory issues important to each of the five scenarios in the Brownsville/Matamoros case study and in other EIPs. Then we show how these issues can be addressed by regulatory reform or flexibility.

Chapter 6 addresses the third research question. First, we provide a framework for identifying technologies that improve the sustainability and success of the EIP. Next, we describe the technological challenges presented by each of the scenarios in the Brownsville/Matamoros case study and other EIPs. Then we discuss generally how some types of technologies meet these challenges and provide some specific examples.

Chapter 7 summarizes the report and briefly discusses research question 4 by noting how our results were specific to the assumptions and conditions of our case study. Then we enumerate the important challenges to EIP success that are addressed in the companion document, *Fieldbook for the Development of Eco-Industrial Parks*.

Five appendices follow Chapter 7. Appendix A contains a brief review of related literature and an extensive annotated bibliography. Appendix B includes technical details from the Brownsville/Matamoros case study. Appendix C contains information about international trade agreements that affect regulatory issues for EIPs located on the U.S./Mexican border. Appendix D contains a list of sources of information about technologies that may support EIPs. Appendix E contains the site visit protocol.

2 EIP Impacts on Firms and Communities

Very little has been written about the magnitude of benefits to expect from participation in an EIP, and a systematic framework for measuring these benefits does not exist.

One of the most pertinent issues related to EIPs and other applications of IE is the size of the potential economic and environmental benefits. The application of IE requires changes in the way members of the business community view their interactions with others, and it may also require substantial investment in managerial talent, training, and infrastructure. Without some evidence of the economic and technical feasibility of EIPs and their potential for reducing the environmental burden of industry, the business and community leaders will hesitate to embrace it. Although we can identify isolated and immature examples of the application of IE in an industrial park setting, very little has been written about the magnitude of benefits to expect from participation in an EIP, and a systematic framework for measuring these benefits does not exist.

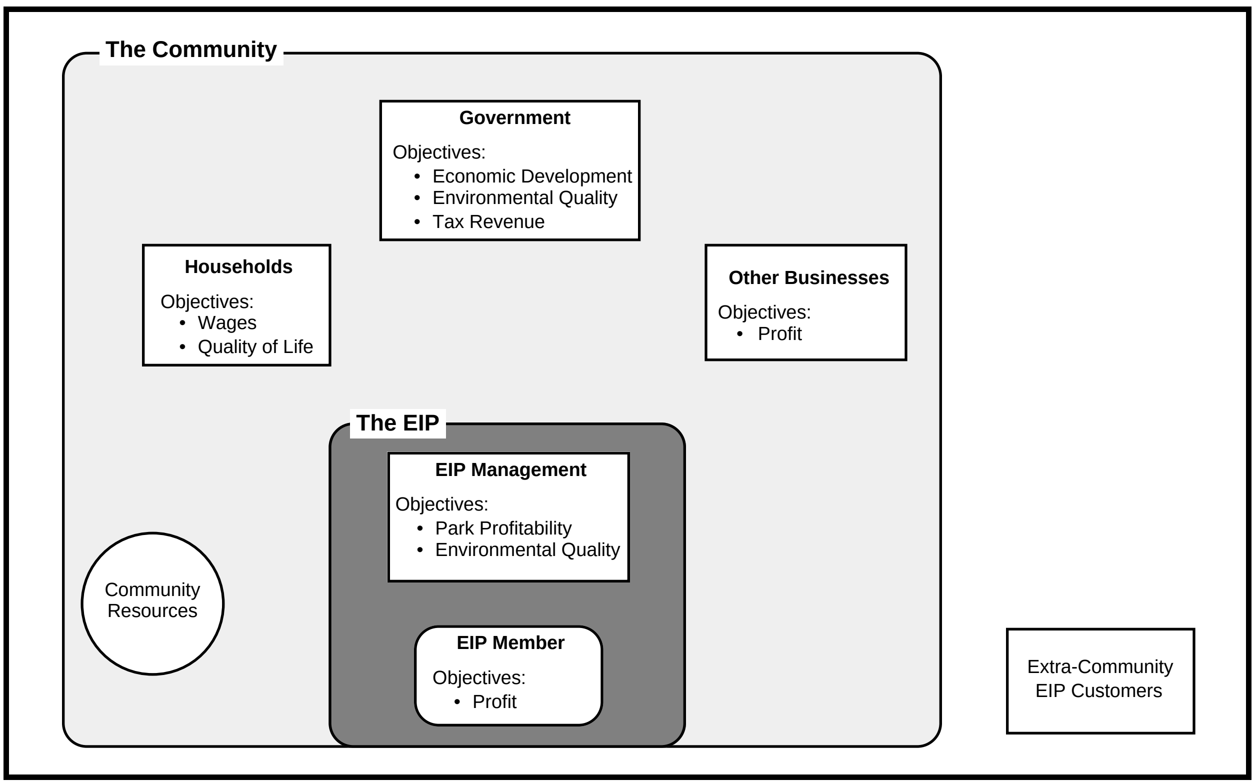
We also need to understand the circumstances under which the potential benefits might be greatest. The magnitude of the benefits of forming an EIP is likely to vary greatly depending on the specific circumstances. Success of an EIP might depend on the industries involved, the location of the EIP, the economic profile of the region, the openness of local developers to a new development strategy, the local political and regulatory environment, and the willingness of the business community to work together.

This chapter lays the groundwork for addressing these issues. First, we identify each of the stakeholders in the EIP process; then we describe the potential benefits and risks to each. Finally, we describe methods for measuring EIP economic and environmental benefits and describe how we applied these methods to the Brownsville/Matamoros case study.

2.1 EIP STAKEHOLDERS

EIPs have the potential to affect the companies that participate in them, the managers of EIPs, the members of the communities that host them, and the wider community. Figure 2-1 illustrates the relationships between these main stakeholders.

Figure 2-1. Agents in the EIP Eco-Environmental Model
The economic and environmental impact of the EIP extends beyond the boundaries of the EIP to the members of the community and even beyond the community.



2.1.1 The EIP Members

The EIP members are the building blocks of the EIP's economic and environmental systems.

EIP members are the building blocks of the EIP's economic and environmental systems. Each EIP member exchanges inputs (labor, capital, and materials) with other EIP members, members of the community, and suppliers and customers from outside the community.

EIP members seek to maximize their profitability. While other objectives, such as reducing the environmental impact of their production may be germane, they are only relevant to the EIP member if they affect the profitability of the operation. For example, some companies may feel that meeting certain environmental performance standards will differentiate their product or service from their competitors' products or services, allowing them to command a higher price and contributing to the company's profitability.

2.1.2 The EIP and Its Managing Entity

> The EIP provides a mechanism for coordinating the activities of its members to achieve maximum efficiency similar to the coordination of branch plants in a multiplant company.

An EIP is a real estate property that must be managed to provide a competitive return to its owners. At the same time, an EIP is a "community of companies" that must manage itself to provide benefits for its members. Thus, the EIP management fills many of the traditional roles of an industrial park manager, while also maintaining a relationship with the EIP members similar to the relationship between a company and its branch plants.[1] The EIP management unit adds value to the production and service functions of its members by performing the following roles:[2]

- championing the objectives of the EIP
- brokering waste materials among EIP members, including "scavengers and decomposers," and to organizations outside the EIP
- gatekeeping, or facilitating the interactions between the EIP members and the community
- providing flexible networking for EIP members
- providing technical support and information
- providing "public" goods and services (e.g. common infrastructure, such as roads, pipelines, wastewater, and solid waste treatment facilities)

Each of these roles in some way supports improvements in the EIP's efficiency. For example, flexible networking allows the EIP members to take advantage of economies of scale and scope, just as the parent company of a firm would provide the same benefits to its branch plants.

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[1] Faye Duchin (1994, 1990, 1992) has drawn an analogy between an industrial ecosystem and a closed economy, analyzing the economic exchanges of the industrial ecosystem within an input/output framework. We choose an alternative analogy to account for the openness of this system.

[2] Côté et al. (1994) have suggested many of these roles.

The EIP as a Multiplant Firm

We assume that production decisions are based on profit maximization for the EIP as a whole. While members of the EIP retain their autonomy over resource allocation decisions, we assume that, given the optimal production plan for the EIP as a whole, each firm will negotiate transfer prices so that each member will be at least as profitable as it would be without the EIP. As explained above, this is a necessary condition for EIP member participation.

In exchange for these services, the EIP managing unit receives payment from the members of the park. In keeping with our multiplant firm analogy, these payments can be viewed as overhead expenditures that are charged to an organizational unit in return for services that are provided companywide, such as accounting or purchasing). The goals of the EIP are tied to the goals of the individual EIP members, because the economic success of the park depends on the success of its members.

2.1.3 The Local and Wider Community

The EIP's community is the local social, environmental, and economic system in which the EIP resides. The EIP is not a closed, independent system but part of a larger economic system, just as a nation's economy must be viewed within the global economy. The boundaries around this community are not physical but social, environmental, and economic. We define the local community as the area in which the EIP has the greatest economic, environmental, and sociological impact. The community is the source of the EIP's labor; it may also be its source of many materials, water, and energy. The local community is most directly affected by the environmental burden of the EIP. Although external communities might supply EIP materials, purchase EIP goods and services, and feel the burden of the EIP's environmental impact, the local community is affected most directly.

The boundaries around an EIP community are not physical, but social, environmental, and economic. The local EIP community is the area in which the EIP has the greatest impact.

Each community member has a different objective for conducting transactions with the EIP. The goals of the community government might include improving local environmental conditions, decreasing the unemployment rate, or increasing tax revenues. The community government has a number of resources at its disposal for achieving these goals, including tax incentives, regulatory alternatives, and infrastructure, such as transportation, landfills, and public utilities. It also has the political infrastructure to channel external resources into the local economy in ways that may affect the success or failure of the EIP. The goals of households living in the community might include decent working conditions, education, income, and improved environmental quality. The labor force offers its labor and skills towards meeting these goals. The goals of other community businesses might include developing relationships with the EIP that are profitable and result in mutually beneficial exchanges of knowledge.

2.2 SOURCES OF EIP BENEFITS AND RISKS

Each of the stakeholders identified above can potentially benefit from the EIP as an alternative form of business organization. However, the EIP also poses risks. In this section, we identify the sources of these benefits and risks for the EIP members, for the EIP management, and for the community.

2.2.1 Benefits and Risks to Members

Membership in an EIP can potentially bring economic benefits to companies by improving their efficiency, reducing their infrastructure requirements, providing access to better information about their customers and suppliers, and reducing their costs for regulatory compliance. However, the EIP also requires that each member form relationships with other EIP members that may bring greater risk than traditional customer/supplier relationships. Furthermore, because the EIP is an emerging form of organization, members face regulatory and technological uncertainties that pose additional risk. Below, we describe these sources of benefits and risk and discuss how members might take them into account in deciding whether EIP membership will provide a net economic gain.

Sources of Economic Benefits

> Many factors interfere with the efficiency of markets. By removing these factors, the EIP concept can improve the economic efficiency of industrial ecosystems.

Application of IE to production activities might lead to improvements in economic efficiency. Economic efficiency refers to using resources in the most efficient manner. An economy is efficient if it is producing at full capacity and employing methods of production and resources as effectively as technology allows. Underutilized resources—labor, capital, or raw materials—represent inefficiency. By applying the principles of IE, we may improve the utilization of resources among the EIP members.

EIPs may improve the economic efficiency of member firms by

- taking advantage of economies of scale and scope,
- improving the flow of information between customers and suppliers, and
- reducing the costs of complying with regulatory requirements.

The EIP can help its members take advantage of economies of scale and scope that normally benefit much larger firms.

Economies of Scale and Scope. A company often can decrease its per-unit capital, materials, and labor required for production by increasing the scale of operations. High fixed costs, such as capital equipment, often prevent a small company from effectively competing with larger companies that can produce at a lower per-unit cost. If the EIP allows companies to share expensive capital equipment, the EIP members enjoy the cost advantages of a bigger company. This is also true of specialized labor. A single small company may not require the full-time services of an environmental engineer, for example, and it may be difficult to hire a professional engineer on a part-time basis. EIP membership may allow the members to share the services of this type of labor through some special employment relationship.

Economies of scope occur between two production activities when one company producing both products can produce one or both more cheaply than two companies specialized in corresponding production processes. Economies of scope occur when the same equipment can be used to produce two products, when worker training in the production of one type of product is applicable to the production of the other, or when the production results in byproducts that are used as an input to the other's production process.

The prototype EIP in Brownsville/Matamoros provides an example of economies of scope. The Brownsville refinery purchased an asphalt company to provide a captive market for its least marketable byproduct, residual oil. It also purchased a limestone company and located it next to the asphalt plant to provide stone to the asphalt plant, thus keeping transportation costs low. These three operations can produce more efficiently than they could individually by synchronizing their production processes (and jointly maximizing profits).

The EIP can help small companies benefit from economies of scale and scope by providing a mechanism for contracting arrangements that mimic the advantages of large-scale and scope operations. Such contracts are routine among electric utilities that contract to pool electric power to eliminate the need for each to invest in peak load equipment (Tirole, 1990).

The EIP can improve efficiency by facilitating transactions among EIP members.

Transaction Costs. Transaction costs, which include the costs to both buyers and sellers of gaining information about the market, may cause inefficiency in markets in which information is costly. One example from our Brownsville/Matamoros case study is the plastics recycling market in Brownsville. At the time we began this study, some companies in Brownsville and Matamoros were landfilling materials that could be recycled by a local company. These companies had previously not recycled their plastics because they expected the cost of finding a local user for their material to be prohibitive. Once they learned of local recycling opportunities, they were able to increase their efficiency by trading unwanted byproducts rather than sending them to the landfill.

The EIP can play a role in decreasing transaction costs. The EIP management can serve as an information clearinghouse regarding all products, byproducts, and inputs of all the companies in the EIP and finance it through leases or EIP fees. Recent research at the Burnside industrial park has stressed the importance of information as crucial to the park's success (Côté et al., 1994).

The EIP may improve efficiency by reducing the regulatory burden on its members without sacrificing environmental quality.

Regulatory Cost Reductions. The EIP may be able to reduce the costs of meeting regulatory requirements. For example, the EIP may eliminate the need for a transportation permit for materials that are transferred between companies.[3] This might occur by virtue of collocation. By reducing the cost of transporting the waste, the firm may find selling a product that provides a substitute for a virgin material more profitable than paying for treatment and disposal. If the product is hazardous, the risk of exposure is reduced by the reduction in transport distance.

Other regulatory arrangements might provide other opportunities for reducing the costs of complying with environmental regulations. For example, the notion of an EIP-wide umbrella permit, covering all facilities, allows for a reduction in the administrative costs of

[3]Regulatory reform and the EIP concept are discussed in Chapter 5.

compliance, as well as possibly allowing the EIP members to determine among themselves the most efficient method for meeting the terms of the umbrella permit. These notions are discussed more thoroughly in Chapter 5.

Sources of Risk

> Membership in an EIP can expose a company to risks that it might not otherwise face.

Despite their potential for improving efficiency and profitability, few companies have actually participated in an EIP, in part, because of the risks associated with EIP membership. Sources of risk include

- supplier/customer relationships with EIP members,
- environmental liability,
- regulatory uncertainty, and
- technological uncertainty.

As alternative forms of the EIP emerge, EIP members and managers will develop methods for reducing these risks. However, the relative novelty of the EIP concept makes these risks very real at this time.

EIP Relationships. Perhaps one of the most important sources of risk in an EIP is the relationships formed among EIP members. In some cases, these relationships represent substantial investments that may not be easily converted to liquid assets if the relationship dissolves. For example, some companies might invest in joint EIP infrastructure such as pipelines or other transportation systems. Others may invest in the specific materials processing technology required to accept another company's waste as an input. Still others may invest in waste treatment systems that transform their waste into an input that another EIP member can use. EIP members stand to lose these investments if their partners leave the EIP or experience some change in their operation that is not consistent with the technical requirements of the partnership.

This situation is similar to that of a company that invests in a just-in-time (JIT) inventory system. A company that develops a JIT relationship with a supplier invests considerable resources in developing and communicating the specifications of the product and information systems that signal the status of inventory and the need for an increase or decrease in production. These investments are at risk because, if the JIT supplier or customer is not able to meet its contractual obligations, it would be costly and time consuming to find and invest in an alternate supplier or customer. Plant shutdowns, strikes, and mechanical failure expose the customer or supplier company to potential losses while their labor and capital are left idle. Assuming that a substitute supplier or customer can be found, the substitution would require another substantial investment in infrastructure and information.

Given the similarity of these two situations, EIP members can learn to mitigate these risks by following strategies practiced by members of JIT relationships. We discuss these issues in greater detail in the companion to this document, *Fieldbook for the Development of Eco-Industrial Parks* (Lowe, Moran, and Holmes, 1996). There, we discuss how members of existing EIPs have developed strategies for reducing this risk.

Environmental Liability. Another source of risk is the potential environmental liability that EIP members may face. EIP members increase their environmental liability risk because of

- the use of potentially hazardous secondary materials in other applications and
- the treatment of industrial parks or regions under single regulatory umbrellas.

Companies may expose themselves to liability if they supply secondary materials to the production or use of a product with serious health or environmental consequences, or if they produce a product derived from hazardous materials.

EIP industries may also face liability issues when one or more industries are treated under a regulatory umbrella within an EIP. All of the companies under the umbrella would be expected to maintain a code of ethics and take responsibility for meeting the compliance standards or the permit. However, monitoring releases from individual members under an umbrella permit may be difficult, especially if industries exchange materials. If one company creates a noncompliance problem or causes a risk to human health or the environment, all members of the EIP may be held liable.

Until regulatory agencies develop more explicit guidelines regarding the regulatory status of EIPs, there is considerable uncertainty regarding how environmental regulations, including liability laws, may change.

Technological Uncertainty. A final source of risk is the technological uncertainty associated with some of the processes that link EIP companies. As explained in Chapter 6, many of the technologies needed to link EIP companies have not been developed or are very new. Applications of new technologies are risky in the sense that their operating costs and other operational parameters may be uncertain.

2.2.2 Benefits and Challenges to Communities

EIPs have the potential to bring economic and environmental benefits to the communities in which they locate. The EIP can provide a basis for industrial recruitment, bringing new jobs and income to a community. In addition, an EIP can bring new industries that diversify the industrial base and insulate it from downturns in economic activity that may affect specific industries. An EIP may lead to the development of industries that add value to the products leaving a community, increasing local income. Finally, as explained above, an EIP arrangement may improve the competitiveness of existing companies, preventing plant closures and the accompanying job losses.

The EIP can also reduce the environmental burden of existing industrial activities and mitigate the environmental impact of new firms. As members of the EIP begin to use each other's byproducts in their production activities, they may reduce their production of solid waste. As the EIP reduces the cost of activities such as solvent recycling, EIP companies may generate less hazardous waste. The application of water cascading techniques may reduce pollutant discharges to water and reduce the use of fresh water. Finally, the collocation of EIP companies can reduce air emissions from combustion of fossil fuels.

However, communities face a number of challenges in developing and supporting an EIP. Finding a source of development funding, determining what organization should manage the EIP, attracting a viable combination of companies, and gaining the cooperation of regulatory agencies all pose significant challenges to making EIPs viable and successful. Perhaps the most significant challenge is building into the EIP design the flexibility required for longevity.

2.3 QUANTIFYING IMPACTS

In this section, we identify several indicators of the profitability of EIP membership and explain how the economic impacts of EIPs on communities can be quantified. Then we describe a framework for measuring the environmental success of the EIP. Finally, we briefly explain our methodology for quantifying the impact of our EIP case study of Brownsville, TX/Matamoros, Mexico. We further develop this methodology in Chapter 3.

2.3.1 Quantifying the Economic Impact of an EIP on Its Members

A company's objective for joining an EIP, as explained in Section 2.1, is to increase its profits. The profit function can be written:

$$\pi = \sum_{i=1}^{n} p_i * x_i - F \qquad (2.1)$$

where p_i refers to the price of good i, x_i is any input or output, and F is a fixed cost that does not vary with the quantity of production. x_i can be positive, if it is an output that is produced, or negative, if it is a material that is used in the production process. This form of the profit function facilitates thinking of the same material as an input and an output. Thus, paper may be an input to one company and an output for another company.

Production Technology and EIP Planning.
An EIP member would consider opportunities for applying IE principles in choosing a production technology. For example, the type of flue gas desulfurization (FGD) technology chosen for a power plant is critical to the potential for selling FGD byproducts.

Using the general profit function of Eq. (2.1), we can identify ways to quantify the impact of EIP membership on profit. All else equal, profits are higher if producers

- receive a greater price for their product,
- pay a lower price for their inputs (production costs decrease),[4] or
- produce a greater quantity of product with the same quantity of inputs (increased productivity).

Input prices must include the *total* cost of using inputs, which might depend on

[4]In this discussion, we assume that prices are exogenous (i.e., producers are not important enough in the market to influence the prices of inputs or outputs by their demand or supply of them).

- transportation costs;
- residual value (this can be negative if, after use, the inputs must be treated or disposed of at a cost);
- operating and maintenance (O&M) costs; and
- regulatory compliance costs (i.e., the cost of lawful permitting, use, and storage of hazardous substances directly assignable to inputs).

Kalundborg: Changes in Production Processes

After beginning to participate in the Kalundborg symbiosis, the power plant found that, to meet the needs of the nearby wallboard factory, it needed to supply a greater volume of gypsum. This was accomplished by burning coal that had a higher sulfur content and therefore provided a greater amount of gypsum for a given amount of energy. This coal was less expensive than the other coal they were using, so this switch was profitable in two ways: the power plant sold a larger quantity of gypsum and burned a less-expensive grade of coal. The environmental impacts of the higher sulfur content were neutralized because the extra sulfur was captured as gypsum. Furthermore, this byproduct gypsum replaced natural gypsum in the production process.

Each of these may be affected by the source of the input and the participation of the company in the EIP. For example, transportation costs may be significantly lower if inputs are obtained from a proximate source. Residual value might be increased if, for example, several EIP members were to agree to use a single type of solvent in their production processes, pool their waste solvents, and thereby obtain a lower per-unit waste management cost or a (lower) bulk rate for treatment or disposal of their waste solvent. O&M costs may change if the capital equipment required to process materials changes. Similarly, the proximity of the supplier may affect permitting for transportation.[5]

The profit-maximization model implies that, when relative input or output prices change, the EIP members may change their production strategy. Thus, an analysis of the resulting change in profit must account for this change in production methodology and any change in the input mix or output mix. Kalundborg is a good example of this phenomenon (see box).

Making Comparisons

To determine the EIP's economic impact, we must compare profitability of the baseline (without EIP) scenario to profitability of with-EIP scenarios. j denotes EIP scenario j (where 1 is the baseline scenario), and the change in profitability between baseline and scenario j is

$$\Delta\pi_j = \left(\sum_{i=1}^{n} p_{i,j} * x - \sum_{i=1}^{n} p_{i,1} * x_{i,1}\right) - \left(F_1 - F_j\right) \qquad (2.2)$$

To facilitate this comparison, we might want to separate the variable revenues and costs from fixed investments:

[5]EIP regulatory issues are discussed in Chapter 5.

$$\Delta\pi_j = \left(\sum_{i=1}^{n} p_{i,j} * x_{i,j} - \sum_{i=1}^{n} p_{i,1} * x_{i,1}\right) - \left(F_j - F_1\right) \qquad (2.3)$$

We call the first part of Eq (2.3) the change in net revenues attributable to moving from baseline to scenario j, while the second part is the investment required to move from the baseline to scenario j.

Defining a Single Time Horizon

We need to ensure that all elements of the profit equation are measured for the same time period. Quantities (x's) are measured in annual quantities. However, capital investments are one-time expenses and may be too large for some facilities to finance with working capital. The costs should be annualized over the expected usable life of the capital equipment to represent the annual cost of financing the lump-sum cost. These annualized costs, plus the net change in O&M costs, represent the change in the affected facilities' annual costs in moving from baseline to scenario j. Thus, we replace $F_j - F_1$ in Eq. (2-3) with I_j to represent the annualized investment required to move from the baseline to scenario j.

Alternative Measures

Table 2-1 provides some indicators of the economic benefits of the EIP to its members. Change in annual profit (also called annual net benefit in our case study analysis) is the best overall indicator of the benefits of the EIP to the company. However, the change in profit is a somewhat long-term indicator. Companies may not see immediate benefits of their investment in the EIP because adapting to a new production relationship takes time. However, shorter-term indicators gleaned from some of the components of the profit function can assist a company in charting its progress; these are also included in the table.

For example, suppose a company enters the EIP and begins to use lower-cost recycled material in the place of virgin materials. At first, production may slow and profits may fall in the short run as workers and processes adapt to working with the new material. However, lower per-unit materials costs for the product may be apparent immediately. In the long run, this may lead to higher profits once production returns to its normal rate.

Table 2-1. Criteria for Measuring the Economic Benefits of the EIP
A bottom-line measure of the economic benefits of the EIP is the change in annual profit; however, a number of other indicators are also useful.

Indicator	Data Required[a]	Method
Change in annual profit (net benefit)	➤ output prices and quantities ➤ input prices and quantities ➤ annualized investment ➤ regulatory costs[b] ➤ transportation costs	$\Delta\pi_j = \left(\sum_{i=1}^{n} p_{i,j} * x_{i,j} - \sum_{i=1}^{n} p_{i,1} * x_{i,1}\right) - I_j$
Change in the cost of production per unit	➤ input prices ➤ input requirement per unit ➤ regulatory costs[b] ➤ transportation costs ➤ annualized investment	$\frac{\text{Total Annualized Costs}}{\text{Output}}$
Change in productivity	➤ quantity of outputs ➤ quantity of inputs	c
Return on investment	➤ annual net benefit of investment (benefit minus cost) ➤ discount rate ➤ years of return expected	$\sum_{i=0}^{n} \frac{\Delta\pi_{t+1}}{(1+r)^i} = 0$
Payback period	➤ number of years required to return investment	$\frac{\text{Total Investment}}{\text{Annual Net Revenue}}$

[a]Pre-EIP and post-EIP data are required to calculate changes.
[b]Regulatory costs associated with using the inputs (i.e., transportation and storage of hazardous material).
[c]Productivity change can be calculated in a number of ways. For a review of methods of productivity measurement, see Grillches (1979).

Some components of profit that may be useful short-term indicators include

- ➤ increase in revenues due to sales of byproducts;
- ➤ decrease in per-unit costs due to using lower-cost recycled materials;
- ➤ change in material, labor, capital, or energy productivity;
- ➤ reduced costs due to services outsourced to the EIP management;
- ➤ reduced materials disposal costs; and
- ➤ reduced regulatory costs.

Participation in the EIP will likely involve some up-front investment from the members, over and above the investment required without participation in the EIP. Return on investment (ROI) and payback period are both popular methods for analyzing capital investments. The ROI is the rate of discount r that reduces the net present value (NPV) of the flow of net economic benefits ($\Delta\pi$) over n years from a project. To measure the return on their investment, companies would calculate the rate r that solves the following equation:

$$\sum_{i=0}^{n}\left[\frac{\Delta\pi_{t+i}}{(1+r)^{i}}\right] = 0 \qquad (2.4)$$

where $\Delta\pi_{t+i}$ represents the net benefits in the ith year after the project under evaluation begins (year t), and n is the total number of years over which benefits or costs are expected to accrue. In our application, investment occurs in year t, so $\Delta\pi_{t+i}$ for i = 0 is the amount of investment. In subsequent years, π_{t+i} equals the change in annual net revenue. Typically, the ROI is compared to other investments to provide a rank ordering of investment projects.

Payback period—the number of years required for the investment to pay for itself—is another indicator often used to gauge the potential success of an investment. Payback period is a more limited indicator than ROI, because it does not indicate the total benefits that can be gained from the investment over its lifetime, while ROI considers the flow of benefits and costs over the entire life of the investment.

Corporations typically set minimum ROI and payback period requirements for investment projects. However, sometimes projects that focus on energy efficiency or environmental benefits are allowed a relaxed ROI or payback period (i.e., the payback period can be longer) because the company recognizes that some of the benefits of this kind of investment cannot be quantified. This may be the case for investments in infrastructure and equipment required for EIP participation.

Our analysis assumes that, if the EIP system has a net economic benefit, the members will negotiate the distribution of that benefit among themselves.

In our analysis of the economic benefits of the EIP, we calculate the net benefit, the ROI, and the payback period for each scenario rather than for each individual member. These measures reflect the joint economic benefits to all members. The exact distribution of these benefits among the members is largely a function of the prices that are negotiated in bilateral contracts. A model that can predict these prices requires demand and supply data for each input and output and is beyond the scope of this study. Instead, we assume that if the EIP system has a net economic benefit, the members will negotiate the distribution of that benefit among themselves.

2.3.2 Quantifying the Economic Impact of an EIP on the Community

EIP economic success will spillover to the community through increases in economic activity, income, spending, tax revenues, and employment.

The leaders of the EIP's community, recognizing the EIP's potential economic benefits, may take a very active interest in its development and success. A profitable EIP can generate primary economic benefits for the community, including the increase in income for the owners of EIP companies and their workers. A number of secondary effects are also possible:

- multiplier spending effects resulting from the spending stimulated by increased income and wages
- increased employment as profitable companies expand their workforce and new companies enter the EIP
- greater tax revenue derived from wages, profits, and expenditures
- reduction of the burden on community solid and liquid waste management as the industrial users rely more heavily on recycling and reuse and use EIP waste management services

Some economic indicators that the community could track to measure the impact of the EIP include

- value added by manufacture;
- total number of production workers;
- total production worker wages;
- average wage;
- tax revenues; and
- public expenditures for sewerage and sanitation, as a percentage of value added or tax revenues.

The U.S. Census Bureau routinely collects these statistics and reports them in its *City and County Data Book*. Communities could track these statistics over time and, with some cooperation by the EIP members, disaggregate this information for EIP members and compare them to other businesses in the community.

The community may want to compare the benefits of EIP development with other types of economic development initiatives. This is especially important if the city is investing resources in the EIP and/or other business recruitment or entrepreneurial development efforts and is trying to determine which strategy is most effective. For a review of methodologies for evaluating state and local economic development initiatives, see Wilson (1989).

2.3.3 Quantifying the Environmental Impacts of the EIP

Although we have focused so far on the economic benefits of applying IE principles to production activities, the environmental performance of an EIP is also an important criterion for determining the usefulness of IE as an organizing principle for industrial activity. Our definition of an EIP stresses that the EIP seeks enhanced environmental performance as well as economic performance.

Some of the actors in the EIP system hold environmental performance as a primary, or at least a secondary, objective for participating in the EIP. Community government represents the environmental interests of households, which care about environmental performance as a factor in the quality of life. The EIP management seeks to improve the environmental performance of the EIP as part of its role as champion of EIP's objectives. EIP members may also pursue environmental performance as part of a profit-maximizing strategy.[6]

Measuring the EIP's environmental performance is particularly important for cases in which the public has provided support for the project. Community support is justified by the assumption that environmental quality is a public good and should be provided, at least in part, through government. If the EIP provides economic benefits to members but no environmental benefits for the community, the rationale for community support may collapse.

[6]EIP members may seek some of the less-tangible benefits of environmental performance, such as a green image, as a way of differentiating their products from similar goods produced by competitors.

In this section, we briefly describe a framework for analyzing the comparative environmental performance of environmental management systems and demonstrate how that framework can be applied to an EIP. Applying this measurement framework in an actual EIP setting poses challenges for data collection and analysis that are described and analyzed in greater detail in the companion report, *Fieldbook for the Development of Eco-Industrial Parks*.

A Minimum Performance Standard: Environmental Compliance

Even if the EIP performs well by any or all of the other criteria listed below, environmental compliance must be attained for the EIP to be considered viable.

The EIP cannot be considered successful unless it fully complies with all applicable environmental regulations. Even if the EIP performs well by any or all of the other criteria listed below, environmental compliance must be attained for the EIP to be considered viable.

In Chapter 5, we discuss a number of changes in environmental regulations that would improve the viability of EIPs without reducing their environmental performance. Regardless of whether these changes are enacted, the EIP must be in compliance with the prevailing regulations.

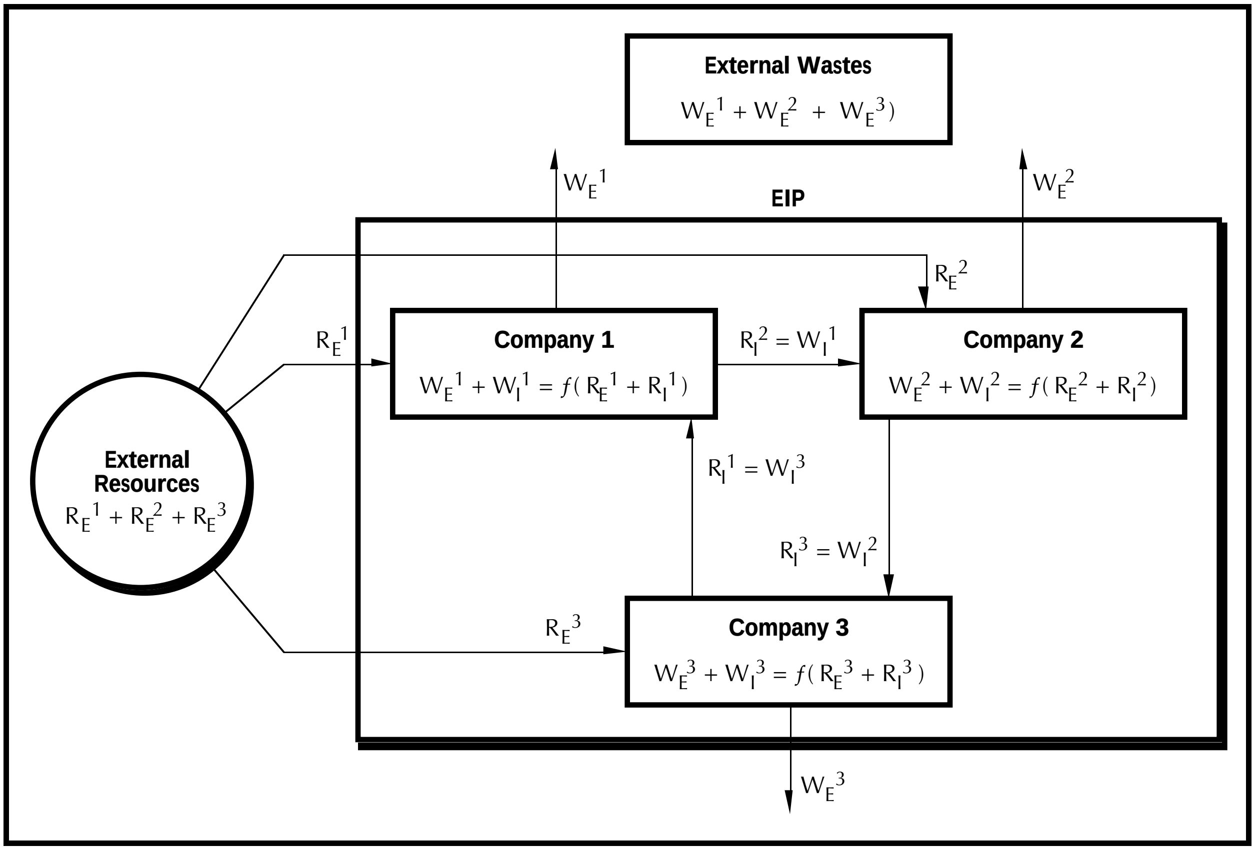
The EIP management can play an important role in ensuring that all members of the EIP are meeting environmental compliance standards. Conducting environmental audits may be one way of accomplishing this.

External Versus Internal EIP Impacts

The environmental impacts of the EIP should be measured as the *net impact of the EIP as a whole*. With the exception of issues concerning worker health and safety and damage to the land on which the EIP sits, only discharges that leave the EIP should be considered. That is, exchanges of wastes among companies should be treated differently from discharges that actually leave the EIP. Similarly, we should only account for the EIP's consumption of natural resources, such as water, when they first enter the EIP. As these resources are exchanged for recycling among members of the EIP, these exchanges should not be counted as additional consumption.

Figure 2-2 illustrates this view. The EIP depicted in this figure contains three companies. Each company obtains resources from

Figure 2-2. Internal Versus External Resource Use and Waste
EIP should count only external resources and external wastes when quantifying their environmental impact.



both external sources (R_E^i) and from the other EIP members (R_I^i). Each company also has two types of waste: waste that is discharged to outside of the EIP (W_E^i) and waste that is exchanged with other companies in the EIP (W_I^i). "Waste" is something of a misnomer for these internally traded substances, because they are really inputs to other production processes.[7] Thus, W_I^1, which is company 1's internally traded waste, is equal to R_I^2, which is company 2's internally obtained resources.

In Figure 2-2, the total waste discharges are equal to $W_E^1 + W_E^2 + W_E^3$, while the total resource use is $R_E^1 + R_E^2 + R_E^3$.

[7]U.S. Environmental Protection Agency (EPA) regulations provide a specific definition of a waste that discourages this type of thinking. We discuss reform of this type of statutory disincentive to EIPs in Chapter 5.

Components of the Environmental Performance Framework

This framework views environmental performance as an index of two elements:

- resource use within industrial processes and other activities within the EIP
- environmental discharges from industrial processes and other activities within the EIP

These two components of environmental performance also have subcomponents, as shown in Figure 2-3 and described below.

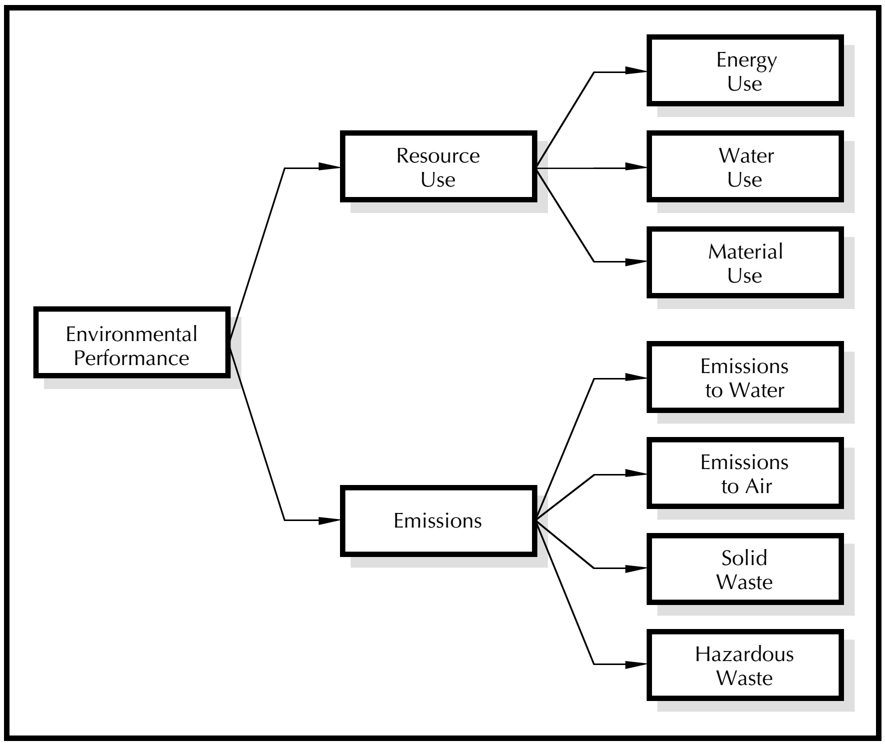


Figure 2-3. Elements of Environmental Performance
Resource use and environmental emissions have several subcomponents.

Resource Use. To measure performance with respect to resource use, we could consider both quantitative measures of the energy, water, and materials used by the EIP and qualitative measures of environmental practices and performance. A widely used quantitative measure is the total quantity of each resource per unit of output.

Qualitative measures can be used to augment quantitative data. Qualitative measures might include an assessment of

- the use of energy-efficient design, construction, and operating procedures;
- the use of solar, wind, water power, and geothermal energy; and
- the use of water and materials saving and recycling technologies.

The results of the practices, if they are effective, should be reflected in the quantitative measures of resource use. Thus, they should be used only as secondary indicators, because their use does not guarantee performance if, for example, the technologies are applied incorrectly or to inappropriate uses.

Environmental Emissions. Environmental emissions include releases to water and air and of solid waste and hazardous waste. Holding the level of output of goods and services constant, minimizing each category of environmental discharges improves environmental performance.

Discharges to water of particular concern to the community might include waste oil and other hydrocarbons, solvents, and other hazardous liquid substances. Discharges to air of particular concern to the community might include

- greenhouse gas emissions,
- ozone-depleting substances releases,
- SO_X and other acidifying substances,
- particulate releases,
- photochemically active substance releases, and
- volatile organic compounds (VOCs).

Noxious odors might also be of concern, particularly if the EIP is located near a residential area. For solid waste, we include solid waste shipped for disposal in either a local landfill or other disposal site. The performance framework could include both the relative level of emissions and the steps that have been taken to reduce them.

Other Environmental Considerations

Some environmental considerations are not covered by considering resource use and discharges. The aesthetics of the EIP and its other impacts on the local ecosystem might also be considered in evaluating its environmental performance. For example, if the EIP is built in an area that supports a particular type of wildlife, care might be taken to preserve the habitat of that wildlife as much as possible. Similarly, the EIP might be designed to minimize its impact on the view of natural landscape features such as mountains or bodies of water.

These qualitative considerations are difficult to integrate into a more quantitative framework that includes resource use and discharges. All else equal, a site that preserves habitats and ecosystems on the EIP grounds performs better than one that does not. A more extensive discussion of these design issues is provided in the accompanying document, *Fieldbook for the Development of Eco-Industrial* Parks. However, we do not include these factors in our quantitative framework.

Data Collection

Waste audits and engineering studies of industrial processes can provide quantities of resource use, discharge, and normalizing variables (such as quantity or value of output). Other data may be required to develop weights for each type of resource use or input. These data, as discussed below, may be obtained from risk studies or from the community's rankings of the importance of alternative environmental goals.

Comparisons to Reference Measures

To determine whether the EIP is environmentally beneficial, we must compare the measures of resource use and discharges mentioned above to some reference measure. The reference measure for an EIP could be the resource use and discharges of the same group of companies if they are not members of an EIP. That is, we can measure changes in discharges and resource use in moving from a without-EIP scenario to a with-EIP scenario. We take this approach in our analysis of a prototype EIP.

Alternatively, the reference could be some measure of the greatest achievable resource efficiency or minimum emissions level given the specific industrial processes involved. One common method for making comparative evaluations is called benchmarking. A benchmarking study of resource efficiency or emissions would measure a site's resource efficiency and emissions levels relative to sites with similar industrial processes that are considered excellent in resource efficiency or environmental emissions.[8]

However, a comparison of emissions and resource use will only provide an unambiguous comparison between the without- and with-EIP scenario (or between the EIP and the comparison company) if each of the indicators is moving either favorably or unfavorably. Otherwise, some weighting system must be used to compare the with- and without-EIP scenarios.

For example, suppose the with-EIP scenario results in a decrease in some types of emissions but an increase in others. How do we determine whether the with-EIP scenario is better? Similarly, what if the with-EIP scenario provides lower discharges but higher use of some types of resources?

It is possible to weight each of the resource efficiency elements to develop a single measure of resource efficiency by estimating technical efficiency.[9] Technical efficiency, a measure commonly used by economists, is the degree to which as few inputs as possible are used to produce a given output level. Typically, an economist uses information about the inputs and outputs of a production process to trace a production frontier, which defines the efficiency standard against which all other production units are measured. This is a fairly data-intensive process that may not be practical in many situations.[10]

Similarly, we could convert the four emissions types into a single emissions risk factor, which is usually done by conducting a risk assessment of each element. A complete analysis of the EIP's environmental benefits requires examining the change in risk to human health, plants, and animals due to changes in discharge patterns attributable to the EIP. Frameworks for assessing this risk are discussed in Cothern (1993).

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[8]An often-cited example of environmental benchmarking is an AT&T analysis of facility-level pollution prevention. See AT&T Bell Laboratories QUEST (1993).

[9]For a detailed description of calculating and applying technical efficiency measures, see Fare, Groskopf, and Lovell (1985); for an example of applying technical efficiency to measuring environmental performance, see Martin (1995).

[10]Technical efficiency can be used to assess environmental performance with respect to environmental discharges as well. For one recent application, see Smith (1994).

Because resource efficiency and emissions risk are measured in different metrics, it may not be possible to combine a weighted resource efficiency measure with a risk-weighted environmental emissions measure. Thus, the limitations of these methods may not allow for an unequivocal comparison between the with-EIP scenario and the without-EIP scenario if the two environmental performance factors provide consistent results.

An alternative weighting scheme, called Community Indifference Curves (CICs), takes into account the importance of a community's specific environmental concerns. For example, if a community has a particular need to conserve a natural resource, such as water, or to prevent discharges of specific types, such as VOCs, we may account for these needs by weighting these items higher in the CICs. This weighting scheme is discussed more thoroughly in the *Fieldbook for the Development of Eco-Industrial Parks*.

2.3.4 Application of the Performance Framework to the Brownsville/Matamoros EIP Prototype

As explained in Chapter 4, our approach to simulating the economic and environmental impacts of the EIP is to compare the without-EIP scenario (baseline) to each of the with-EIP scenarios. For each scenario, we examine changes in the activities of the EIP members that are directly caused by their simulated EIP membership. For each of these activities (e.g., resource exchanges, shared infrastructure, collocation), we examine its impact on the profitability of the companies as a group, as described in Section 2.3.1, and its impact on the resource use and emissions of the group of participating companies. Because of data and resource constraints, we limited our environmental impact simulation and analysis to changes in resource use and solid waste; a more complete characterization of the environmental risk effects of the EIP would be possible with additional time and data. However, we do note the importance of considering the EIP's effect on emissions to all media and considering its cross-media effects.

2.4 SUMMARY

Several groups of stakeholders are potentially affected by EIPs. The companies that are members of EIPs, the managers of EIPs, the members of communities in which EIPs locate, and the wider community each may gain from the establishment of a successful EIP. EIP members may increase their profitability, and EIP managers may derive profits from their management activities. Communities may benefit economically from hosting successful, competitive businesses that provide relatively little harm to the local environment. The wider community may gain from potential reduction in the environmental burden of industrial activities.

However, each of these stakeholders also faces a number of challenges and risks. EIP members risk

- developing dependent relationships with suppliers and customers within the EIP,
- incurring environmental liability for the actions of other EIP members,
- facing unforeseen changes in regulations governing the EIP, and
- dealing with uncertain effectiveness and profitability of applying specific technologies.

The successful EIP manager must

- manage relationships between companies,
- keep EIP positions filled,
- keep the EIP flexible enough to withstand changes in its membership over time,
- collect EIP data and apply it to the management process,
- assess the EIP's performance, and
- manage relationships with the community.

Communities considering developing an EIP face a number of risks and challenges. First, they must consider the alternative ownership schemes for an EIP and their implications on the community's control over the EIP and its objectives. Second, they face the challenge of finding funding and attracting the right developer and companies to the EIP. Finally, they must work with a variety of regulatory agencies to gain their cooperation and determine the regulatory status of the EIP and its members.

The economic benefits to EIP members can be measured in terms of several indicators of profitability and investment return:

- changes in annual profit
- change in the cost of production per unit
- change in productivity

- ROI
- payback period

Economic benefits to communities can be measured in terms of the EIP's contribution to

- value added by manufacture;
- total number of production workers;
- total production worker wages;
- average wage;
- tax revenues; and
- public expenditures for sewerage and sanitation, as a percentage of value added or tax revenues.

These statistics can be compared for the EIP and for other types of development.

The environmental impact of the EIP can be determined by examining the resource use and emissions of groups of companies in a with-EIP versus without-EIP scenario. A weighting scheme may be used, if necessary, to place all discharges on a risk-based metric and to convert quantities of resource use to a single metric of resource efficiency. Other weighting schemes can be developed that account for a community's special environmental concerns. Other environmental factors, such as the EIP's impact on community aesthetics and wildlife habitat, can also be considered.

3 A Prototype EIP for Brownsville, TX/ Matamoros, Mexico

In Chapter 1, we defined a five-step method for our EIP case study:

1. Develop methodology.
2. Build a prototype.
3. Define scenarios.
4. Collect data.
5. Calculate results.

We focused on the Brownsville/Matamoros area to take advantage of the richness of the issues that might be explored there, including border issues, environmental challenges to economic development, the importance of the support of a local champion, and the influence of incoming industry.

In this chapter, we introduce the prototype EIP and five EIP scenarios. We explain the changes in EIP members' operations that take place as we move from one scenario to the next. In the next chapter, we review our data and the results of our calculations of the economic and environmental impacts of these scenarios.

We focus on the Brownsville/Matamoros area to take advantage of the richness of the issues that might be explored there, including border issues, environmental challenges to economic development, the importance of the support of a local champion, and the influence of incoming industry. Appendix B provides some background information about Brownsville/Matamoros.

The prototype EIP comprises a group of EIP member relationships that we think are feasible for the area, given the community's resources, the existing economic structure, and the available technology. To develop the prototype and the scenarios, we used information we collected from many companies operating in the area, as well as one company that operates in another location, but which we believe would fit well with the economic and environmental conditions of the proposed EIP.

3.1 BUILDING THE PROTOTYPE EIP

The prototype EIP consists of a group of companies modeled after existing companies. Some of the relationships among these companies and their potential economic and environmental impacts depend on details specific to a site. Below, we describe how we chose a site for our prototype EIP and how we identified the potential symbiotic relationships among the EIP members. Then we describe each of the EIP members.

3.1.1 Choosing a Site

Our analysis of the benefits of moving from one EIP scenario to the next sometimes depends on site-specific details such as available infrastructure. To provide a basis for these details, we must choose a specific site for our prototype EIP. Choosing a site for an EIP is an important challenge to communities and EIP developers.

After considering several potential sites, we chose to assume that the prototype EIP is centered at the Port of Brownsville (Port).[1] The Port provides excellent infrastructure and access to industry, and several of the anchor members of the prototype EIP are currently located at the Port. The companion to this report, *Fieldbook for the Development of Eco-Industrial Parks* (Lowe, Moran, and Holmes, 1996), discusses in detail issues related to choosing an appropriate site.

Although we specify the Port as the location for the purposes of this analysis, we do not imply that an EIP could not be built at other locations in the Brownsville/Matamoros area. We will be careful to point out where our analysis depends on conditions specific to the Port so that an analogy to other locations might be developed.

The analysis scenarios include some companies that are currently located at the Port and some that are not. In Scenario 5, we analyze the benefits that collocation can have as compared to symbiotic

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[1] A brief description of the Port of Brownsville is provided in Appendix B.

relationships that occur between companies that are not collocated. In this case, we assume that all other costs (such as labor and land) are the same aside from the costs that are directly affected by the symbiosis. Certainly, this may not always be the case, and, as explained in the *Fieldbook*, these costs are important to a company's location decision. However, we concentrate on the potential cost savings from the symbiosis and assume that, if these outweigh other cost considerations, the company will benefit from the collocation.

3.1.2 Choosing the Members of the Prototype EIP

To choose members for our prototype EIP, we looked for companies that presented opportunities for symbiotic linkages with other companies in the area and were willing to participate in the exercise. The *Fieldbook for the Development of Eco-Industrial Parks* describes a procedure for analyzing potential byproduct exchanges among EIP members.

With the help of the Brownsville Economic Development Council we identified a subset of the businesses in Brownsville and Matamoros as potential candidates for the prototype EIP. Our criteria for choosing these companies were the following:

- Industry: The Brownsville Economic Development Council officials guided us to focus on electronics and metal plating firms, because of their potential growth and opportunities for waste exchange.
- Size: Larger establishments and establishments that are owned by large firms tend to be more conscious of their opportunities for economic improvement through environmental improvement and are more likely to employ a process engineer who will be able to determine the environmental and economic benefits of potential symbiotic relationships.
- Existence of a maquiladora sibling company: Brownsville establishments that have maquiladora plants in Matamoros must by law receive and process the wastes of their sibling companies. We felt that these companies would present an important opportunity for demonstrating how border proximity can affect the potential for EIP development.

A member of the project team phoned each of the companies on the candidate list and implemented a screening questionnaire.[2] The results of these questionnaires were examined for

- agreement to participate and
- opportunities to provide environmental and economic benefits through symbiotic links with other companies.

After determining which of the plants were best candidates, we called them again to schedule site-visit appointments.

[2] A copy of the questionnaire is provided in Appendix E.

Two to three project team members visited the companies for periods of 3 to 4 hours to review their operations, loosely following a predetermined site-visit protocol. We paid special attention to the inputs and outputs of each company and to the potential for using recycled material where virgin material is currently used and the potential for marketing byproducts that the company currently processes as waste. We summarized these site visits and prepared a chart detailing the inputs and outputs of each company. From this chart, we identified several opportunities for symbiotic byproduct exchange.

We further explored the opportunities that appeared promising. We interviewed the companies' engineers, consulted technical literature, and talked with consultants to determine the technical and economic feasibility of each relationship.

3.1.3 EIP Members

The prototype EIP contains 12 members. In the baseline scenario, four are located at the Port, and seven are located in the Brownsville/Matamoros area, but not at the Port. The final member of the prototype EIP is located near Houston.

EIP Port Members

1. 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.[3]
2. 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.
3. 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.[4]
4. 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

[3]The refinery is not actually operating at the moment. However, our conversations with refinery management personnel indicate that they plan to begin operating in the near future and eventually to operate at this level of capacity. We have assumed that they are operating at baseline.

[4]Currently, the asphalt plant actually imports its oil from outside the community. When the refinery is operating, it will use residual oil from the refinery. We assume this at baseline.

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

5. 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 percent of its scrap plastics.
6. 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.
7. Auto parts manufacturer—This company uses plastic injection molding, metal stamping, and powdered metal forming to make small parts for assembly at a maquiladora facility. A distant recycler buys the company's plastic scrap. The company also pays for disposal of several types of oil.
8. Plastic recycler—This recycler accepts 12 types of plastic, grinds it, and sells the grind overseas. The company also manufactures plastic pellets from scrap.
9. 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.
10. 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).
11. Manufacturer of magnetic ballasts—This company produces electronic and magnetic ballasts. It currently landfills about 332,200 kilos of waste asphalt per year.
12. Gypsum wallboard company—This EIP member, located in Houston, is the only member not located in the Brownsville/Matamoros area. This wallboard producer relies exclusively on synthetic gypsum as an input to its wallboard production process.

Not all of the EIP members participate in each scenario. At baseline, very few of the companies are working together. As we move from one scenario to the next, the level of cooperation among the members increases. In Scenario 5, each EIP member interacts with the others in some way.

Not all of the EIP members participate in each scenario. At baseline, very few of the companies are working together. As we move from one scenario to the next, the level of cooperation among the members increases.

3.2 EIP SCENARIOS

This section provides a qualitative description of the five analysis scenarios. We investigated these scenarios because they appeared to have the greatest potential for economic and environmental benefits. Many other potential analysis scenarios are probably possible. Those we examined are illustrated in Figure 3-1 and briefly summarized below.

Figure 3-1. Five Scenarios for the Prototype EIP Analysis
The five EIP scenarios build on each other as new symbiotic relationships are added in each step.

Scenario 1 *Baseline*	Baseline EIP members and production activities.
Scenario 2 *Pollution Prevention*	Members implement noncooperative pollution prevention activities.
Scenario 3 *Pollution Prevention plus Industrial Symbiosis*	EIP members develop symbiotic relationships with other EIP members and remote partners.
Scenario 4 *New EIP Members*	New symbiotic relationships develop as a result of new EIP members.
Scenario 5 *Collocation and Joint Services*	Remote partners locate within the EIP. EIP provides environmental services.

- **Scenario 1: Baseline Activities**. These are production activities assumed to be taking place among the members and remote partners of the prototype EIP.
- **Scenario 2: Pollution Prevention.** The existing EIP members implement P2 activities independently from the other members of the EIP. This scenario is useful because it allows us to show the benefits and limitations of individual P2 efforts and the gains achievable by looking outside the plant boundaries for waste reduction opportunities. Much of our analysis in this section is qualitative.
- **Scenario 3: Pollution Prevention plus Industrial Symbiosis.** We show the changes in production activities inspired by potential gains in environmental and economic efficiency from applying the concepts of IE. This scenario contains the

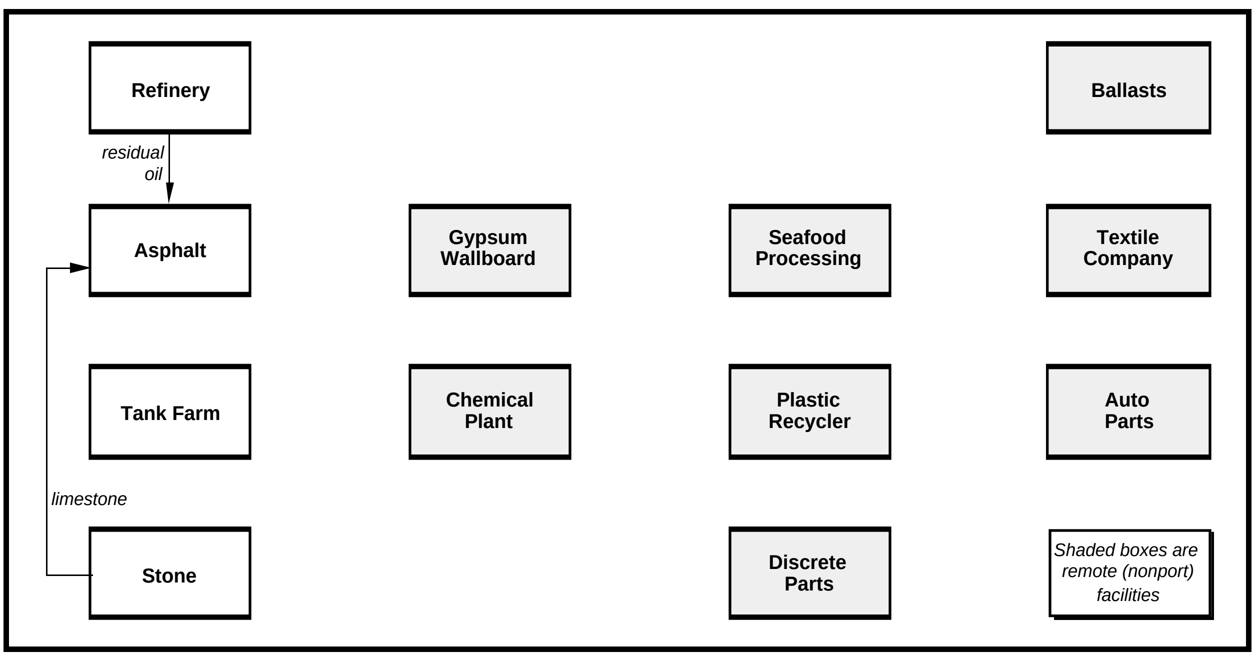
same group of companies as Scenario 2; however, in this scenario, they work together.

- **Scenario 4: New EIP Members.** We examine how new members of the EIP can enhance its environmental and economic benefits. The economic opportunity for these new members is created by companies interacting within the EIP.
- **Scenario 5: Collocation and Joint Services.** We analyze the additional benefits that can be derived from existing remote members if they are collocated. We consider additional opportunities for symbiosis that would be open to a company had it located at the Port. We also analyze the impact of the Port providing joint services.[5]

3.2.1 Scenario 1: Baseline Production and Trade Activities

Figure 3-2 provides a graphical representation of the baseline scenario. Companies' production activities and exchanges relevant to the EIP scenarios are briefly explained below.[6]

Figure 3-2. Scenario 1: Baseline Activities
These companies form the baseline scenario for the Brownsville/Matamoros EIP.



[5]We do not analyze other aspects of the location decision (e.g., differences in the lease or mortgage price of land at the Port vs. the previous location).

[6]Each of these descriptions is based on the operations of companies in the Brownsville/Matamoros area. However, we have also made assumptions about operation data where the actual data were not available.

At baseline, very few symbiotic relationships exist between these companies:

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

We also note that at baseline

- ➤ the freshwater source for the companies located at the Port is the City of Brownsville and
- ➤ wastewater treatment is provided for Port tenants.

These relationships have obvious economic benefits. The proximity of the asphalt plant to the refinery and the stone company minimizes transportation costs for these materials. In successive scenarios, more symbiotic relationships emerge. We describe these scenarios below and analyze their economic and environmental implications in Chapter 4.

3.2.2 Scenario 2: Pollution Prevention

This scenario describes some P2 and recycling opportunities that can provide economic and environmental benefits to the companies acting independently of other members of the EIP. P2 engineers from the Texas Natural Resources Conservation Commission (TNRCC) identified some of these opportunities during brief site visits to the companies; the companies identified others as projects in process or projects they were considering. We qualitatively analyze the following opportunities, which are relevant comparisons for later scenarios:

- ➤ The discrete parts manufacturer introduces an aqueous cleaning system and an oil water separation system.
- ➤ 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 noncritical cleaning processes.

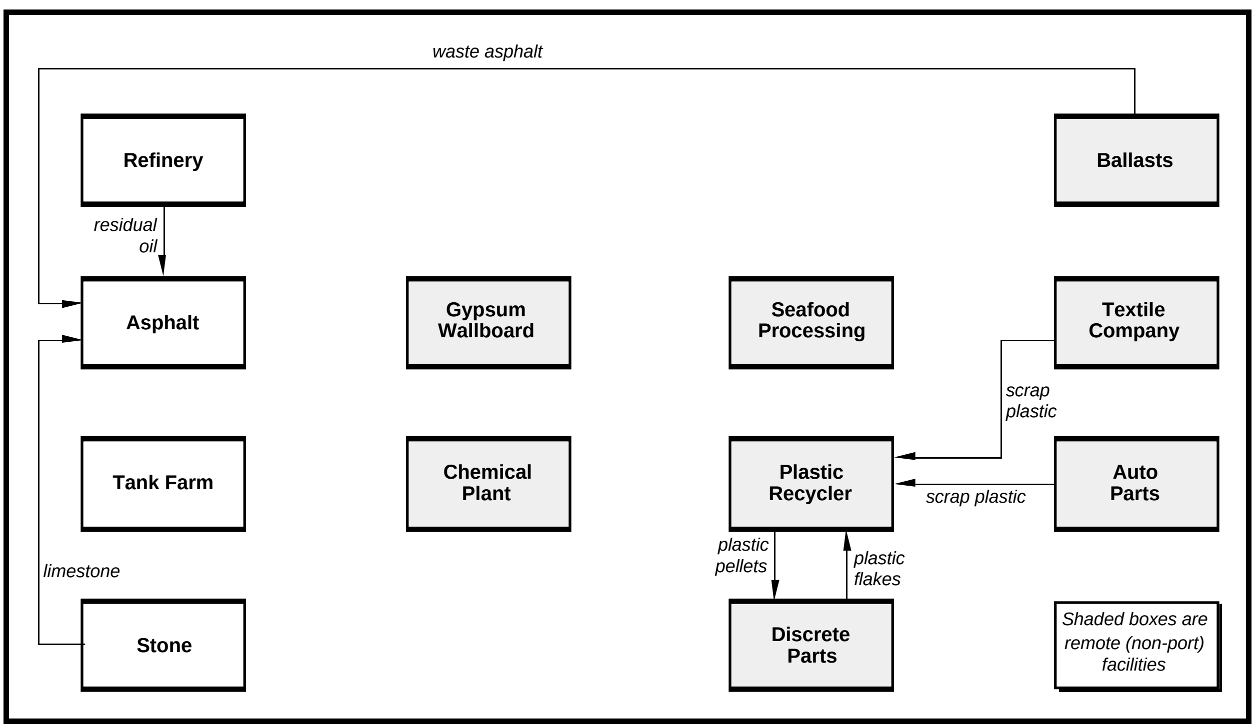
These opportunities were fairly limited in many cases because these companies had already taken steps to implement P2 programs. Côté et al. (1994) point out that the extent to which companies can accomplish P2 on their own is limited. By implementing these activities among larger groups of plants the possibilities for waste minimization increase as economies of scale make waste reduction techniques more cost-effective. The next scenario explains how the opportunities improve when interactions with other companies are considered.

3.2.3 Scenario 3: Industrial Symbiosis

The first development stage of the EIP is fairly limited (Figure 3-3). As explained above, this stage takes advantage of exchanges that can take place with little or no additional investment. Thus, it is not surprising that few opportunities arise from this "low hanging fruit."

- The discrete parts manufacturer sells scrap plastic, which is currently landfilled, to the recycler. He also purchases plastic pellets, which he currently purchases from a more distant source, from the plastic recycler. 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 3-3. Scenario 3: Industrial Symbiosis
The exchange of scrap plastic and waste asphalt among noncollocated companies characterizes this scenario.



3.2.4 Scenario 4: New EIP Members

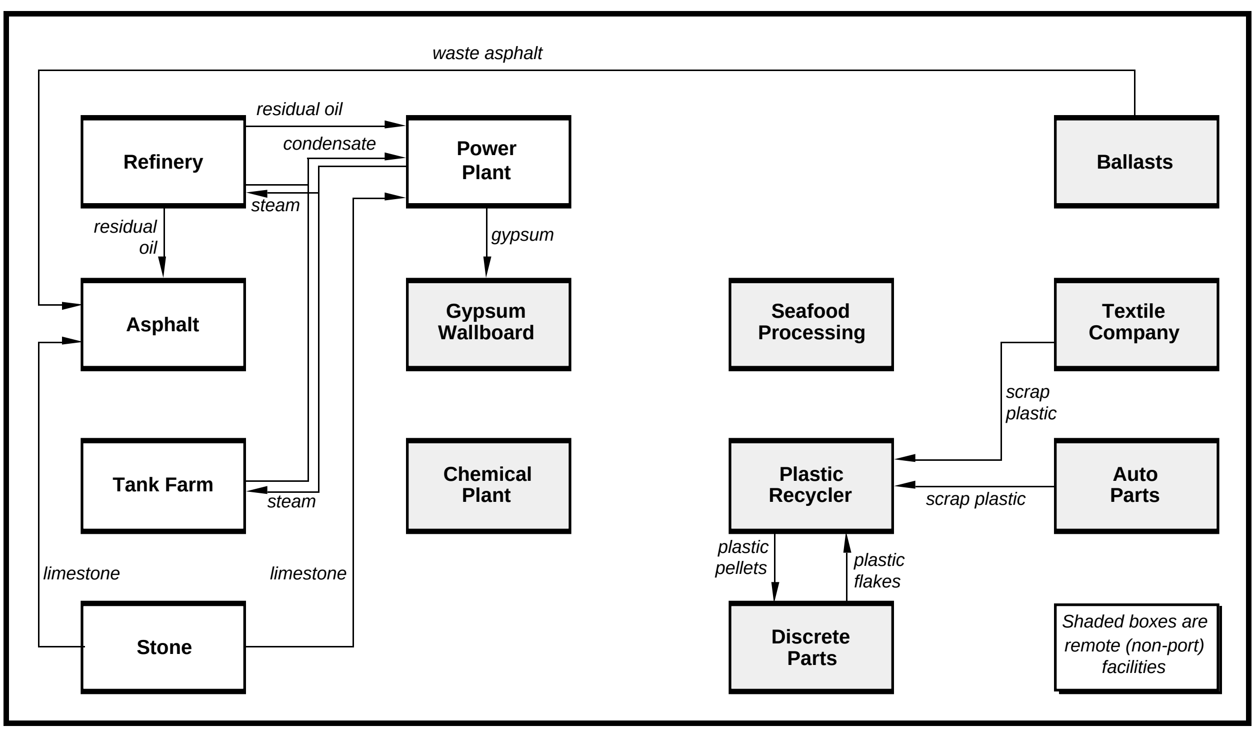
In this stage, we examine the environmental and economic benefits of creating new businesses within the EIP (Figure 3-4). These new businesses develop a niche in the industrial ecosystem that is forming among the members and remote partners of the EIP. The new members include the following:

- 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 3-4. Scenario 4: New EIP Members
A power plant and a remote gypsum wallboard company are added to the EIP.



3.2.5 Scenario 5: Pollution Prevention, Industrial Symbiosis, and Collocation; Joint EIP Services

In this stage, we assume that the remote partners are collocated with the remainder of the EIP members. We *do not* analyze their decision to move into the park from their current location; we only show the additional benefits that could be derived from collocation. We also analyze 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 takes place with lower transportation costs.
- ➤ The water pretreatment 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
  - √ textile company.

Figure 3-5 also shows the seafood processor providing brown water to the textile company. In our prototype, this brown water is used to provide a rooftop sprinkling system to cool the textile company. Although we do not quantify the benefits of this relationship in Chapter 4, we include it in Figure 3-5 because it demonstrates one important method for conserving water—water cascading. We discuss the technology that underlies this relationship in Chapter 6.

3.2.6 Summary of EIP Scenarios

Table 3-1 provides an overview of the exchanges simulated in Scenarios 3 through 5 that we quantitatively analyze in Chapter 4. We analyze Scenario 2 qualitatively, because we were unable to obtain sufficient data to quantify the economic and environmental effects of this scenario.

Figure 3-5. Collocation and EIP Services
All previously remote facilities are assumed to be located at the Port and solvent and oil recycling facilities serve the EIP.

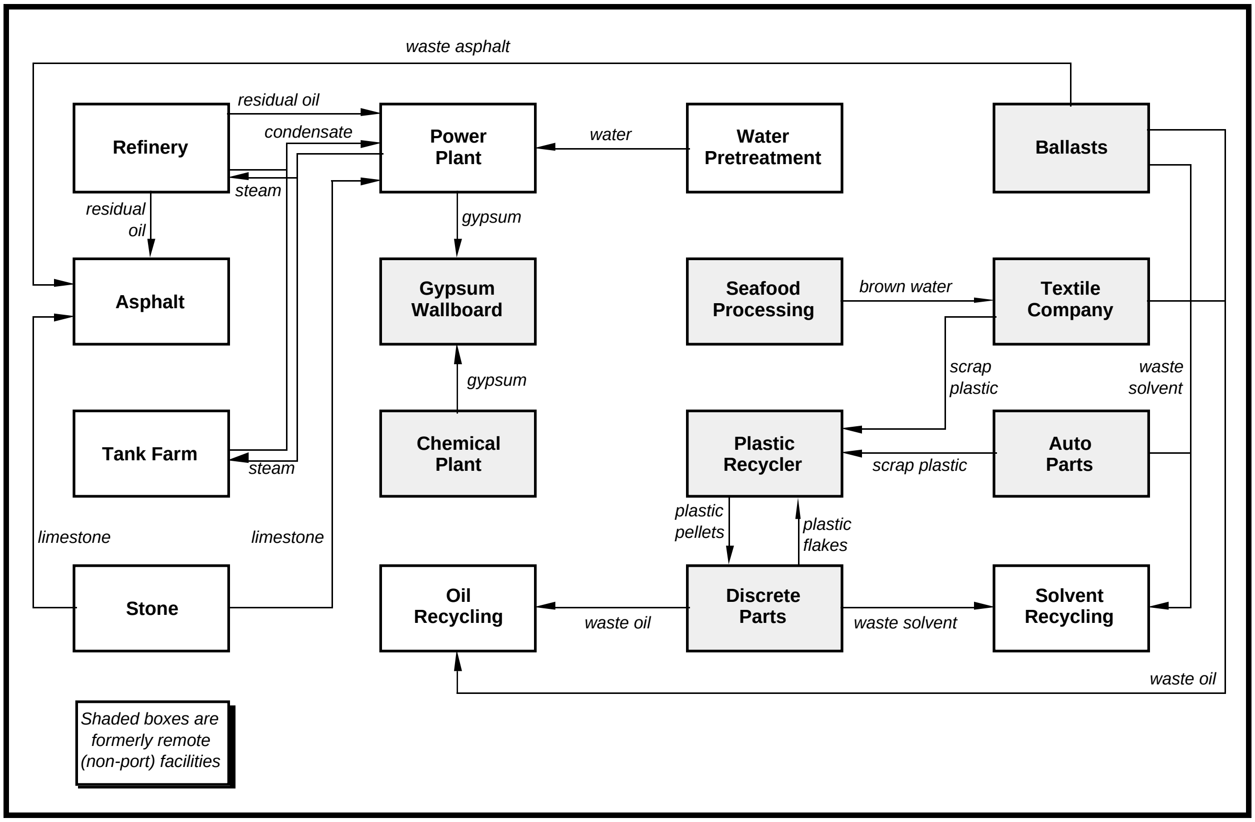


Table 3-1. Summary of Changes In Resource Flows Simulated for the Prototype EIP
EIP members and remote partners have a variety of ways of exchanging resources.

Resource Simulated (Units) and Affected Facility	Resource Management Approach
Orimulsion™ (bbl/Yr)	
Power Plant	The power plant enters the EIP at Scenario 4. We assume that without the EIP the power plant will burn just enough Orimulsion™ (4,661,196 bbl/yr) in its boiler to operate a 300 MW facility at 80 percent capacity. We also assume that this quantity will increase by 3.5 percent in Scenario 4 to permit delivery of process steam to the refinery without reducing the amount of electricity generated.
Electricity (kWh/Yr)	
Power Plant	We assume the power plant will generate 2,049,840,000 kWh of electricity for use by industry and the public in the Lower Rio Grande Valley if it were not in the EIP. In Scenario 4 we assume that 0.5 percent of this will be needed to provide extra power for an improved FGD system that can recover a superior synthetic gypsum byproduct.
Heat (Btu/Day)	
Refinery	The refinery needs heat to vaporize crude oil. At baseline, it burns 456,250 bbl/yr of residual oil for this purpose. We assume that in later scenarios the refinery will receive 262,000,000 Btus/hour of heat in the form of process steam from the power plant.
Power Plant	Without the EIP, the power plant operates as a stand-alone facility, with no exchange of heat with neighboring facilities for use in their industrial processes. In Scenario 4 we assume the power plant provides 262,000,000 Btus per hour for use at the refinery.
Residual Oil (bbl/Yr)	
Refinery	At baseline, the refinery produces 3,041,667 bbl/year of residual oil. Of this, 456,250 bbl/yr of residual oil are used for fuel in the refinery's burner to heat crude oil to its flashpoint leaving 2,585,417 to sell. In Scenario 4 the refinery's fuel requirements are reduced by the availability of process steam from the power plant.
Boiler Feed Water (Gal/Yr)	
Power Plant	Without an EIP the power plant will require 63,072,000 gal/yr of boiler feed make-up water. More boiler feed make-up water is needed in later scenarios to permit delivery of process steam to the refinery.
Pretreatment Chemicals ($/Yr)	
Power Plant	The power plant would spend $157,680/yr to pretreat its boiler feed make-up water if no arrangements are made to cascade heat to neighboring facilities. This expense will increase as more boiler feed make-up water is needed to permit delivery of process steam to the refinery.

(continued)

Table 3-1. Summary of Changes In Resource Flows Simulated for the Prototype EIP (continued)

Resource Simulated (Units) and Affected Facility	Resource Management Approach
Synthetic Gypsum	
Chemical Plant	The chemical company generates 281,050 tons/yr of synthetic gypsum and disposes of this byproduct by giving it to the Mexican government for use in road building. This volume decreases when the gypsum is dried more thoroughly to permit a wallboard manufacturer to reuse it.
Power Plant	In the absence of an EIP, we assume that the power plant will landfill the 121,545 tons/yr of synthetic gypsum collected from its FGD system. For the with-EIP scenarios we assume that the volume of gypsum produced will increase as more fuel is burned to offer process steam to the refinery but that it will decrease with gypsum recovery efforts, because synthetic gypsum must be dried more completely to be of value to a wallboard manufacturer.
Limestone	
Power Plant	Without an EIP the power plant uses 73,803 tons/yr of limestone for its FGD system. This quantity increases in Scenario 4, when additional fuel must be burned to provide steam for the refinery to use.
Stone Company	The stone company increases its sales of limestone to the power plant by 73,2,496 tons/yr in Scenario 4 to meet the additional needs of the power plant's FGD system when additional fuel is burned to provide process steam to the refinery. We assume that net annual revenues increase by just 10 percent of the annual increase in sales.
Asphalt	
Asphalt/Hot-Mix Co.	The asphalt company produces a hot-mix product that is 10 percent residual oil from the refinery and 90 percent crushed limestone from the stone company. We estimated the price of this asphalt company output using a weighted average of the factor input prices.
Waste Asphalt	
Ballast Manufacturer	At baseline the ballast manufacturer landfills 730,831 tons/yr of waste asphalt at a cost of $35/ton. In later scenarios it delivers this waste to the asphalt company at the EIP for a net savings of $35/ton minus transportation costs.
Asphalt/Hot-Mix Co.	We assume that in Scenario 3 the asphalt company receives 730,831 tons/yr of waste asphalt from the ballast manufacturer at no charge. We assume the net impact of this arrangement on asphalt company revenues to be equal to 10 percent of sales of an identical volume of its finished product.
High-Value Scrap Plastic	
Auto Parts Co.	At baseline the auto parts manufacturer sells its high-value scrap plastic to a plastic recycler in Chicago. In later scenarios we assume that it sells its scrap plastic to the local plastic recycler for the same delivered price. This results in a net savings equivalent to the difference in transportation costs for each recycling alternative.
Plastics Recycler	At baseline the plastic recycler receives no plastic materials from any of the prototype EIP members. In later scenarios it is assumed to pay $0.15/lb for the 29,952 lbs/yr of high-value scrap plastic that it buys from the auto parts manufacturer.

(continued)

Table 3-1. Summary of Changes In Resource Flows Simulated for the Prototype EIP (continued)

Resource Simulated (Units) and Affected Facility	Resource Management Approach
Low-Value Scrap Plastic	
Auto Parts Co.	At baseline the auto parts manufacturer sells its low-value scrap plastic to a plastic recycler in Chicago. In later scenarios it sells its scrap plastic to the local plastic recycler for the same delivered price. This results in a net savings equivalent to the difference in transportation costs for each recycling alternative.
Textile Company	At baseline the textile company disposes of its scrap plastic in a landfill at a cost of $0.416/lb, which includes transportation costs to the landfill. In later scenarios it sells this waste to the plastic recycler for an effective price of $0.03/lb minus transportation costs.
Plastic Recycler	At baseline the plastic recycler receives no plastic materials from any of the prototype EIP members. In later scenarios it pays $0.05/lb for the low-value scrap plastic that it buys from the auto parts manufacturer and the textile company.
Unsorted Plastic Flakes	
Discrete Parts Co.	At baseline the discrete parts manufacturer grinds its scrap plastic into unsorted plastic flakes, which it then landfills at a cost of $25/ton plus transportation costs to the landfill. In later scenarios it sells this waste to the plastic recycler for an effective price of $0.03/lb minus transportation costs.
Plastic Recycler	At baseline the plastic recycler receives no plastic materials from any of the prototype EIP members. In later scenarios it buys 11,232 lbs/yr of unsorted plastic flakes from the discrete parts manufacturer for $0.03/lb.
Sorted Plastic Flakes	
Plastic Recycler	We assume that the plastic recycler converts all of the plastic materials that it receives from prototype EIP members to sorted plastic flakes, which it then sells for an average price of $0.1333/lb.
Solvents/Oils	
Discrete Parts, Ballasts, Auto Parts, Textiles	Centralized facilities for solvent and oil recycling are set up at the EIP in Scenario 5. We assume that, before the EIP, these companies collectively used two types of solvents and paid $1.50/gal to dispose of solvent waste. The EIP collectively purchases a solvent distillation unit and recycles solvents back to the EIP.

4 Results of the EIP Prototype Simulation

In Chapter 3, we introduced the prototype EIP and the five EIP scenarios, briefly describing the operational changes resulting from EIP participation. In this chapter, we review the results of our economic and environmental analysis of each EIP scenario. First, we review our analysis approach. Then we explain how we quantified the economic and environmental benefits of each EIP scenario. Finally, we summarize our results, draw conclusions, and discuss the limitations of our analysis. Some of these limitations are addressed in Chapters 5 and 6 of this report, and in the *Fieldbook for the Development of Eco-Industrial Parks* (Lowe, Moran, and Holmes, 1996).

4.1 ANALYSIS APPROACH

> The case study is a model for demonstrating the potential economic and environmental impacts of applying IE principles and exploring the way those impacts vary with changes in the specific circumstances.

This section describes the analysis procedures and spreadsheet model used to simulate changes in economic and environmental performance that might be achieved in the prototype EIP in Brownsville. This model can provide three basic types of information for each EIP scenario:

- net changes in their materials flows
- changes in their net annual revenues
- their incremental annualized fixed costs

The model can quantify these expected changes for each proposed symbiotic relationship or collectively for all new relationships included in the EIP development scenarios presented in Section 4.2.

From this information, we calculated changes in annual profit, ROI, and payback periods.

Our profitability measures refer exclusively to the profitability of the EIP relationships we describe, rather than to the overall profitability of an EIP member, which would require complete knowledge of each company's baseline operations and finances.

Net changes in materials flows represent the expected environmental impact of each EIP scenario. These analyses are somewhat incomplete. First, the level of detail is not sufficient to capture all of the secondary environmental impacts of the symbiosis. For example, whenever transportation is eliminated because companies collocate, we do not examine the decreases in air emissions resulting from the decreased use of fossil fuels. Second, the effects cannot be aggregated across input and output types to determine their combined effect on the local ecosystem. Aggregating these effects would require a risk weighting scheme similar to that discussed in Section 2.3.3. Such an effort is beyond the scope of the case study.

4.1.1 Data Sources

Data sources include
- company representatives operating similar plants in the Brownsville/ Matamoros area
- responses to questions about baseline inputs and outputs

The facilities described in this case study are model plants that are based on information obtained from representatives of the companies operating similar plants in the Brownsville/Matamoros area. We compiled information about materials flows, costs, and revenues at baseline from responses to questions regarding the quantity of inputs required and outputs produced at baseline levels of production. This is not an exhaustive inventory of materials flows, rather it is an accounting only of materials and process costs that are projected to change as a result of the hypothetical symbiotic relationships simulated for each stage of the prototype EIP. Some of the baseline materials flow data reflect EIP members' best estimates of costs and quantities rather than historical costs and quantities, because even the baseline scenario involves some hypothetical interactions among fledgling facilities and businesses that are not yet fully operational.

We call this analysis a simulation, rather than an estimate, because, although we used actual engineering and economic data wherever possible, we encountered difficulty obtaining the level of detail and accuracy necessary for credible estimates of the impact of the simulated symbioses. Individuals that provided estimates of cost changes or changes in the required inputs or outputs made it clear that they could not evaluate the accuracy of their estimates without first conducting a detailed engineering analysis of the assumptions used to make their estimates. This is particularly true of symbiotic relationships involving the fledgling facilities included in our baseline scenario, whose operations are in some cases still in the planning stage, and of relationships described in Scenarios 4 and 5 that involve new EIP members and collocation of remotely sited facilities.

4.1.2 Net Benefit

As explained in Chapter 2, the net benefit attributable to an EIP relationship is the change in annual net revenue minus the annualized investment required to move from baseline to each EIP scenario.

> In our case study, we refer to the net benefit, rather than the annual change in profit, of a symbiosis. This is the combined annual change in revenue for all EIP companies minus the combined annualized investment and O&M costs required to facilitate the symbiosis. Although this is basically the same as profit for all companies combined, we do not know how these benefits will be distributed among the EIP members; thus we refrain from calling these benefits profits.

We cannot realistically predict how these net benefits would be distributed among the companies. This estimate would depend on the specific bilateral contracts negotiated between the partners to an exchange. Instead, we compare the combined annual change in revenue for all EIP companies to the combined annualized investment and O&M costs required to facilitate each new level of symbiosis. We call this the net benefit of the symbiosis, because it is not really appropriate to speak of profit when discussing the joint benefits of the EIP. If the net change in annual cash flows anticipated from a new symbiotic relationship is sufficient to cover both the incremental annualized investments and annual O&M costs associated with the relationship, then one can reasonably assume that the affected parties will be able to negotiate a cost-sharing arrangement that would benefit each of them. Thus, if we let

i = index of inputs and outputs subject to change due to participation in the EIP and

j = the index of EIP scenarios (where Scenario 1 represents activities at baseline),

then the appropriate formula for calculating the change in profit that is attributable to the symbiotic relationships described by Scenario j would be

$$\Delta\pi_j = \left(\sum_{i=1}^{n} p_{i,j} * x_{i,j} - \sum_{i=1}^{n} p_{i,1} * x_{i,1} \right) - I_j \qquad (4.1)$$

where

$\Delta\pi_j$ = the changes in annual profit under Scenario j,

$p_{i,j}$ = the Scenario j price of good i,

$x_{i,j}$ = the estimated quantity of good i used or produced in Scenario j,

$p_{i,1}$ = the baseline price of good i; and

$x_{i,1}$ = the quantity of good i used or produced at baseline,

I_j = the annualized capital investment required to implement Scenario j.

Input or Output?
In our analysis, inputs to a production process are shown as negative numbers while outputs are positive. This facilitates thinking of the same material as an input and an output.

x_i is positive if it is an output and negative if it is an input to the production process. This form of the annual profit function facilitates thinking of the same material as an input and an output. Gypsum, for example, an input to production for the wallboard company, is a byproduct of production for the chemical plant and the power plant. We distinguish between inputs and outputs only by noting that inputs constitute "negative output" and therefore are entered as negative quantities in the simulation model. Similarly, the price received for an output can be negative if it is costly to dispose of that output.

4.1.3 Annualizing Fixed Costs of EIP Development

Some types of industrial symbiosis developed for this case study involve process changes at one or more EIP-member facilities that are not possible without significant new investments in capital equipment. These capital investments are one-time expenses and may be too large for some facilities to finance with working capital. In many cases they would have to be paid for with debt financing. The costs associated with new capital investments should be annualized over the expected usable life of the capital equipment to represent the annual cost of financing the lump-sum cost. These annualized costs, plus the net change in O&M costs, represent the amount of change in affected facilities' annual costs.

To annualize capital costs associated with each level of industrial symbiosis we used the following formula:

$$I_j = \frac{F_j - F_1}{\frac{1-(1+r)^{-t}}{r}} \quad (4.2)$$

where

I_j = annualized cost of capital investment,

$F_j - F_1$ = lump-sum cost of capital investment to move from baseline to Scenario j,

r = interest rate at which capital investments are financed, and

t = the term of the loan and estimated life of investment.

For this case study we assumed that all capital investments would be debt financed at an interest rate of 7 percent[1] over 20 years. Actually, individual companies will have different costs of capital that will vary according to their financial health and their relative reliance on commercial debt versus equity financing. Differences in companies' borrowing power can have enormous impact on the potential success or failure of cost-sharing negotiations. The hypothetical nature of most capital investments projected in this analysis and respect for the confidentiality concerns of the companies that have contributed to this case study prevented us from attempting to estimate company-specific costs of capital.

4.1.4 ROI

ROI is normally used to compare alternative investment scenarios. For the EIP, it can be used to compare alternative investments in EIP infrastructure.

We calculated an ROI for each relationship. As explained in Section 2.3, the equation used to calculate the ROI is

$$\sum_{i=0}^{n} \frac{\Delta\pi_{t+1}}{(1+r)^i} = 0 \quad (4.3)$$

where $\Delta\pi_{t+i}$ is the net benefit (benefit minus cost) of the investment in the ith year after the project begins (year t); n is the number of years over which the investment provides benefits (or costs), and solving for r provides the ROI. The ROI is compared to expected returns on alternative investments to determine which investment strategy should be undertaken.

[1]This is the discount rate recommended by the Office of Management and Budget for conducting cost-benefit studies. See OMB Circular A-94.

4.1.5 Payback Period

We calculated the payback period for each scenario. As explained in Section 2.3, the payback period is total investment divided by annual net revenue.

4.2 SIMULATION OF ECONOMIC AND ENVIRONMENTAL BENEFITS

This section describes how we developed the simulations for each of the EIP scenarios described in Chapter 3. Recall that at baseline, several of the EIP members were already exchanging byproducts: the refinery is selling residual oil to the asphalt company, and the stone company is selling limestone to the asphalt company. Each of the scenarios below builds on these baseline relationships. Some of the technical details of these scenario analyses are provided in Appendix B.

4.2.1 Scenario 2: Pollution Prevention

We visited each of the EIP companies with P2 engineers from the TNRCC and performed a brief audit of their wastes. The engineers provided suggestions regarding how each company might reduce its wastestream on its own, without the cooperation of other EIP members.

The opportunities for P2 among these companies are somewhat limited. Most of these companies have on-site environmental engineers that work to identify opportunities for reducing waste. Thus, they have already implemented most of the steps that they could take on their own.

Table 4-1 provides a list of P2 opportunities for some of the prototype EIP companies.

4.2.2 Scenario 3: Pollution Prevention Plus Industrial Symbiosis

In addition to the baseline exchanges of limestone and residual oil, this scenario includes the exchange of scrap plastic and waste asphalt among companies that are not collocated. Table 4-2 summarizes the changes in materials flows and net revenue resulting from this scenario. Below, we explain our assumptions and method for deriving these results.

Table 4-1. Analysis of Pollution Prevention Opportunities for Members of the EIP
Prototype EIP companies have a few additional pollution prevention opportunities.

EIP Member	Activity	Economic Impact	Environmental Impact
Discrete parts manufacturer	Introduction of aqueous cleaning system	Inferior cleaning (reduced disposal costs) Cost: $15,000	Replace other solvents; waste is oily water rather than used solvents
	Introduction of oil-water separation system	Can re-use water; Cost: $16,000 Water savings = 0.3 cents/gal	Less water use Replaces large volumes of oily waste water with smaller volumes of oil waste
Textiles	Recycling of cutting room clippings	Requires purchase of bailer and one employee; Net savings = $30,000/yr	2.25 million lbs less to landfill
Auto parts	Purchase of ringer system for absorbent socks and rags	Replace socks and rags less often	Reduces landfill waste
Seafood processor	Use of brown water for noncritical cleaning	Water savings = 0.3 cents/gal	Less water use

Plastic Recycling

We assumed that four types of plastic products are exchanged among members of the EIP: low-priced scrap plastic, high-priced scrap plastic, unsorted flaked plastic, and sorted flaked plastic.[2] We based the prices paid for plastics and the revenues received for ground plastics on price estimates provided by a recycler in the Brownsville/Matamoros area. The recycler pays between 5 and 15 cents/lb for scrap plastic, depending on the type of plastic, and receives between 15 and 25 cents/lb for flaked plastic, also depending on the type (Maupome, 1995a). We assumed there are two types of scrap plastic: low-value scrap plastic, for which the recycler pays 5 cents/lb, and high-value scrap plastic, for which the recycler pays 15 cents/lb. We assumed the recycler pays 3 cents/lb for unsorted plastic flakes.

[2]There is also the possibility of an exchange of plastic pellets between the plastic recycler and the discrete parts manufacturer; however, we did not include this exchange in the quantitative analysis because of a lack of information about the specific plastic requirements of the discrete parts manufacturer.

Table 4-2. Simulated Changes in Materials Flows and Net Revenues Under Scenario 3
Changes in net revenues occur in this scenario when scrap plastic and waste asphalt are exchanged among companies.

Resource Simulated (Units) and Affected Facility	Input or Output	Baseline Parameters: Baseline Quantity[a]	Baseline Parameters: Baseline Price ($1995)	Scenario 3 Parameters: Δ Annual Quantity[a]	Scenario 3 Parameters: Price ($1995)	Net Annual Changes in Benefits and Costs: Δ Annual Net Revenues ($1995)	Net Annual Changes in Benefits and Costs: Δ Annual Fixed Costs ($1995)
High-Value Scrap Plastic (lbs)							
Auto parts	Output	29,952	0.0950	0	0.1475	1,572	0
Plastic recycler	Input	b	0.15	(29,952)	0.15	(4,493)	0
Low-Value Scrap Plastic (lbs)							
Auto parts	Output	29,952	(0.005)	0	0.0475	1,572	0
Textile company	Output	119,995	(0.4166)	0	0.0475	55,690	0
Plastic recycler		b	0.05	(149,947)	0.05	(7,497)	0
Unsorted Plastic Flakes (lbs)							
Discrete parts	Output	11,232	(0.015)	0	0.0275	477	0
Plastic recycler	Input	b	0.03	(11,232)	0.03	(337)	0
Sorted Plastic Flakes (lbs)							
Plastic recycler	Output	b	0.1333	191,131	0.1333	25,478	0
Asphalt (lbs)							
Asphalt/hot mix	Output	5,718,914,754	0.3568	730,831	0.3568	26,076[c]	0
Waste Asphalt (lbs)							
Asphalt/hot mix	Input	0	0	(730,831)	0	0	3,944
Ballast manufacturer	Output	730,831	(0.0207)	0	(0.00325)	12,790	0

Scenario 3: Economic and Environmental Impacts

Symbiotic Relationship Simulated	Δ Annual Net Revenues ($1995)	Δ Annual Fixed Costs ($1995)	Net Benefits ($1995)	Payback Period (Years)	ROI	Reduction (lbs) in Material Sent to Landfill
Plastics	72,463	0	72,463	N/A	N/A	131,227
Asphalt	38,865	3,944	34,921	0.28	359%	730,831
Both	111,328	3,944	107,384	N/A	N/A	862,058

[a]Quantities in parentheses are negative. Input quantities are assigned negative values to denote resource use.
[b]We do not know the baseline quantity of plastic handled by the recycler, but this does not affect the analysis.
[c]The value shown is an estimate that assumes that the net increase in facility net revenue is 10 percent of the dollar increase in sales.

Transportation costs for plastic were also based on information provided by the local plastic recycler. We assumed that transportation of plastics from Brownsville to Chicago costs 5.5 cents/lb; transportation within the Brownsville area costs 0.25 cents/lb (Maupome, 1995b).

Landfill costs are $25/ton for trash from Brownsville (Ayala, 1995). We assumed that transportation costs to send plastic to the local recycler will be no different from the costs at baseline to ship plastic to the landfill. Thus, although transportation costs reduce the effective prices received by the EIP members that sell plastics to the recycler, they do not affect the choice between selling to the EIP recycler and sending the plastics to a landfill.

We assumed that three companies will use the local EIP plastic recycler's services: the discrete parts manufacturer, the auto parts manufacturer, and the textile company.

Discrete Parts Manufacturer. The discrete parts manufacturer is currently grinding and landfilling approximately 15 gaylords of mixed plastics per year. An approximate conversion for mixed ground plastics is between 500 and 1,000 lbs/gaylord (CDM, 1993). Using the median value, 750 lbs/gaylord, we assumed the company is landfilling approximately 11,250 lbs of mixed plastic per year.[3] The effective baseline price per pound received by the discrete parts manufacturer for scrap plastic (-1.5 cents) reflects the landfill cost and the transportation cost of taking the plastics to the landfill.

We assumed in this scenario that this manufacturer sells his ground plastic to the recycler, who separates it and sells it.[4] This scenario requires no change in operations, no purchase of machinery, and no additional labor. The discrete parts manufacturer would receive an effective price of 2.75 cents/lb for the plastic; the recycler pays him 3 cents, and he pays 0.25 cents in transportation costs.

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[3]The value in the table is slightly different due to rounding from daily values.

[4]We actually considered two other options for the manufacturer: purchasing of a separation machine to separate the plastics after they are ground or instituting a program to sort the plastics prior to grinding. Both of these alternatives led to lower net revenues than the option of simply selling the ground plastic to the recycler. For a more detailed analysis of these other options, see Appendix B.

Increasing Value Added in the Community
The EIP provides a community the opportunity to increase its value added, which is the difference between the value of what is imported to the community and what is exported from the community. For example, if a company sends its plastic byproducts to a local company, rather than to a company outside the community, the value added to the plastic during processing by the recycler stays within the community. Value added is an important economic indicator because it measures the EIP's contribution to the local economy.

Auto Parts Manufacturer. The auto parts manufacturer generates approximately 60,000 lbs of scrap plastic per year.[5] Based on our conversations with the plant manager, we assumed that this plastic is evenly divided between high-value plastic and low-value plastic. Prior to our visit, this company was selling its scrap plastic to a broker in Chicago, not realizing a local recycler would handle it. We assumed that the recycler in Chicago was paying the manufacturer the same prices he would receive from the local recycler. However, by using the local recycler, the manufacturer saves the difference in transportation cost of transporting the plastic to Chicago versus shipping it locally. The effective price the manufacturer receives for each type of plastic rises by 5.25 cents/lb.

Textile Company. At the time of our original visit to the textile company, the company was landfilling approximately 10,000 lbs of plastic per month,[6] which consisted mostly of high-density polyethylene, a low-value plastic. The cost of landfilling this plastic, as cited by the company representatives, was approximately $50,000/year. In this scenario, the textile company saves the landfill costs and gains the revenue from selling the low-value plastic to the local recycler.

Waste Asphalt Recovery

Maquiladora Plants and the EIP
Companies in the U.S. that have twin plants in Mexico under the maquiladora policy must return any byproducts of U.S. origin to the U.S. This offers an opportunity for the U.S. plant to engage in symbiotic relationships that use byproducts from both their U.S. and their Mexican operations cost-effectively.

An asphalt company that the refinery plans to build at the Port presents another opportunity for industrial symbiosis within the EIP prototype. Asphalt is made from about 90 percent crushed limestone and 10 percent heavy residual oil. The refinery plans to build the asphalt plant next to the limestone depot on the Port and will transport the stone by conveyor and the residual oil by truck.

The ballasts manufacturer currently landfills about 30 tons each month of a "Class 2 nonhazardous" asphalt material, "pitch," that is used to dampen the vibrations and ensuing hum from transformers encased in the fluorescent light ballasts they produce. This company operates under a maquiladora framework with six licensed production and assembly facilities in Matamoros and a warehousing and administrative office in Brownsville. Many of the material inputs they use, including the pitch, are produced in the

[5] The baseline values in the table are slightly different due to rounding from daily values.

[6] The baseline value in the table is slightly different due to rounding from daily values.

U.S., and input materials that are wasted must be disposed of in their country of origin. The company recognizes the value of the materials they use in production and already takes steps to efficiently minimize the amount of pitch that is wasted. Tipping fees for such wastes at the landfill are $35/ton (Ayala, 1995).

If the asphalt company accepted the waste asphalt from the magnetic ballast manufacturer, the asphalt company would save the landfill cost associated with this waste. The effective price of this ballast company output at baseline is a negative value equal to $35/ton plus $6.5/ton for transportation to Brownsville, or 2.08 cents/lb, the cost of delivery and disposal of waste from a maquiladora facility in the Brownsville landfill. Under Scenario 3, the landfill cost is eliminated, but the company still incurs transportation costs from the asphalt company to the Port. Thus, the effective price under Scenario 3 is -$6.50/ton or -0.325 cents/lb (Ostos, 1995). This arrangement requires investing $10,000 for a new tank and $3,000/month for testing the recovered asphalt for impurities (Linck, 1995).

Scenario 3 Summary

Table 4-2 summarizes the economic and environmental benefits of the plastics and asphalt exchange under Scenario 3. The change in annual net revenue is $111,328; the change in annual net revenue minus annualized fixed costs is $107,384.[7] The ROI for the investment in the asphalt tank, which was calculated from the benefits of the asphalt exchange only, is 359 percent.

The environmental benefits include a reduction in landfill waste of 131,227 lbs of plastic and 730,831 lbs of waste asphalt per year.

4.2.3 Scenario 4: New EIP Members

Two new members—a power plant and a remotely located gypsum wallboard company—are added to the EIP in this scenario. This results in an exchange of heat in the form of steam between the power plant and the refinery[8] with condensate returned to the

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[7]Of this, $13,151 is additional revenue to the recycler; because we did not calculate the increase in the recycler's operating costs that would accompany the increase in throughput, net revenue increases for the EIP as a whole could be overstated by as much as $13,000 per year.

[8]The details of the relationship between the tank farm and the power plant are not estimated quantitatively.

power plant from the refinery and tank farm. This scenario also includes an exchange of waste gypsum between the power plant and the wallboard facility.

The prototype EIP power plant is modeled after one type of plant currently under consideration by the Brownsville Public Utilities Board (PUB). Appendix B describes some background on the PUB's decision to build a new power plant. Planning for the power plant project is still in its infancy, and no final decisions have been made about the type of fuel it should burn, how large it should be, or even where the plant should be located, but these decisions will be made in the very near future.

> Orimulsion™ is an emulsion of heavy bitumen (70 percent) dispersed in water (30 percent). The bitumen was first discovered in 1935 in Venezuela. Until recently, it was considered unmarketable as a source of fuel because its viscosity made it very difficult to transport. During the 1980s, the emulsification technique was perfected that renders the fuel comparable to a #6 fuel oil in terms of ease of handling and stability in transport. The fuel can be burned with minor equipment modifications, in much the same way as heavy fuel oils. It has relatively low NO_x emissions, and 98 percent efficiency in desulfurization can be achieved with several common FGD systems (Hernandez-Cartens and Rodriguez, 1991).

The prototype EIP will have a 300 MW power plant that will burn Orimulsion™, a newly developed fuel for power generation that was researched and developed, and is now produced and marketed by a subsidiary of the Venezuelan national energy monopoly Petroleos de Venezuela (PVDSA). The sidebar provides some details about this fuel. For the purpose of this analysis, it is important to note that

- the fuel can be handled, stored, and burned, with minor modifications, in much the same way as heavy fuel oils (Hernandez-Cartens and Rodriguez, 1991);
- it has relatively low NO_X emissions; and
- 98 percent efficiencies in desulfurization can be achieved with several common FGD systems.

A variety of symbiotic relationships are possible in the prototype EIP that involve a power plant of this type. Two of the byproducts of generating electricity are waste heat and a gypsum material captured in the power plant's FGD system. The Scenario 4 analysis assumes that the power plant will begin to sell steam to the refinery and tank farm and compares the operation of the power plant with this cogeneration capacity to the operation of the power plant without this arrangement. We also assumed in Scenario 4 that the power plant will begin selling its synthetic gypsum to a remotely located wallboard plant and compared this outcome to the baseline situation in which the power plant is landfilling its waste gypsum. In Scenario 5, we consider the effect of collocation of the wallboard facility with other members of the EIP.

Below, we provide an overview of our assumptions regarding the relationship between the power plant and the refinery. Then, we introduce the wallboard facility added to the EIP under Scenario 4 and present the simulation approach used to model the relationship between the power plant and the gypsum wallboard company.

Cogeneration and Heat Cascading

> Cogeneration is the simultaneous production of electrical or mechanical energy and thermal energy, usually in the form of hot liquids or gases.

Estimating the economic effects of a cogeneration relationship requires a number of technical assumptions. Appendix B includes the details regarding cogeneration and the assumptions used for this analysis. Some of the more relevant details are reviewed below.

When the power plant moves from a stand-alone plant to operating within a cogeneration relationship, it must increase the amount of fuel, water, water pretreatment chemicals, and limestone it uses to maintain its level of electricity generation. It also produces a greater amount of synthetic gypsum. Based on our conversations with technical consultants, we made the following assumptions regarding the power plant's operations:

1. The 300 MW power plant operates at an average capacity utilization rate of 80 percent.
2. To generate the extra steam required by the refinery without reducing its production of electricity, the power plant burns 3.5 percent (163,142 barrels per year) more Orimulsion.
3. In the cogeneration relationship, the power plant provides the refinery with 262,000,000 Btus/hour (Hurd, 1995) of heat in the form of 800^{o} F steam, which is extracted from the boiler at the power plant. The steam is used by the refinery to preheat its crude prior to vaporization.
4. Operating at 80 percent capacity, the power plant must extract and pretreat about 43,200 gallons of boiler feed water per day to offer the steam to the refinery without reducing its electricity production.
5. The price of city water at the Port is $1.64/1,000 gallons and the cost of pretreatment is assumed to be $2.50/1,000 gallons (Hurd, 1995).
6. As a result of the heat cascading relationship between the power plant and the refinery, the amount of limestone used in the FGD process and the amount of gypsum produced by the FGD process will increase by 3.5 percent.
7. The refinery will require 60 percent less fuel (about 750 fewer barrels of residual oil per day) to heat its crude to 1,200° F than it would without using the 800^{o} F steam to preheat the crude (Linck, 1995). This residual oil can then be sold rather than used.

8. The cost of laying the steam distribution system and the condensate recovery system is $1.50/linear foot of piping (Hurd, 1995), and the cost of a waste heat recovery boiler capable of reheating "waste" steam to temperatures usable by the refinery is $7.5 million (Kellerman, 1995). These one time costs of $8.4 million were annualized over 20 years at a 7 percent interest rate to arrive at the incremental annualized fixed cost estimate of $792,000 that was assigned to the power plant.
9. The refinery must purchase a heat exchanger and a burner that are appropriately sized for the cascading relationship. The difference between this cost and the cost of a larger burner that would heat the crude if the steam were not available is $2 million (Linck, 1995). When annualized over 20 years, this translates to an annual cost of $188,786/year. This simulation assumes these costs are incurred by the refinery.
10. We assumed that the additional costs incurred by the utility as a result of the heat cascading symbiosis (cost of the steam distribution system, cost of waste heat recovery boiler, plus cost of additional fuel, water, and pretreatment chemicals) are included in the price paid by the refinery for the steam. To arrive at an appropriate unit cost we divided the total annual cost by the amount of heat (Btus) provided to the refinery each year.[9]
11. We assumed that the net increase in revenue to the stone company is 10 percent of the price it receives for limestone.

> In our analysis, the gypsum exchange scenario requires that the power plant invest an extra $6,000,000 in an FGD system that is capable of lowering the moisture content of the gypsum to less than 5 percent.

Gypsum Exchange. In this scenario, we examined the net benefits of the exchange of waste gypsum between the power plant and a remote wallboard facility. We also considered adding an exchange between the chemical plant and the wallboard facility; however, the relationship was not beneficial to the chemical plant, as explained below.

The chemical plant would not save any money by sending its byproduct gypsum to the remote wallboard plant. Currently, the chemical plant has a comfortable disposal arrangement with the Mexican government agency responsible for building roads. The chemical plant dries its byproduct gypsum in sedimentation ponds on site at a very low cost per ton, and the Mexican government pays the cost. Once the gypsum has dried to about 17 to 25 percent

[9]The infrastructure required to build the power plant could be funded through municipal bonds or through increases in the price of electricity. However, our pricing method allows us to test whether the cost of the symbiosis is economically beneficial overall, even if it had to be financed privately. The overall net benefits to the EIP of the relationship are not affected by the price the refinery and the power plant agree on, because the transfer is between EIP members. For further discussion of this issue, see Appendix B.

moisture, construction crews collect it free of charge by the truckload to use as road-base material at no cost to the chemical plant. If the chemical company were instead to sell its byproduct gypsum to the wallboard company near Houston, their revenue from the sales would have to recover the cost of operating and maintaining the sedimentation ponds plus the cost of about $6.50/ton to transport the material to the Port by truck (Ostos, 1995), plus the estimated $11/ton to deliver it by barge to the Houston area and $2 to $3/ton at the wallboard plant for final drying. Not counting the current O&M costs for the sedimentation ponds that the chemical company would have to take over from the Mexican government, the chemical plant would lose about $10.50/ton in the transaction. Thus, we wait until Scenario 5, where the wallboard plant becomes a collocated member of the EIP, to examine this relationship.

The following assumptions are required to develop the analysis. Appendix B provides details on how these assumptions were derived.

1. This analysis of gypsum exchange assumes that the power plant is a stand-alone plant not providing steam to the refinery.
2. Before the EIP relationship begins, we assumed that the gypsum produced by the power plant's wet-limestone FGD system is dried to approximately 35 percent moisture content and is subsequently landfilled.
3. To develop a gypsum product that is capable of being used in the wallboard facility, the power plant must upgrade the FGD system to lower the moisture content of the gypsum to about 5 percent. The cost of this upgraded system would be $6,000,000 (Kellerman, 1995). This cost was annualized over 20 years at a 7 percent discount rate for a total annualized cost of $566,358.
4. This upgraded FGD uses more electricity than the baseline system: it uses 3 percent of the power plant's electricity production, compared to 2.5 percent for the old system.
5. The new power plant will begin to deliver its gypsum byproduct to the wallboard producer located in Houston, instead of landfilling it (as is the case in the without-EIP scenario). Before cogeneration, the power plant generates about 233 tons/day of gypsum with a 35 percent moisture content. We adjust this figure downward to account for the reduced moisture content (5 percent) required to sell it to the wallboard company.

6. The price paid by the wallboard company to the power plant is $11/ton for their synthetic gypsum dried to a 5 percent moisture content.
7. The power plant incurs the gypsum transportation costs.
8. The cost of landfilling gypsum, if not sold, is $25/ton for the power plant.
9. The cost of transporting the 5 percent moisture content synthetic gypsum to Houston from the Port would be about $11/ton.[10]

> Combining the cogeneration scenario with the gypsum exchange scenario leads to some interactions between the two symbioses. Thus, the incremental net benefits from Scenario 4 are greater than the sum of the benefits from the cogeneration scenario and the benefits from gypsum exchange.

When the gypsum exchange and the cogeneration scenarios are combined, there are some interactions between the two symbioses. The cogeneration scenario leads to a higher quantity of synthetic gypsum produced for sale by the power plant to the wallboard company; however, the additional drying required to sell the gypsum to the wallboard company leads to a 31 percent net reduction in the volume of gypsum produced. Selling gypsum to the wallboard company decreases the costs under the cogeneration scenario because there are no landfill costs. Table 4-3 provides a summary of the annual change in net revenues, net benefit, investment costs, resource use, and landfill amounts, ROI, and payback period for Scenario 4, which includes all of the relationships discussed in Scenario 3.

4.2.4 Scenario 5: Collocation and Joint Services

In this scenario, two types of relationships change:

1. We assumed that all previously remote facilities are now located at the Port. Collocation provides several additional opportunities for industrial symbiosis. The chemical company can now profitably exchange its waste gypsum with the EIP wallboard plant, and the seafood processor can provide brown water to cool the roof at the textile company.[11] In addition, transportation costs decrease for all material exchanges involving members who previously were remote facilities.

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[10]The transportation cost includes a barge rate of $8 per ton; a loading charge of $2 per ton; and a wharfing fee of $1 per ton, which would be paid to the Brownsville Navigation District (Hoskins, 1995).

[11]This symbiosis is not quantitatively analyzed. For more information about water cascading technologies, see Chapter 6.

Table 4-3. Summary of Changes due to Cogeneration and Gypsum Exchange under Scenario 4
Scenario 4 includes the relationships discussed in Scenario 3.

Resource Simulated (Units) and Affected Facility	Input or Output	Baseline Parameters		Scenario 4 Parameters		Net Annual Changes in Benefits and Costs	
		Baseline Quantity[a]	Baseline Price ($1995)	Δ Annual Quantity[a]	Price ($1995)	Δ Annual Net Revenues ($1995)	Δ Annual Fixed Costs ($1995)
Orimulsion (bbl)							
Power plant	Input	(4,661,196)	8.63	(163,142)	8.63	(1,407,915)	0
Electricity (kWh)							
Power plant	Output	2,049,840,000	0.05	(10,512,000)	0.05	(525,600)	0
Heat (as Steam) (million Btus)							
Power plant	Output	21,024,000	0.970	2,295,120,	0.970	2,226,785	792,901
Refinery	Input	0	0.970	(2,295,120)	0.970	(2,226,785)	188,786
Residual Oil (bbl)							
Refinery	Output	2,585,417	18.61	273,750	18.61	5,094,488	0
Boiler-Feed Water (gals/yr)							
Power plant	Input	63,072,000	0.00164	(15,768,000)	0.00164	(25,860)	0
Pretreatment Chemicals ($)							
Power plant	Input	c	0.0025	0	0.0025	(39,420)[c]	0
Synthetic Gypsum (tons)							
Chemical company	Output	281,050	0	0	0	0	0
Power plant	Output	121,545	(25.00)	(37,697)	0	3,038,625	566,358
Limestone (tons)							
Power plant	Input	(73,803)	15.00	2,583.1	15.00	(38,747)	0
Stone company	Output	73,803	15.00	2,583.1	15.00	3,875	0
Asphalt (lbs)							
Asphalt/hot-mix company	Output	5,718,914,754	0.3568	730,831	0.3568	26,076	0

(continued)

Table 4-3. Summary of Changes due to Cogeneration and Gypsum Exchange under Scenario 4 (continued)

		Baseline Parameters		Scenario 4 Parameters		Net Annual Changes in Benefits and Costs	
Resource Simulated (Units) and Affected Facility	**Input or Output**	**Baseline Quantity[a]**	**Baseline Price ($1995)**	**Δ Annual Quantity[a]**	**Price ($1995)**	**Δ Annual Net Revenues ($1995)**	**Δ Annual Fixed Costs ($1995)**
Waste Asphalt (lbs)							
Asphalt/hot-mix company	Input	0	0	(730,831)	0	0	3,944
Ballast manufacturer	Output	730,831	(0.02075)	0	(0.00325)	12,790	0
High-Value Scrap Plastic (lbs)							
Auto parts	Output	29,952	0.0950	0	0.1475	1,572	0
Plastic recycler	Input	0	0.1500	(29,952)	0.1500	(4,493)	0
Low-Value Scrap Plastic (lbs)							
Auto parts	Output	29,952	(0.0050)	0	0.0475	1,572	0
Plastic recycler	Input	0	0.0500	(149,947)	0.0500	(7,497)	0
Textile company	Output	119,995	(0.4166)	0	0.0475	55,690	0
Unsorted Plastic Flakes (lbs)							
Discrete parts	Output	11,232	(0.0150)	0	0.0275	477	0
Plastic recycler	Input	0	0.0300	(11,232)	0.0300	(337)	0
Sorted Plastic Flakes (lbs)							
Plastic recycler	Output	0	0.1333	191,131	0.1333	25,478	0

Scenario 4: Economic and Environmental Impacts

Symbiotic Relationship Simulated	**Δ Annual Net Revenues ($1995)**	**Δ Annual Fixed Costs ($1995)**	**Net Benefits ($1995)**	**Payback Period (Years)**	**ROI**	**Reduction (lbs) in Material Sent to Landfill**
All Scenario 4 relationships	6,210,774	1,551,988	4,658,786	2.64	37.77%	243,952,058

[a]Quantities in parentheses are negative. Input quantities are assigned negative values to denote resource use.
[b]The value shown is an estimate that assumes that the net increase in facility revenues is 10 percent of the dollar increase in sales.
[c]The cost of pretreatment chemicals is $2.50 per 1,000 gallons of water treated (Hurd, 1995).

2. We considered developing a solvent and oil recycling facility to serve the EIP. This analysis is hypothetical and follows a different methodology than the analyses of the previous scenarios. Thus, we discuss it separately from the other analyses.

Note that we do not analyze the decision to move a plant from its current position to a position within the EIP. We use this analysis to demonstrate the additional benefits that can be captured when EIP members are situated in the same park.

Power Plant Gypsum. Analysis of the potential benefits of cascading synthetic gypsum to a new wallboard company located at the Port is conducted in much the same way as with a remote wallboard producer, except that in this case the power plant and the chemical plant would not incur the estimated $11/ton cost of transporting their byproducts to Houston. This raises the effective price that the power plant would receive for its gypsum by $11/ton.[12] The net change in annual revenues for the power plant under Scenario 5 is therefore calculated by multiplying 83,848, the estimated volume of gypsum (dried to 5 percent moisture) by the $11/ton delivered price of gypsum (which assumes a $1 reduction in price to cover the cost of final drying at the wallboard facility) and adding back the without-EIP disposal costs.

Chemical Plant Gypsum. With the assumption that both the chemical plant and the wallboard facility are located at the Port, there are no transportation costs, and the effective price is $11/ton, just as it is for the power plant. We assumed that the amount of gypsum decreases by 44,968 lbs as the gypsum is dried from the original 21 percent moisture content to the 5 percent moisture content required by the wallboard facility. We were unable to obtain an estimate of the capital costs that the chemical company could incur in modifying its sedimentation pond drying area to permit the additional drying of the gypsum required by the wallboard company.

[12]In fact, the power plant is likely to have a net reduction in transportation costs on the order of $0.10/ton-mile as a result of initiating this relationship, because it is unlikely that the wallboard manufacturer would be located farther away than the local landfill. However, since no transportation costs are included in the estimated disposal costs of $25/ton at the Brownsville landfill in the without-EIP scenario, no change in transportation costs is included in the Scenario 5 simulation.

Asphalt Waste. Under Scenario 5, we assumed that the magnetic ballast plant is located at the Port. The transportation costs of $6.50/ton that were assumed in Scenario 3 are now eliminated. Thus, the effective price the ballast plant receives for the waste asphalt rises to 0.

Plastics. In Scenario 5, all of the companies selling plastics to the recycler save the $0.25 cents per pound in transportation costs that they were paying to ship their plastics to the local recycler.

Summary of Collocation Scenario. Table 4-4 summarizes the change in net revenues, fixed costs, and materials flows associated with the collocation scenario described above compared to baseline, in conjunction with the relationships described in Scenarios 3 and 4. Considering all of the relationships taken together, we estimated a net economic benefit of $8,221,214. The payback period is 1.68 years; the ROI, considering all the investments required for each scenario, is 55 percent.

Solvent and Oil Recycling. In this section, we explore the possibility of the EIP operating a closed-loop solvent recycling/ recovery operation.[13] We analyze this symbiosis separately from the collocation scenario presented above for two reasons:

- The methodology we use for this analysis is somewhat different from the methodology used for the previous analyses.
- The simulation is based on assumptions that are somewhat unrealistic.

We provide this analysis to demonstrate how an EIP manager might decide whether a solvent recycling operation would benefit the EIP.

After exhausting the P2 possibilities as discussed in Scenario 2, we consider recycling, reuse, and reclamation as alternatives for reducing the costs of disposal and the costs of virgin materials.

[13]We also explored the possibility of an oil recovery operation but did not include it in the quantitative analysis.

Table 4-4. Summary of Changes for Combined Symbiotic Relationships in Scenario 5

This summary of changes includes the relationships described in Scenarios 3 and 4.

Resource Simulated (Units) and Affected Facility	Input or Output	Baseline Parameters: Baseline Quantity[a]	Baseline Parameters: Baseline Price ($1995)	Scenario 5 Parameters: Δ Annual Quantity[a]	Scenario 5 Parameters: Price ($1995)	Net Annual Changes in Benefits and Costs: Δ Annual Net Revenues ($1995)	Net Annual Changes in Benefits and Costs: Δ Annual Fixed Costs ($1995)
Orimulsion (bbl)							
Power plant	Input	(4,661,196)	8.63	(163,142)	8.63	(1,407,915)	0
Electricity (kWh)							
Power plant	Output	2,049,840,000	0.05	(10,512,000)	0.05	(525,600)	0
Heat (as Steam) (million Btus)							
Power plant	Output	21,024,000	0.970	2,295,120,	0.970	2,226,785	792,901
Refinery	Input	0	0.970	(2,295,120)	0.970	(2,226,785)	188,786
Residual Oil (bbl)							
Refinery	Output	2,585,417	18.61	273,750	18.61	5,094,488	0
Boiler-Feed Water (gals)							
Power plant	Input	63,072,000	0.00164	(15,768,000)	0.00164	(25,860)	0
Pretreatment Chemicals ($)							
Power plant	Input		0.0025	0	0.0025	(39,420)	0
Synthetic Gypsum (tons)							
Chemical company	Output	281,050	0	(44,968)	11.00	2,596,902	0
Power plant	Output	121,545	(25.00)	(37,697)	11.00	3,960,953	566,358
Limestone (tons)							
Power plant	Input	(73,803)	15.00	2,583	15.00	(38,747)	0
Stone company	Output	73,803	15.00	2,583	15.00	3,875	0
Asphalt (lbs)							
Asphalt/hot-mix company	Output	5,718,914,754	0.3568	730,831	0.3568	26,076	0

(continued)

Table 4-4. Summary of Changes for Combined Symbiotic Relationships in Scenario 5 (continued)

		Baseline Parameters		Scenario 5 Parameters		Net Annual Changes in Benefits and Costs	
Resource Simulated (Units) and Affected Facility	**Input or Output**	**Baseline Quantity[a]**	**Baseline Price ($1995)**	**Δ Annual Quantity[a]**	**Price ($1995)**	**Δ Annual Net Revenues ($1995)**	**Δ Annual Fixed Costs ($1995)**
Waste Asphalt (lbs)							
Asphalt/hot-mix company	Input	0	0	(730,831)	0	0	3,944
Ballast manufacturer	Output	730,831	(0.02075)	0	0	15,165	0
High-Value Scrap Plastic (lbs)							
Auto parts	Output	29,952	0.0950	0	0.1500	1,647	0
Plastic recycler	Input	0	0.1500	(29,952)	0.1500	(4,493)	0
Low-Value Scrap Plastic (lbs)							
Auto parts	Output	29,952	(0.0050)	0	0.0500	1,647	0
Plastic recycler	Input	0	0.0500	(149,947)	0.0500	(7,497)	0
Textile company	Output	119,995	(0.4166)	0	0.0500	55,690	0
Unsorted Plastic Flakes (lbs)							
Discrete parts	Output	11,232	(0.0150)	0	0.0300	505	0
Plastic recycler	Input	0	0.0300	(11,232)	0.0300	(337)	0
Sorted Plastic Flakes (lbs)							
Plastic recycler	Output	0	0.1333	191,131	0.1333	25,478	0

Scenario 5: Economic and Environmental Impacts

Symbiotic Relationship Simulated	Δ Annual Net Revenues ($1995)	Δ Annual Fixed Costs ($1995)	Net Benefits ($1995)	Payback Period (Years)	ROI	Reduction (lbs) in Material Sent to Landfill
All Scenario 5 relationships	9,732,857	1,551,988	8,180,869	1.69	59.29%	243,952,058

[a]Quantities in parentheses are negative. Input quantities are assigned negative values to denote resource use.
[b]The value shown is an estimate that assumes that the net increase in facility revenues is 10% of the dollar increase in sales.

> **Benefits of Closed-Loop Solvent Recycling**
> The benefits of the closed-loop system include minimizing the environmental impact of the EIP on the community (i.e., what leaves the EIP) and limiting the liability of companies compared to liability concerns when using outside recyclers. That is, when companies use outside recycling services, they can be held liable for environmental damage caused by improper management of the solvents or acceptance of nonqualifying materials. Within the EIP, the EIP management has more control over the mix of products that are being recycled, since it is aware of the production activity of its members. A closed-loop process also encourages companies to take steps to reduce the costs of solvent recycling and reuse, because the cost savings translate directly into lower recycling costs, for them.

The EIP has several possibilities for assisting its member companies with handling waste oils and solvents. First, it can operate a closed-loop solvent and/or oil recycling center. By closed loop, we mean that no solvents would be accepted from outside the EIP and no solvents would be sent outside the EIP for recycling (some disposal, for example, of still bottoms, is unavoidable). Second, the EIP can provide these services by operating a facility in the park that accepts solvents for recycling from outside the EIP. Finally, the EIP can operate as a broker, rather than having a recycler on site. This approach takes advantage of the market power of marketing all the solvents and oils of all the EIP members.

The following simulation provides an example of how the feasibility of a closed-loop system might be analyzed. We based this analysis on information obtained from several companies visited in the Brownsville/Matamoros area and on a number of assumptions that abstract from the conditions that actually exist in those firms.

Baseline Assumptions. We assumed that four facilities are involved in this analysis. Table 4-5 lists their baseline consumption of solvents. We discuss our baseline assumptions below.

1. All facilities use only two types of solvents. The companies we originally talked with were using about five different types of solvents. This complicated the analysis and limited the possibility of economical solvent recycling. Within an EIP, the members may be able to look for ways to reduce the number of different solvents used in the EIP. In reality, retroactively limiting the number of solvents used in a park with diverse industries will be difficult.
2. The price of the two solvents is $2.00/gallon and $6.00/gallon, respectively, and the disposal cost (incineration) is $1.50/gallon. The companies quoted several different prices for disposal costs for spent solvents. We assumed that only one price would apply. Of course, even if we were only using one solvent, the price of disposal could depend on the application of the solvent and consequent type of contaminants.
3. These two solvents can be separated by a fractional distillation unit. Actually, a number of factors influence the separability of the solvents, including the relative volatilities of the two solvents (Hulm, 1987), the susceptibility of the mixture to exothermic reactions, the viscosity of the liquids, and the solid content of the solvents. Fractional distillation is not suitable for polyurethanes or inorganics (Glynn et al., 1987).

Table 4-5. Baseline Assumptions about Solvent Use in the EIP
The quantities of solvents used by each of the companies in the EIP are fairly small.

	Discrete Parts	Ballasts	Auto Parts	Textiles	Total
Annual use, Solvent 1 (gals)	800	10,000	550	60	11,410
Annual use, Solvent 2 (gals)	400	4,000	250	60	4,710
Annual waste, Solvent 1[a] (gals)	500	1,500	200	50	2,250
Annual waste, Solvent 2 (gals)	300	3,000	200	50	3,550
Solvent 1 cost (at $2.00/gal)	$1,600	$20,000	$1,100	$120	$22,820
Solvent 2 cost (at $6.00/gal)	$2,400	$24,000	$1,500	$360	$28,260
Fuel blending cost ($/gal)	$800	$4,500	$400	$100	$5,800
Total costs	$4,800	$48,500	$3,000	$580	$56,880

[a]The difference between annual use and annual waste is solvents that are used through evaporation or mixed with other materials (i.e., as a paint thinner). For a discussion of the technology used to capture solvent VOC wastes, see Chapter 6.

Over 1,500 different types of solvents are used in industry. One way to improve the feasibility of solvent recycling in the EIP is to agree on a limited number of solvents for use by companies within the EIP. This is easiest during the planning stages of an EIP or when companies are considering machinery replacement.

4. At baseline, the companies have two choices for disposing of their solvents. They can pay $1.50/gallon for incineration of spent solvents, or they can send the solvents to a fuel-blending program at a cost of $1.00/gallon.
5. The recovery process is 90 percent efficient. In Table 4-6, we assumed that 90 percent of the processed solvents are returned as virgin material. The remaining 10 percent of volume, which are the residues from the still, must be disposed of at a cost of $1.50/gallon.
6. The EIP purchases a fractional distillation unit with a batch capacity of 120 gallons. This unit's total installed cost is $39,670. Each batch takes about 5 hours. Assuming that one batch can be run in a day, the still will run for 48 days out of the year. Thus, the operation of the unit will require less than 10 hours of labor time per week.[14]

This scenario shows that an EIP solvent recycling unit, operating under the assumptions we have specified, will save the companies jointly about $20,000 each year, will provide an ROI of about 50 percent, and will pay for itself in about 2 years. However, altering even one of the parameters, such as the price of the virgin solvent, the proportion of the solvent that is wasted, the efficiency of the recovery process, the labor costs, or the operating costs of the unit would have an important impact on the results.

[14]Hiring a person for a 10-hour per week job is not usually feasible. We assumed that these responsibilities can be combined with other EIP responsibilities.

Table 4-6. Hypothetical Analysis of the Economics of Installing an EIP On-Site Solvent Recycling Unit
Ninety percent of the processed solvents are returned as virgin material.

Installation Costs			
Capital Costs	$32,150		
Freight[a]	$1,930		
Tax[b]	$2,090		
Installation, labor, and equipment	$3,500		
Total Investment Cost	$39,670		
Annual Operating Costs	Current	With New System[c]	Change
Cost of virgin solvent			
Solvent 1	$22,820	$18,770	4,050
Solvent 2	$28,260	$9,090	19,170
Disposal costs[d]	$5,800	$870	$4,930
Labor costs, with fringe[e]	0	$6,552	($6,552)
Utilities[f]		$1,740	(1,740)
Total annual cost			19,858
Return on Investment[g]			50%
Payback period (years)			<2

[a] Estimated as 6 percent of capital cost.
[b] 6.5 percent sales tax.
[c] Cost of solvent with the recycling system is equal to the original cost less the amount recovered, which is 90 percent of the annual solvent waste.
[d] Disposal cost with the new system is equal to $1.50 for each pound of unrecoverable solvent, which is 10 percent of the total amount recycled waste.
[e] Estimated 10 hours/week @ $9.00/hr plus 40 percent fringe benefits.
[f] Based on a still operating cost of $0.30/gal for recovered solvent.
[g] Assuming a 20-year life for the distillation unit.

4.3 SUMMARY AND CONCLUSIONS

The benefits of an EIP expand as companies take on greater investment, greater risk, and a greater level of cooperation among each other.

Table 4-7 summarizes the results of the quantitative analysis of the EIP, comparing a number of economic and environmental indicators from the baseline.

Our case study demonstrates that the benefits of an EIP expand as companies take on greater investment, greater risk, and a greater level of cooperation. In Scenario 2, we described some efficiencies that companies capture on their own by engaging in waste reduction activities. In many cases, they gain concrete economic and environmental benefits with little investment and little risk. These opportunities require no cooperation or dependence on other companies.

Table 4-7. Summary of Simulation of EIP Benefits Over Baseline
The economic and environmental benefits of the EIP grow as the symbiosis expands to include more partners and as those partners locate closer to each other.

Indicator	Scenario 3	Scenario 4	Scenario 5
Net annual economic benefit	$107,384	$4,658,786	$8,180,869
ROI	359%[a]	38%	59%
Payback period (years)	0.28	2.64	1.69
Reduction in landfill waste			
Plastic (lbs)	131,227	131,227	131,227
Asphalt (lbs)	730,831	730,831	730,831
Gypsum (tons)		121,545	121,545
Change in resource use			
Orimulsion (bbls)		163,142	163,142
Residual oil (bbls)		–273,750	–273,750
Water (gal)		15,768,000	15,768,000

[a]This reflects only changes in net revenue from asphalt, since the plastics exchange required no investment.

In Scenario 3, we demonstrated that the opportunities to improve economic and environmental performance expand when companies are informed about how they might work together to improve the "industrial ecosystem" in their community. For this scenario, the economic benefits were small, but the risk and investment required were also small, since the relationships between the companies involved operations that were peripheral to their main production activities.

In Scenario 4, we found that a single new member of an industrial ecosystem can have an important impact on the opportunities available to the EIP. We also saw the dramatic increase in potential EIP benefits derived from increasing dependence of the EIP members on each other. These increased benefits were accompanied by increases in investment and risk.

In Scenario 5, we demonstrated that collocation of EIP members can increase the opportunities and benefits of an industrial symbiosis. Although many profitable opportunities for symbiosis do not require collocation, these benefits can expand if EIP members locate in a single physical location, under a single management structure that includes shared infrastructure, regulatory structure, and joint services. This implies, of course, an even greater level of dependence of companies on each other and on the EIP management.

4.3.1 Lessons from the Case Study Analysis

Our case study was based on a number of assumptions and much conjecture. However, it served to demonstrate some important points about the elements required for a successful EIP:

1. The first and most essential input to the EIP is information about members' operations.
2. The success of the EIP requires that members are open to depending on each other.
3. To achieve the greatest economic benefits, the EIP will require substantial investment in infrastructure.
4. 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. Retrofitting existing plants, while possible, decreases the economic benefits.

4.3.2 Limitations of the Analysis

Our analysis of the potential economic and environmental impacts of an EIP was limited in several ways. First, within the scenarios we examined, we did not consider the influence of the changes in operations on several important factors that may affect the EIP's economic and environmental impact:

- the risk to companies of investing in symbiotic relationships with suppliers and customers
- the risk to companies that they may be liable for the environmental impacts of other EIP members' operations
- the implications of the operations changes depicted by the scenarios for the regulatory costs faced by each EIP member

The first two types of risks may decrease the economic benefits of the EIP to the members. We explore strategies for reducing these risks in the *Fieldbook for the Development of Eco-Industrial Parks*. Changes in regulatory requirements and costs are explored in Chapter 5.

The second way in which our analysis was limited was that we did not examine whether the EIP member would rather locate at the EIP than at alternative locations. That is, we assumed that everything else about the baseline scenarios and the with-EIP scenarios were the same except for the byproduct exchanges. This would certainly not be true if a company was trying to decide whether becoming a member of an EIP would be more profitable than some alternatives.

Other differences between the EIP and other potential locations that a potential EIP member would consider include

- the cost of the lease;
- the cost and quality of labor;
- proximity to suppliers and customers aside from EIP members; and
- the cost of energy, water, and other essential services.

Each of these can affect the economic benefits of the EIP compared to other locations.

The third way in which our analysis was limited was the exclusion of aspects of the EIP aside from the symbiotic relationships between companies, shared infrastructure, and shared EIP services. EIPs may differ from traditional industrial parks in other ways that affect the magnitude of the environmental and economic benefits. These include design considerations, such as

- siting the EIP to minimize its environmental impact,
- using renewable energy, and
- designing infrastructure from the beginning to anticipate the exchange of byproducts among tenants.

Finally, we did not consider the costs of managing the EIP. The EIP manager plays an important role in facilitating the EIP relationships that were discussed in the case study. The EIP manager must

- keep EIP vacancy to a minimum,
- process and exchange information among the EIP members to facilitate exchanges,
- assess the performance of the EIP, and
- maintain the flexibility of the industrial symbioses.

We did not account for the costs of these and many other roles of the EIP manager in the case study.

5 Regulatory Issues and Approaches for Encouraging EIP Development

The second research question we addressed with this project was, "What is the range of government's appropriate role in facilitating the development and management of EIPs, and how might this role vary in alternative EIP venues? We address this question in this chapter by describing how environmental regulations affect EIPs. The EIP *Fieldbook* (Lowe, Moran, and Holmes, 1996) describes additional roles for government, including the developing zoning, permitting, and other development regulations; developing appropriate technology; promoting technology transfer; providing technical training; and encouraging the exchange of information among EIPs.

General environmental policy considerations affect and may support, discourage, or limit the development of EIPs. For example, potential conflicts between hazardous materials transfer regulations and waste exchange opportunities could lead to political pressure to prevent any changes in regulations needed to develop EIPs. This chapter investigates the role of regulations in promoting or discouraging P2 and IE technologies and formulates a regulatory framework for EIPs.

A variety of key stakeholders affect or are affected by environmental regulations. In the context of EIP development they include the following groups: industries participating in EIPs; state, local, and federal government agencies; citizens of regions where EIPs are sited; and the environment as a whole. Considering the "environment" as a stakeholder may be a new way of thinking, but it is essential when discussing IE—the integration of natural and man-made systems. Although this chapter considers each of these stakeholders equally, its primary focus is on how regulations affect industry.

Our approach to developing a regulatory framework for EIPs is based on the Brownsville/Matamoros prototype EIP as described in Chapter 3. Because we did not consider changes in regulatory requirements in our case study analysis, we believed it was important to provide some idea of the regulatory considerations and costs that might face companies in the prototype EIP. Similar to the phased "scenario" approach to developing the prototype, the regulatory framework also uses a phased approach—focusing first on modifying existing regulations to encourage P2 and then progressively evolving regulations to support a fully collocated EIP.

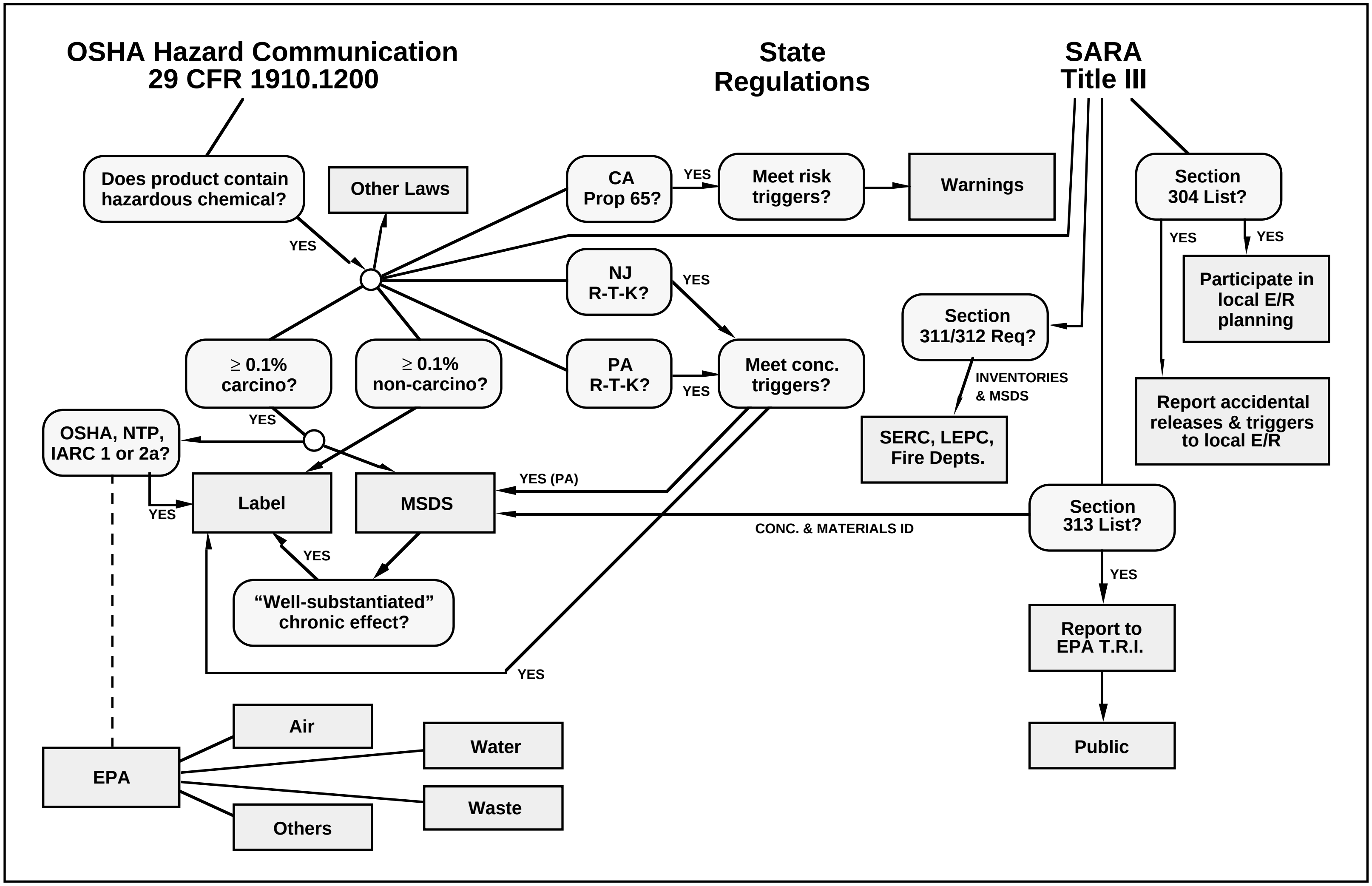
Section 5.1 describes a few general regulatory issues surrounding EIP development. In Section 5.2, we describe the regulatory environment for each scenario of the prototype EIP described in Chapter 3. Section 5.3 outlines a set of possible regulatory strategies that may be useful for encouraging EIP development in the context of the EIP's current regulatory environment. Section 5.4 describes current regulatory initiatives that may lead to progress toward supporting EIP development. Section 5.5 provides a summary of regulatory issues and policy recommendations.

5.1 REGULATORY ISSUES SURROUNDING EIP DEVELOPMENT

The literature offers many comments on and examples of how environmental regulations often create disincentives for industry to develop and implement P2 programs as well as exchange potentially useful byproduct materials for other applications. Figure 5-1 demonstrates the complexity of the regulations governing a typical manufacturer. The complexity of the process creates uncertainties that increase the risk of pursuing innovative environmental strategies such as participation in an EIP. This section highlights some of the key regulatory issues affecting EIP development.

Figure 5-1. Regulatory Road Map

While the focus of this chapter is on the limitations of, and potential improvements to, existing laws and regulations as promulgated by EPA Program Offices (Air, Water, Waste, Others), there is a myriad of additional state and federal laws and regulations that companies must track and comply with. This figure illustrates the potential complexity of merely tracking different environmental laws and regulations.



Source: Sayad, R.S. et al. 1994. "A Road Map for Regulatory Survival in the 1990s." *Adhesives and Sealants Industry* June/July:27-33.

5.1.1 Definition of Waste

Under current regulatory language, little distinction is made between solid and hazardous wastes and secondary materials that are usable inputs for other applications.

The definition and classification of solid and hazardous wastes under the Resource Conservation and Recovery Act (RCRA) and other federal statutes directly affect the way industry manages different waste materials. Under current regulatory language, little distinction is made between solid and hazardous wastes and secondary materials that are usable inputs for other applications. Without this distinction, companies find reusing and recycling usable materials that are not contained in a closed-loop recycling system difficult.

Under RCRA, solid waste is defined broadly as

> any garbage, refuse, sludge from waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities, but does not include solid or dissolved material in domestic sewage, or solid or dissolved materials in irrigation return flows or industrial discharges which are point source subject to permits under Section 1342 of Title 33, or source, special nuclear, or byproduct material as defined by the Atomic Energy Act of 1954, and amended (68 Stat. 923). (42 U.S.C., Sec. 1004[27])

Hazardous waste is defined under RCRA as

> a solid waste, or combination of solid wastes which because of its quantity, concentration, or physical, chemical, or infectious characteristics may [a] cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness; or [b] pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed. (42 U.S.C., Sec. 1004[27])

The lack of distinction between solid and hazardous wastes and secondary materials in the language of RCRA means that all waste or byproduct materials that fall under RCRA's definition of solid or hazardous waste are subject to RCRA requirements. Over the years, the complexity of defining a material as a hazardous waste has increased with the evolution of RCRA, leading to explicit exemptions, management-based standards (burning as a fuel, recycling), and land-banned wastes.

Anything done at the source to eliminate or reduce the amount of hazardous waste is outside the scope of RCRA. Thus many potentially usable secondary materials may be required under RCRA to be disposed of in accordance with RCRA guidelines and procedures, leaving little room for generators to reuse, recycle, or reclaim the waste to recover any beneficial constituent or use any property of the waste.

In addition to RCRA, statutes such as TSCA, CAA, CWA, and CERCLA affect the management of solid and hazardous wastes.

Many other statutes in addition to RCRA also affect the management of solid and hazardous wastes generated by industry. Among the different federal statutes, the terms "hazardous" and "toxic" waste often differ from that used by RCRA, depending on the particular goals and environmental issues the statute addresses. As a result, different statutes can regulate some substances as hazardous or toxic that otherwise would not designated as hazardous by RCRA. For example, polychlorinated biphenyls (PCBs) are regulated by the Toxic Substances Control Act (TSCA), asbestos is regulated by the Clean Air Act (CAA) and the Asbestos Hazard Emergency Response Act, and wastewater discharges are regulated by the Clean Water Act (CWA). The Comprehensive Environmental Response and Liability Act (CERCLA) designates as "hazardous substances" any substance so designated by one of the other federal statutes. This means that a waste that was legally managed under RCRA Subtitle D could contribute to the creation of a Superfund site if it is mismanaged. Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986, also known as Title III of the Superfund Amendments and Reauthorization Act, requires companies to submit information on releases of specified toxic chemicals (Toxics Releases Inventory), many of which are not listed as hazardous under RCRA.

The definition and management of hazardous waste discharges under RCRA and CWA further illustrate the complexity of this issue. RCRA covers storage, treatment, or management of such wastes prior to discharge. CWA regulates discharges to surface waters. These differences are not necessarily a problem, except that the two acts cover different constituents and regulate them differently. CWA focuses on 126 "priority pollutants" and uses technology-based standards, which often specify a required removal percentage for a particular pollutant. RCRA focuses on a much different list or on testing leachable concentrations of specified constituents. This means that different constituents may by regulated at different points in the processing of one waste stream.

Redefining selected waste materials as secondary materials, however, may create more of a regulatory burden on industry because of Occupational Safety and Health Administration (OSHA) and Department of Transportation (DOT) materials tracking and transportation requirements. For example, waste materials generally are not tracked as closely as hazardous material inputs, which must comply with materials safety data sheets requirements. Determining the regulatory implications of redefining waste materials as useful secondary materials requires industry to work in cooperation with their state regulatory bodies. States generally are given flexibility in administering federal regulations as long as they do not violate the regulation. Solutions are achievable but will likely differ by state.

Recent efforts by federal and state governments have been initiated to better support reusing and recycling materials that otherwise fall under RCRA regulation. Section 5.4.2 discusses recent initiatives by EPA's Definition of Solid Waste Task Force to redefine or modify RCRA so that it may better promote reusing and recycling materials.

5.1.2 Definition of a "Source"

A significant issue related to environmental standards and permitting in the context of EIP development is the meaning of the term "source," which essentially has a dual meaning in policy language. It can be an entire industrial facility that must aggregate emissions to meet the size thresholds for application of the control and permit requirements.

More commonly, the term "source" applies to each point at which emissions are released; the emissions limitations may apply individually to each point of release. As a result, a large industrial facility may contain dozens, hundreds, or even thousands of "sources." As explained in Chapter 2, it is most appropriate to view the EIP as a single source for some pollutants. Since wastes may be traded among companies and transformed into usable products, the sum of discharges from each company may be greater than the net discharges of the EIP.

Furthermore, the current definition of source poses a significant administrative burden on industrial facilities. Specifying applicable requirements for every individual "source" under a single permit could be a monumental undertaking. Where a permit establishes emissions limitations for each source and pollutant, and if emissions cannot be altered without a permit change, it will be very difficult to simplify permitting and reporting. Although the CAA Amendments of 1990 authorize a single permit to cover all sources at an industrial plant, it is unclear whether the permitting process will be able to cope with the paperwork consequences of such single permits.

5.1.3 Liability

EIPs must contend with a number of possible liability concerns. We focus on two liability issues:

- the use of potentially hazardous secondary materials in other applications
- the treatment of industrial parks or regions under single regulatory umbrellas

During company site visits in the Brownsville/Matamoros border area, many companies cited liability as a major concern when asked about their willingness to exchange waste materials with other potential EIP members.

During company site visits in the Brownsville/Matamoros border area, many companies cited liability as a major concern when asked about their willingness to exchange waste materials with other potential EIP members. They were concerned that, if the production or use of a product containing secondary materials had a serious health or environmental concern, the company that supplied the secondary materials also could be held liable for damages.

For example, in the reuse of scrap plastics, the remanufacturing processes for new plastics products often do not require high enough temperatures to volatize potentially hazardous contaminants. Similarly, when plastic products are manufactured in injected molding and other in-vessel type operations, there is no place for the hazardous constituents to volatize even if temperatures are high enough.

In addition, the RCRA "derived from" rule states that any material derived from a listed hazardous waste is itself a hazardous waste. The obstacles for delisting a derived material are so great that generators and recyclers may not spend the time, effort, and resources required to delist the derived material, enabling them to reuse a hazardous waste.

EIP industries may also face liability issues when one or more industries are treated under a regulatory umbrella within an EIP. All of the companies under the umbrella would be expected to maintain a code of ethics and take responsibility for meeting the requirements of the permit. However, from a regulatory standpoint, monitoring releases from individual industries under an umbrella permit is not always straightforward, especially if industries exchange materials. In addition, if one company in the EIP creates a noncompliance problem, who is held liable—just the noncomplier or all those under the umbrella permit?

Furthermore, EIPs may likely contain a mixture of large, medium, and small companies. Policymakers need to address burdens not only on large companies but also on medium and small companies and to develop equitable solutions. Perhaps establishing an EIP regulatory "association" would be the most effective way to manage regulatory permitting and compliance matters. Through the association, each EIP tenant would pay a weighted up-front cost and monthly fee based on their level of regulated releases. Some of the regulatory association's funds could be leveraged against future environmental liabilities. When considering joint liability, the association could exercise the authority to fine or remove tenants if they remain in noncompliance.

5.1.4 Single-Medium Permitting

The single-medium focus of environmental regulations has largely shifted waste from one form (and medium) to another, without significantly reducing the totals.

Congress has passed a large body of legislation aimed at restoring and maintaining the quality of the environment. Existing environmental regulations now cover air quality, water quality, hazardous wastes, toxic substances, and other environmental media. However, environmental regulation by EPA and other government agencies has largely focused on imposing regulations on environmental releases by medium. Generally, each legislative act mandates a bureaucracy that formulates and enforces a set of regulations addressing emissions by point source to a single medium.

As a result of this media-specific focus of environmental regulations, industries eliminated some air pollution by converting it to another form of waste, such as sludge, which is then landfilled. Similarly, some forms of waterborne wastes were captured and converted to sludges for land disposal or incineration. Air and water pollution were reduced but largely by resorting to land disposal, which in turn causes water (leachate) and air pollution due to anaerobic decay processes. In short, the single-medium focus of environmental regulations has largely shifted waste from one form (and medium) to another, without significantly reducing the totals.

For EIP development to be successful, a multimedia approach to regulation will be necessary. Issuing true multimedia permits is not, however, a straightforward process. During our interviews with permitting officials of TNRCC, officials indicated that, although a single permit documents could be issued, it would essentially contain individual permits for air, water, and solid/hazardous waste based on existing regulations (Saitas, Worst, Mauk, Neblet, and Weber, 1995). In addition, implementing a true multimedia permit would require a statutory change, which could take a significant amount of time.

5.1.5 Brownfield Versus Greenfield Issues

Brownfield sites often are contaminated with toxics and heavy metals and are very expensive to clean up. Because of the high cost of cleanup, as well as liability concerns, brownfield sites are usually left to sit untreated and undeveloped. A general lack of support for reclaiming brownfield sites offers additional incentive to develop greenfield, or clean and safe, sites on farmland and other previously undeveloped areas. To prevent EIP development from encroaching on green spaces, more incentives are needed for companies to develop in brownfield sites. EPA's (1995) *Brownfields Action Agenda* will contribute to clarifying and cleanup issues, testing redevelopment models, and removing regulatory barriers without sacrificing protectiveness. The *Fieldbook for the Development of Eco-Industrial Parks* discusses some federal and state brownfield initiatives.

Industrial tax credits or exemptions could be offered to encourage companies to locate in and develop brownfield areas. The savings from exemptions could then be used in conjunction with state/federal funds to clean up brownfield sites. To make this approach feasible, companies would require that the exemption be large enough to at least offset the cost of clean-up and remediation. Additional options currently are being tested in 50 pilot studies.

5.1.6 U.S.–Mexico Border Issues

Over the past decade, environmental problems along the U.S.–Mexico border area have grown with the increase in industrial development. Currently, over 1,800 maquiladora companies occupy the border area. Although economic development remains critical to the prosperity of the border region, the combined effects of urban and industrial growth have contributed to problems such as air and water pollution, improper handling and disposal of hazardous waste, and inadequate environmental infrastructure, challenging virtually all communities along the border area (EPA, 1994a). Cooperation and action are needed between the U.S. and Mexico to address the unique border-area environmental problems. Appendix C discusses federal-level initiatives to address border-area environmental problems.

With respect to EIP development located in the border area, regulation can be complicated by different sets (U.S., Mexico, and bilateral) of environmental regulations. Differing rules can affect the feasibility of waste exchange between border-area and nonborder-area industries. Some interest has been expressed in establishing binational "border-area" permits that cover facilities located in border areas with both U.S.' and Mexico's environmental protection laws under a single piece of legislation.

5.2 PROTOTYPE EIP REGULATORY CASE STUDY

The Brownsville/Matamoros prototype EIP scenarios, as described in Chapter 3, provide a backdrop for analyzing regulatory issues surrounding each scenario and possible regulatory approaches to encourage EIP development. The EIP scenarios contain several facilities, some located at the port; others are, at baseline, remote partners of the EIP:

Baseline Port Members

- Refinery
- Stone Company
- Asphalt Company
- Tank Farms

Remote Members

- Discrete Parts Manufacturer
- Textile Plant (cut and sew only)
- Auto Part Manufacturer (Matamoros)
- Plastic Recycler

Remote Members (continued)

- Seafood Processor and Cold Storage Warehouse
- Chemical Plant (Matamoros)
- Magnetic Ballast Manufacturer

Table 5-1 highlights the coverage of a few key federal statutes for each of these EIP members. In Sections 5.2.1 through 5.2.5, we discuss potential regulatory issues that may arise for each EIP member in each of the five EIP scenarios. These scenarios range from Scenario 1, "business as usual," through Scenario 5, a fully collocated EIP with joint services (refer to Chapter 3 for a more complete description of these scenarios). Table 5-1 provides a useful starting point for determining where regulatory issues might arise for each scenario.

5.2.1 Scenario 1: Baseline Activities

Scenario 1 represents the current state of operations or "business as usual," where existing incentives alone are sufficient to encourage a certain amount of symbiosis, mainly that which is economically beneficial. As discussed in Chapter 3, we assumed that the City of Brownsville provides water and wastewater treatment to all companies. Thus, each company is individually responsible for meeting all major CWA statutes.

The major materials exchanges in Scenario 1 result from primarily economic arrangements that are fostered by the close proximity of the three facilities in the Port of Brownsville. The materials exchange opportunities for Scenario 1 include the following:

- **Petroleum refinery:** sells residual oil to the asphalt company. This exchange requires that the refinery and possibly the asphalt company apply for a new source review permit, permit variance, or flexible permit from TNRCC to comply with 40CRF262 (standards for generators of hazardous waste) and 40CFR279 (used oil management standards). Getting a permit can cost between $450 and $75,000, depending on the type of permit sought and details (e.g., quantity of oil) of the exchange.
- **Stone company:** sells residual stone to the asphalt company. There are no major regulations that would limit the sale of residual stone.

Table 5-1. Baseline Coverage of Some Major Regulatory Statutes
The EIP members are regulated under most of these key statutes.

		EIP Members[a]											
		1	2	3	4	5	6	7	8	9	10	11	12
RCRA	40CRF261 (identification of hazardous wastes)	x	x	x	x	x	x	x	x	x	x	x	x
	40CRF262 (standards for generators of hazardous waste)	x	x	x	x	x	x	x	x	x	x	x	x
	40CRF268 (land disposal regulations)	x	x	x	x	x	x	x	x	x	x	x	x
	40CRF279 (used oil management standards)	x		x	x							?	
	40CRF264-5 (tanks and containers)	x		x	x						x	?	
	40CRF280 (underground storage tanks)			?	?						?		
	40CRF266 (boilers and industrial furnaces)	x			x						x	?	
CERCLA	40CFR302 (Haz. Sub. Release reporting regs)	x	x	x	x	x	x	x	x	x	x	x	x
	40CFR300 (Haz. Sub. Responses)	x	x	x	x	x	x	x	x	x	x	x	x
	EPCRA302 (notification of excess hazardous substances)	x	x	x	x	x	x	x	x	x	x	x	x
	EPCRA304 (notification of non-exempt release)	x	x	x	x	x	x	x	x	x	x	x	x
	EPCRA311-12 (MSDS reporting)	x	x	x	x	x	x	x	x	x	x	x	x
	EPCRA313 (TRI reporting)	x	x	x	x	x	x	x	x	x	x	x	x
CAA	40CFR52 (new source review)	x	x	x	x	x	x	x	x	x	x	x	x
	40CFR60 (new source performance standards)	x	x	x	x	x	x	x	x	x	x	x	x
	40CFR61 (national emission standards for HAPs)	x	x	x	x	x	x	x	x	x	x	x	x
CWA	CWA402 (NPDES permit requirements)	x	x	x	x	x	x	x	x	x	x	x	x
	40CFR122 (storm water discharge)	x		x	x		x			?	x	?	
	CWA307 (pretreatment controls)	x	x	x	x	x	x	x	x	x	x	x	x
SDWA	40CFR144-148 (underground injection control)	?									?		
TSCA	TSCA5 (premanufacture notice)	x			x						x		
	TSCA6 (ban of chemicals posing unreasonable risk)	x		x	x	?		?	?		x	?	?

Note: Question mark indicates uncertainty about whether the statute is applicable.

[a]EIP Members are:

1. Refinery
2. Stone Company
3. Asphalt Company
4. Tank Farms
5. Discrete Parts Manufacturer (metal and plastic)
6. Textile Plant (cut and sew)
7. Auto Parts Manufacturer (Matamoros)
8. Plastic Recycler
9. Seafood Processor
10. Chemical Plant (Matamoros)
11. Magnetic Ballast Manufacturer
12. Gypsum Wallboard Manufacturer

5.2.2 Scenario 2: Pollution Prevention (Without Symbiosis)

In Scenario 2, all Port and remote EIP members implement P2 activities independently from the other existing EIP members. Only P2 activities that are economically beneficial to the EIP members to merit the materials or process modifications. Much of this economic benefit, however, could be realized in terms of improved materials use efficiencies and reduced environmental pollution. The following P2 projects were identified and evaluated as part of the EIP scenario analysis presented in Chapter 3:

- **Discrete parts manufacturer:** introduces an aqueous cleaning system and oil–water separation system. Implementing these two systems would require purchasing new equipment and modifying the process for cleaning parts and pretreating wastewater. The systems may also require the use or production of new hazardous substances. For both the aqueous cleaning system and oil–water separation system, the parts manufacturer would be required to obtain a new source review permit, permit variance, or flexible permit from TNRCC. Getting a permit can cost between $450 and $75,000, depending on the type of permit sought and details of the process or facility modification.
- **Textile company:** recycles cutting room clippings. This recycling effort would merely reduce the amount of waste clippings being sent to the landfill and instead divert the clippings back to the textile manufacturing company for reuse. Implementing this recycling effort would not require any regulatory permitting modifications since the clippings contain no hazardous substances and the process for collecting, baling, and shipping the clippings would remain unchanged.
- **Automobile parts manufacturer:** purchases a ringer system for absorbent socks and rags. Addition of the ringer system would not require any permit modifications unless there is a substantial increase in waste solvent being stored on-site. In this case, the facility would be required to obtain a new source review permit, permit variance, or flexible permit from TNRCC. Getting a permit can cost between $450 and $75,000, depending on the type of permit sought and details of the process or facility modification.
- **Seafood processor:** uses brown water, rather than potable water, for noncritical cleaning processes. Modification of processes to use brown water may require prior approval from TNRCC permitting offices. The primary regulatory issues are the use of brown water for food preparation and the release of contaminants into the water. The seafood processor's use of brown water is limited by the Food and Drug Administration (FDA), which requires that the seafood plant follow specific procedures to prevent contamination of

food products (*Federal Register*, 1994). Regarding the release of contaminants to the water, the seafood processor has not changed the total amount of effluents from their process. They have only reduced the amount of potable water they use. However, since the pollutants in the discharge water may be more concentrated, this poses a regulatory issue if the pollutant levels are above regulatory standards for pretreatment.

5.2.3 Scenario 3: Symbiosis Among Existing EIP Industries

In Scenario 3, symbiosis activities among the existing EIP members occur as a result of potential economic and environmental changes in efficiency from applying the concepts of IE. The approaches for Scenario 3 are different in focus from those examples provided for Scenario 2 in that they encourage not only on-site materials and process modifications to reduce pollution, but also off-site (among existing EIP members) recycling of materials. This scenario takes advantage of exchanges that can take place with little or no additional investment:

- ➤ **Discrete parts manufacturer:** sells scrap plastic, which is currently landfilled, to the EIP recycler. The manufacturer also purchases recycled plastic pellets from the recycler. Because the scrap plastic generated by the parts manufacturer has not been contaminated by any hazardous substances, no regulatory issues should be associated with selling the plastic to the recycler. No permit modifications will be needed.
- ➤ **Textile company:** sells scrap plastic (from worn out pallets and collection bins) to the EIP recycler. Again, because the scrap plastic generated by textile company has not been contaminated by any hazardous substances, no regulatory issues should be associated with selling the plastic to the recycler. No permit modifications will be needed.
- ➤ **Auto parts manufacturer:** sells scrap plastic to the EIP recycler rather than to the current recycler used in Chicago. Because the auto parts manufacturer already has a system for collecting and selling scrap plastic to another recycler, there should no additional regulatory issues in selling the scrap plastic to the EIP recycler. However, the auto parts manufacturer is a maquiladora firm. It may be required to report to its governing body that the scrap is being shipped to another U.S. site.
- ➤ **Ballast manufacturer:** sells scrap asphalt to the asphalt company for mixing with its "virgin" materials. Because the scrap asphalt contains oil, it is treated as a RCRA hazardous waste. Selling the scrap asphalt to the EIP asphalt company may require modifying the ballast manufacturer's RCRA permit to comply with 40CFR262 (standards for generators

of hazardous waste) and 40CFR268 (land disposal regulations). The re-permitting process or application for a permit variance would cost the manufacturer from $450 to $75,000, depending on the type of permit sought and details of the proposed modification.

5.2.4 Scenario 4: Symbiosis Among Existing EIP Industries and External Industries

In Scenario 4, symbiosis activities among the existing EIP members encourage linkages with remote EIP partners to further potential gains in economic and environmental changes in efficiency. This scenario contains many of the same approaches as those developed for Scenario 3, but they are expanded to include new EIP members. New EIP members include a power plant that burns Orimulsion and distributes process steam to other EIP members and a gypsum wallboard company. The addition of these two members will result in the following symbiotic relationships:

- **Power plant:** delivers cogenerated steam through a steam pipeline to the refinery, tank farm, and asphalt company. The condensate is returned to the power plant and used to produce more steam. A new source review permit may be required for generating steam; however, since it does not produce any air pollutants, there shouldn't be any major regulatory issues.
- **Stone company:** delivers limestone to the power plant for use in the scrubber system. Because limestone contains no hazardous substances, no additional regulatory issues are associated with its delivery to the power plant.
- **Gypsum wallboard company:** receives waste gypsum from the power plant. Since the gypsum is pure, it does not present a regulatory issue. However, if for some reason the gypsum were contaminated and the contaminant levels were above RCRA standards, the gypsum would be categorized as a hazardous waste, and a RCRA permit modification would be required to use the gypsum for wallboard manufacture. In addition, the wallboard company could be required to conduct an environmental and human health impact assessment of the wallboard produced with the waste gypsum to ensure that its use and disposal present no threats or risk to human health or the environment.

5.2.5 Scenario 5: Symbiosis with Collocation and Joint Services

In Scenario 5, we model the relationships resulting from the collocation of all members at the EIP and the provision of joint EIP services. Collocation and joint services present opportunities to improve economic and environmental efficiency. These joint services include the following:

- **Solvent recycler:** receives waste solvents from the discrete parts manufacturer, ballast manufacturer, auto parts manufacturer, and textile company. All parties involved would be required to submit an application for variance or flexibility to 40CFR262 (standards for generators of hazardous wastes) and 40CFR264-265 (tanks and containers). The recycler would be required to obtain new source permits for all major Federal and State statutes.
- **Oil recycler:** receives residual oil from the discrete parts manufacturer, ballast manufacturer, auto parts manufacturer, and textile company. All parties involved would be required to submit an application for variance or flexibility in complying with 40CFR262 (standards for generators of hazardous wastes) and 40CFR279 (used oil management standards). The recycler would be required to obtain new source perm its for all major federal and state statutes.

5.3 REGULATORY STRATEGIES FOR SUPPORTING EIP DEVELOPMENT

The challenge over the coming years will be to balance the tradeoffs between regulatory strategies that meet aggressive environmental goals and those allowing and encouraging innovative approaches, such as EIP development, to meet those goals. This section contains a variety of generic regulatory strategies for encouraging P2 and IE in the context of EIP development.

5.3.1 Modify Existing Regulations

Although not the primary intention of most existing legislation, many regulations (or the language used in regulations) can prohibit or discourage reusing and recycling waste and byproduct materials. Redefining or modifying existing regulations such as RCRA, TSCA, and CERCLA may allow facilities greater flexibility in managing their wastes to better achieve P2 goals. For example, the still bottoms produced by the refinery are classified as a RCRA hazardous waste, which must be disposed of appropriately. Such regulatory requirements can limit the use of these still bottoms in other potential applications at the Port, such as mixing with residual oil that is used in the asphalt plant or mixing with residual oil that is used in boilers to heat the tank farm. Modifying the language used in RCRA to allow facilities the option to use still bottoms (if they can

Modifying Existing Regulations to Promote P2

In late 1993, Intel Corporation, EPA, and the Oregon Department of Environmental Quality joined in a partnership to evaluate opportunities to incorporate flexibility and P2 in permits issued under Title V of the CAA as amended in 1990. Completed in 1994, the project created a draft Title V permit that will demonstrate the ability of P2 to perform equally well in reducing air emissions as traditional end-of-pipe controls. The draft permit contains the following requirements:

- emission limits and performance standards
- plant site emission limits
- reasonably achievable control technology standards
- aggregate hazardous air pollutants emission limits
- P2 condition
- pre-approved changes
- monitoring requirements
- reporting requirements
- general conditions

Information developed from such initiatives will provide valuable baseline data for EPA to possibly establish regulatory standards with a P2 option, rather than restricting companies to only end-of-pipe technologies.

show that they will do so in a manner that does not cause environmental or health risks) can facilitate technology development for P2, driven by real economic incentives to reduce the use and production of hazardous materials.

Existing regulations also may be modified to better support on- and off-site exchange of waste or byproduct materials from pollution control equipment to other applications that can use the waste or byproduct material as an input to their production processes.

5.3.2 Streamlining Existing Permitting and Reporting Processes

In many cases, companies find discarding their waste materials more profitable than undergoing a lengthy and costly process to modify existing permits to allow for constructing and using equipment to transform waste into usable inputs to other applications. For example, the oil refinery at the Port EIP may need to process or treat its still bottoms before they can be

Accelerated Permit Review

One concern among industries is that the permitting process can be time-consuming and risky, making it difficult for them to plan effectively and respond quickly to changing market forces. To encourage P2, regulatory agencies can make it a policy to elevate the priority and expedite the review process for permits that include P2. EPA Region 9 has worked with state and local agencies in southern California to try this approach. In a single test case, they were able to substantially cut the time needed for the permit modification process for a company seeking changes to its air and water permits. Interest from industry in this effort has been limited, however, in preference for a more comprehensive streamlining of permitting procedures in California.

used in other applications at the asphalt plant and tank farm, as described in the previous section. To do this, assuming that it is economically attractive, the oil refinery would need to get a new permit or modify its existing permit for the processing and treatment equipment to be used. The lengthy re-permitting process, however, can negate any potential economic benefits realized by the oil refinery, and they may instead decide that disposing of their still bottoms as usual is easier and cheaper. Such regulatory hurdles would likely discourage potential EIP participants from making the process changes necessary to participate in an industrial ecosystem.

Consolidated or "One-Stop" Reporting

A recent study entitled "Evaluation of the Effectiveness of Industry Pollution Prevention Planning Requirements & Guidance for Integrating Pollution Prevention Plans" was completed by a group of graduate students at Tufts University. One of the study's results was that industry overwhelmingly felt that the redundancy and the temporal relationships of the planning and reporting requirements mandated by the many different regulations restrict the implementation of P2 projects during the first half of the year. Environmental managers noted the need to reduce the duplicative nature of the planning and reporting requirements and simultaneously to coordinate the timing and data requirements between the multiple federal requirements and individual state requirements. The study forecasted the need for streamlined planning and reporting requirements and includes a guidance document on how a company might develop one single P2 plan that would reduce the redundancy of the many plans currently required while allowing compliance with many regulatory programs.

A streamlined approach to permitting and reporting should integrate the permitting procedures of each regulatory program. An integrated permitting system would make it easier and less costly for facilities to modify or develop new technologies for using waste materials in other applications.

EIP members require technical flexibility for the EIP to remain viable. As explained in the EIP *Fieldbook*, EIP members must be able to respond to market changes and changes in suppliers and customers. A new input supplier may require a slight process change to accommodate variations in input quality or composition. Similarly, new customers may ask for products with different characteristics. Special streamlined processes for minor process or equipment modifications in EIPs would encourage continued participation in the industrial ecosystem.

Consolidated, or "one-stop," reporting is needed to consolidate routine emissions reporting to EPA and state regulatory agencies to reduce the multitude of reporting forms for different kinds of pollutants from a single facility. Achieving this goal would require a fundamental change in how EPA, states, and the regulated community manage information. Given the magnitude of this change, a phased approach to implementation would be required, perhaps beginning with tests sites or states. Based on the results of preliminary testing, consolidation reporting can be refined and transferred to other locations or states.

5.3.3 Move From Technology-Based to Performance-Based Regulations

Flexible Performance-Based Alternatives (Summarized from Clinton and Gore, 1995)
EPA has developed a coordinated series of demonstration projects designed to provide industry the opportunity to implement alternative management strategies. Such flexibility will enable environmental managers to employ technological innovation to achieve environmental goals beyond what the law requires, while requiring accountability for performance. Project XL is such an example. In partnership with the states, EPA is to provide a limited number of responsible companies the opportunity to demonstrate excellence and leadership. The companies will be given the flexibility to replace the requirements of the current system at specific facilities with an alternative strategy developed by the company if the alternative strategy

- provides superior performance to that which would be achieved by full compliance with current laws and regulations,
- is "transparent" to the public,
- does not create worker safety or environmental justice problems,
- is supported by the surrounding community, and
- is enforceable.

The environmental laws in place today can generally be characterized as technology-based performance standards. EPA and other regulatory agencies set industry standards based on the performance of a particular available and well-demonstrated technology. Because the standards are set by technologies already available, technology developers have few incentives to develop or deploy innovative technologies that exceed the performance standards set by the regulatory agency. Consider RCRA, which requires treating hazardous waste before disposal to attain levels achieved by the best demonstrated available technology (BDAT) at the time of regulation. Developers of technology have little incentive to test and commercialize technologies that perform better than those achieved by the BDAT, since using existing technology is codified in RCRA.

Performance-based standards allow firms to choose the pollution control technologies that are most economically efficient while achieving the required environmental performance. In the case of an EIP, the most economically efficient technology may be one that renders waste streams usable as feedstocks elsewhere. For example, suppose the stone company needed a dust collection or water filtration system. If regulations do not specify the BDAT, the company is free to choose a technology that recovers limestone that can be sold (or given away) to the oil refinery for use in their pollution control equipment. Similarly, from among several alternatives to control air emissions, the oil refinery can choose a scrubber technology that uses lime and results in the production of gypsum as its byproduct. This gypsum can in turn be sold to a gypsum wallboard manufacturer located outside of the Port EIP. If the revenue generated by the byproducts is greater than or equal to the marginal cost of the technology required, the company benefits economically from the new technology while achieving environmental performance.

Prescribing specific equipment or obsolete processes under technology-based regulations locks companies into existing technology, limiting the possibilities for reducing the total environmental impact of the EIP through resource exchange. The flexibility allowed by performance standards for pollution control as opposed to fixed technology standards was necessary for developing several of the symbiotic linkages in the Kalundborg, Denmark, EIP. Performance-based regulations give companies the flexibility required to modify process technology to best minimize pollution from their facilities. This also creates a demand for the development and commercialization of new P2, recycling, reclamation, reuse, and control technologies.

Opponents to performance-based regulatory standards note, however, that many industries would still be locked into specific technologies to meet performance-based standards. This shortcoming may be alleviated by facilitywide permitting, which does not focus on separate regulation of specific point sources of pollution. Facilitywide permitting is discussed in the following section.

5.3.4 Promote Facilitywide Permitting

Facilitywide Permitting
The New Jersey Department of Environmental Protection has issued its first facilitywide permit in its pilot project designed to integrate P2 into a single environmental permit. The permit, issued to Schering, Inc., a pharmaceutical manufacturer, will replace the company's previously existing permitting requirements. In addition to integrating actual medium-specific permit requirements, the facilitywide permit integrates P2 planning components as a result of a comprehensive P2 plan that the company was required to develop. This first facilitywide permit is part of a program involving 18 facilities in New Jersey. The program's goal is to issue single permits that are based on P2 to the 18 facilities and offer a more coordinated approach to permitting.

Facilitywide permits will be useful for both large and small facilities. In small facilities, such as the textile company in the prototype EIP, facilitywide permits may reduce the total cost of permitting. In larger facilities, such as the chemical plant, facilitywide permitting may not only reduce the total cost of permitting but also may encourage the facility to develop and implement P2 and/or closed-loop recycling technologies. However, a facilitywide permit may be more difficult to amend with subsequent process modifications or additions. One option might be a combination of a facilitywide permit and a flexible permit that allows facilities to make process changes for achieving facilitywide P2 goals without having to file for new permits or modify existing permits.

Taking the concept of facilitywide permitting one step further, a co-located EIP may provide a good opportunity to use umbrella permitting—where the entire EIP is treated under a single regulatory permit. Umbrella permitting currently is being applied to some larger companies, usually those with two or more facilities that otherwise would require separate permits and compliance records. However, in the context of EIPs, an established EIP tenant would have to maintain records, among other things (see Section 5.1.3 for a discussion of the role of regulatory association), for the umbrella permit. EIPs may also have difficulties modifying a large umbrella permit. In general, the more companies that are located in the EIP, the more difficult it will be to implement and/or modify the umbrella permit.

5.3.5 Promote Multimedia Permitting

Multimedia Permitting
Multimedia permits may provide an avenue for reducing the time and effort that a company—and the regulatory agency—spend on permitting, while simultaneously encouraging a company to look at P2 as a means to reducing overall emissions, rather than shifting pollutants between media. New Jersey's multimedia permitting program integrates P2 at its core while providing companies with an avenue for streamlining their permit needs. Massachusetts is also adopting multimedia permit approaches. Multimedia approaches may not be appropriate for all facilities, and not all facilities eligible for multimedia permits have shown interest in pursuing them.

Facility wide permit programs may be used to account for transfers of waste to different media and to explore P2 options before less desirable options. Multimedia permits would encourage more regulations that focus on reducing total mass emissions for an entire facility as opposed to emissions rates for particular pieces of equipment. Also, multimedia permitting can be based on the company's P2 plan, thus incorporating the waste management hierarchy into the permit process. This approach would reduce bias towards single-medium solutions and encourage more efficient waste management.

5.3.6 Market-Based Approaches

The primary objective of market-based approaches is to implement financial incentives or disincentives that make it profitable for polluters to reduce resource and energy use or generation of waste. Permit trading programs, such as those used under the CAA, can provide companies with an economic incentive to reduce their pollution—specifically because they can trade emissions credits that are not used. Similarly, permit trading programs also may be used to encourage IE. Under a permit trading scheme in an EIP, two or more firms can gain, environmentally and economically, from symbiotic relationships that will reduce their overall combined levels of pollution by enabling the companies to trade remaining permits on the open market. Credits from permit trading will further lower their total cost of maintaining a symbiotic relationship.

Incentives such as tax credits or exemptions, subsidized interest loans, and innovative technology grants can be linked to industrial environmental performance or to the initiation of closed-loop permits and other multimedia solutions. In the context of an EIP, tax credits or exemptions could be issued for industries that meet a determined performance standard or possibly for industries that are developing and/or implementing P2 technologies as older plants and equipment depreciate.

Open-Market Air Emissions and Water Effluent Permit Trading (summarized from Clinton and Gore, 1995)
EPA currently is pursuing an emissions trading rule for smog-creating pollutants that will allow states to obtain automatic approval for open-market trading of emissions credits with accountability for quantified results. Expanding the use of market trading on a local and regional level will give companies broad flexibility to find lowest cost approaches to emissions reductions. The rule will encourage experimentation with new trading options, while enabling states to pursue more quickly allowance-based cap systems, which are already under development in some areas. In addition, EPA will place top priority on promoting the use of effluent trading to achieve water quality standards. EPA will achieve this by establishing a framework for different types of effluent trading, issuing policy guidance for permit writers, and providing technical assistance. Trading can be used to achieve higher water quality in watersheds at a lower cost than inflexible discharge requirements for individual sources.

In a fully collocated EIP, market-based incentives can help to bring into the EIP joint services that serve EIP member companies. For example, if an oil or solvent recycling company gets all the tradable permits for the whole EIP for oil and solvents, the company has great incentive to serve the EIP members and to recycle rather than dispose of used oil or solvents. The permits that are remaining then may be sold to external industries, which in turn would lower the cost of the recycling company to do business in the EIP.

Financial disincentives, such as pollution taxes or “green taxes,” can be implemented on resource consumption, wasted raw materials, and pollution. Similarly, pollution taxes could be levied on releases to all media; pollution taxes must be implemented on a multimedia basis to avoid focus on single-medium solutions.

Market-based solutions could be implemented to drive the development of technologies that increase energy and materials efficiency. Market-based programs make symbiotic relationships more economically viable than nonsymbiotic arrangements. For example, a regulation requiring recycled content in products may be implemented most cost effectively by establishing a tradable recycling credit scheme to encourage industries who can incorporate secondary materials most cheaply to do so.

On the downside, market-based approaches are extremely difficult and costly to implement and enforce (Shireman, 1993). However, the application of air and water permit trading programs has yielded additional demands for new technologies.

5.3.7 Voluntary Agreements

Federal- and State-Level Voluntary Agreements
In the U.S., EPA has had considerable success with voluntary agreements with industry such as the 33/50 Program. The 33/50 Program is designed to encourage companies to reduce the release and transfer of 17 target chemicals. The goal established by the 33/50 Program is to reduce national releases and transfers of target chemicals by 50 percent in 1995, with the interim goal of 33 percent in 1992. Companies are encouraged to participate by developing their own reduction goals. An example of a voluntary agreement at the state level is Massachusetts' Toxics Use Reduction Act (TURA), which was developed through negotiations involving government, industry, and public interest groups. Under TURA, companies are required to develop facility plans with self-set goals to reduce the use (in addition to release) of toxic chemicals.

Increased emphasis on voluntary agreements with industry to promote P2 and environmental technologies—such as materials substitution, product redesign, process reformulation, closed-loop recycling, and more efficient materials tracking and management—is perhaps the best means of achieving flexibility. Voluntary agreements tend to be easier and faster to implement than legislation and regulations and may be more attractive to industry because it has more control over the goals and timetables. In addition, voluntary agreements could include state and local agreements that encourage industry to develop plans for reducing the use of toxic chemicals, requirements for industry disclosure of hazardous chemicals in products, and creation of hazardous and nonhazardous wastes.

In the P2 scenario, federal, state, and/or local agencies could promote voluntary agreements with industry that support P2 goals. In the case of the prototype EIP, voluntary agreements could be encouraged with the park tenants to create plans for developing and implementing P2 technologies or to work together to reengineer processes and byproducts to increase their reusability. In Kalundborg, Denmark, for instance, firms are required to submit plans to the overseeing county government detailing their efforts to continually reduce their environmental impact. Through these plans, a cooperative relationship is fostered between government and industry. As a result, the firms seem to focus efforts on finding creative ways to become more environmentally benign, instead of fighting the regulators.

5.3.8 Manufacturer "Take-Back" Regulations

Germany Manufacturer Take-Back Laws (summarized from OTA, 1992)
Because packaging accounts for up to 30 percent of German municipal solid waste by weight, the country recently enacted a law that redefines the responsibilities of companies and requires product recycling. The German Federal Ordinance Concerning Avoidance of Packaging Waste, passed in April 1991, mandates that companies take back and recycle used packaging. For some types of packaging, the law gives industry an opportunity to establish its own collection system and recycling system. If such independent management fails, the law places responsibility on manufacturers and distributors to collect the packaging and arrange for recycling. The take-back idea appears to be gathering momentum throughout Europe and is being introduced in the U.S. New Jersey and other states, for instance, have enacted take-back requirements for rechargeable nickel-cadmium batteries.

Take-back regulations give manufacturers responsibility for recovering and recycling the products they produce. By shifting the burden of solid and hazardous waste management from local governments to industry, the costs of waste management are internalized by manufacturers. Thus manufacturers have a direct incentive to design and produce products that are more amenable to recycling.

On the surface, manufacturer take-back regulations have considerable appeal. Making manufacturers responsible for recovering their own products, rather than telling them how to do it, gives them flexibility to find the least-cost solution. In addition, take-back regulations encourage the integration of P2 and recyclability considerations in product design and manufacturing.

Take-back regulations, however, may not be a cost-effective alternative for all products. For nondurable products, take-back regulations would create additional costs for manufacturers without unambiguous benefits. For example, collecting and recycling potato chip bags would probably be inefficient and would likely cause more pollution from transporting the bags to a recycling facility than would result from landfilling or burning the bags (Office of Technology Assessment, 1992). Take-back regulations would also be difficult to implement for companies whose product is indistinguishable from others (e.g., used oil), public utilities, or companies that manufacture only a component of a final product. An alternative to take-back laws may be a deposit-refund system on such items as toxic chemicals or their containers.

5.3.9 Technology Transfer

A wide variety of federal- and state-level programs already have been implemented for promoting P2. However, few technology transfer programs exist for encouraging IE or EIP-type development. For example, finding information about different pollution control and environmental technologies and ways they can be used to transform waste streams into valuable, usable materials is difficult (refer to Chapter 6 for more discussion of environmental technologies). Such technology transfer in what may be considered intermediary processes is greatly needed to support the principles of

IE and to turn otherwise unusable waste into valuable products that may be used in other applications.

5.3.10 Opportunities for Technology Development and Commercialization

The development and implementation process for environmental regulations can take as long as 5 years. This long process is supposed to provide an early warning system to industry of the need for new technology. However, industry often has little information about the stringency of proposed regulations, and often requirements typically become effective soon after the regulation is implemented. Thus although companies are reluctant to incur the cost and risk of P2 and innovative technologies without a firm regulatory standard, if they wait until the final rule is made, they may not have enough time to respond to the rule with an effective strategy for P2. The alternative, which is anti-innovative, is to design and install treatment equipment. In the current system, companies may be penalized for being innovative because they may be fined for noncompliance and forced to reinstall a conventional technology if an innovative approach fails.

Incorporating a time period for technology development and commercialization into the regulatory development process could decrease the risk that new technologies will lack regulatory applicability. Reduced risk would encourage P2 and technology development and commercialization.

5.3.11 Industrial Ecology Technology Development Grants

To provide greater incentive for companies to risk the development and implementation of new technologies to promote IE concepts, a national competitive action grant could be offered to states, regions, or localities. The grants would encourage local companies to coordinate efforts to promote the development of technology that connects sustainable economic and environmental development in an IE context. Such technologies would make industrial ecosystems more sustainable and could include low-emissions “closed” production systems, internal and external recycling and reuse of wastes, shared inputs, improved efficiencies of energy and materials use, and

Lower Rio Grande Empowerment Zone
The Empowerment Zone/Empowerment Community initiatives is a type of national action grant. Recently, the Lower Rio Grande Region received a $30 million Empowerment Zone Grant. Such a grant provides a source of funds for supporting sustainable economic and environmental development. In addition, such funds will allow for local and regional industrial planners and managers to cooperate with state regulatory agencies to develop more flexible alternatives to existing regulations—as long as the alternative approach(es) proves to be as, or more, effective than existing regulations.

life-cycle design. The application process would include demonstrating the relationship of the project to a comprehensive, cross-media, environmental needs assessment of the area. A successful application would demonstrate a high level of stakeholder involvement and community involvement and demonstrate that the technology development strategy would allow companies to exceed existing environmental requirements. Recipients would be expected to leverage direct private-sector investment in place-based environmental protection.

5.4 CURRENT REGULATORY INITIATIVES ENCOURAGING EIP DEVELOPMENT

While Section 5.3 outlined some possible regulatory strategies for promoting EIP development, recognition of the benefits of P2 and IE already is driving some regulatory initiatives to promote not only source reduction but also the reuse and recycling of waste and secondary materials. This section describes some of these current regulatory initiatives.

5.4.1 EPA's Pollution Prevention Policy Statement

EPA's P2 Policy Statement, as published in the *Federal Register*, was a major step toward eliminating some of the confusion surrounding the terms P2, waste reduction, waste minimization, and recycling. The policy statement replaces the RCRA term "waste minimization" with the term "P2" to bring about a multimedia focus as opposed to a more restrictive focus created by a term associated with RCRA. Furthermore, the policy establishes a hierarchy of waste management by placing P2 (source reduction and environmentally sound recycling) above waste treatment, control, and disposal.

The policy statement leaves unaddressed, however, where waste minimization resulting from reuse, recycling, and reclamation fits into P2. Wastes once generated and removed from the process seem to fall outside the umbrella of P2. Yet such wastes, properly managed on-site through segregation, improved work procedures, and good housekeeping can be reduced in amount, reducing on-site or off-site treatment requirements. Similarly, open-loop and off-site recycling are not recognized in the policy statement as fitting into the scope of P2.

Finally, EPA's P2 policy makes no mention of reuse and reclamation of secondary materials (i.e., waste exchange). If beneficial reuse and reclamation activities can be undertaken in an environmentally sound manner and result in "minimizing the present and future threat to human health and the environment," then they should be included in the realm of P2 (or if not, at least in an EIP policy statement).

5.4.2 Solid Waste Task Force

EPA is revising the rules governing hazardous waste recycling in an effort to give industry more flexibility for recycling. Over the last 2 years, the solid waste task force and state representatives held extensive meetings with industry and the environmental community, and in April 1994 the group issued a set of draft recommendations for consideration by EPA management (EPA, 1994c).

The task force report envisions a system in which recycling would fall under one of three broad categories: RCRA-Exempt/Excluded, RCRA Recycling, and RCRA Hazardous Waste Recycling. The "exempt" category would offer a few new exemptions from Subtitle C of RCRA for fuel use activities and would remove some existing exemptions for direct reuse of spent materials sent off-site and emissions control residues. The "hazardous waste recycling" class, would include, among other things, used oil recycling and recycling of inherently waste-like materials.

For "RCRA recycling," under which most recycling activities would fall, the report suggests streamlined regulations for both on-site and off-site recycling activities and proposes new requirements to ensure adequate environmental protection. The key new requirement proposed by the task force is a "toxics along for the ride" (TAR) test, which a material must pass to qualify for streamlined regulations. Both EPA and states say that a TAR test is necessary to ensure that companies do not use illegitimate recycling to avoid more stringent Subtitle C regulation.

Industry representatives are concerned that rulemaking could result in more burdensome regulations instead of simplifying the RCRA system and fostering recycling. Of particular concern to industry is the TAR requirement, which some say could prevent a host of otherwise acceptable recycling practices. In the December 9, 1994, issue of *Inside EPA*, one industry source says the TAR test proposed in the report "wouldn't let much get out," and another industry source says some companies "resent the innuendo and referred accusation" that industry may be "cheating" and such a test is mandatory. The same report, however, highlights that most industry sources are encouraged that EPA is taking a closer look at these issues and that the Agency is considering less prescriptive rules for on-site recycling operations.

5.4.3 EPA Permits Improvement Team

EPA's 1993 National Performance Review provided many recommendations for improving the permitting process. In addition, the President issued an executive order requiring agencies to "identify and assess available alternatives to direct regulation, such as user fees or marketable permits." The executive order also requires agencies to "consider incentives for innovation" and "to the extent feasible, specify performance objectives, rather than specifying the behavior or manner of compliance that regulated entities must adopt" (E.O. 12866, September 30, 1993).

Responding to the need to improve the permitting process, EPA created a Permits Improvement Team. Permits Improvement Team members include representatives of states, tribes, and EPA headquarters and regions. EPA also has launched other major initiatives that will have significant permitting components: the Common Sense Initiative, the Environmental Justice Advisory Committee, the Ecosystem Management Initiative, the State/EPA Capacity Steering Committee, and the Customer Service Initiative. Each of these initiatives will improve the permitting process, and the Permits Improvement Team will guide the overall direction of these improvements.

The Permits Improvement Team has formed the following task forces:

- alternatives to individual permits
- administrative streamlining
- enhanced public participation
- P2 incentives
- training
- performance measures

As of December 1994, each task force had defined a set of short-term and long-term goals.

5.4.4 Brownfields Economic Redevelopment Initiative

The purpose of EPA's Brownfields Economic Redevelopment Initiative is to empower states, communities, and other stakeholders in economic redevelopment to work together in a timely manner to prevent, assess, safely clean up, and sustainable reuse brownfields (EPA, 1995). The *Brownfields Action Agenda* includes four broad categories of efforts:

- brownfield pilots, which will test redevelopment models, direct special efforts toward removing regulatory barriers without sacrificing protectiveness, and facilitate coordinated public and private efforts
- clarification of liability and cleanup issues
- partnerships and outreach
- job development and training

5.4.5 Technology Transfer Initiatives

A variety of federal-level initiatives have been undertaken to advance environmental technology development and transfer. A few of President Clinton's administrative initiatives are presented below, as summarized from the National Science and Technology Council (1994).

Technology for America's Economic Growth: A New Direction to Build Economic Strength (February 1993) outlines the key elements of the Administration's technology policy, including initiatives to promote long-term economic growth that creates jobs and protects the environment.

Summarizing actions taken in the 9 months following the February 1993 technology policy is *Technology for Economic Growth: President's Progress Report* (November 1993). Actions discussed in this report include incentives for private-sector research and development and new business formation, development of a new export strategy, aggressive pursuit of bilateral and multilateral trade agreements, investment in workers' skills, and forging of industry partnerships.

Environmental Technologies Exports: Strategic Framework for U.S. Leadership (November 1993) proposes an administration strategy to enhance exports of U.S. environmental technologies. In connection with the recommendations of this report, EPA is working with key federal agencies to review environmental policies and procedures to identify specific steps needed to reduce barriers and stimulate innovation in environmental technology development and commercialization.

The January 1994 *Draft Technology Innovation Strategy* describes broad strategies that will be used to guide the new Interagency Technology Initiative, coordinated by EPA. The initiative is designed to encourage the development of advanced environmental systems and treatment techniques.

Chapter 6 provides a more complete discussion of environmental technologies to support EIP development.

5.5 REGULATORY POLICY RECOMMENDATIONS FOR SUPPORTING EIP DEVELOPMENT

To encourage EIP development, we must find ways to increase the flexibility of the regulatory structure so that it functions to encourage greater innovation.

One of government's roles in supporting EIP development is to increase the flexibility of the regulatory structure so that it functions to encourage greater innovation. Moving the regulatory structure to more flexible, more resilient, systemic solutions will require environmental regulations that are less focused on single-medium and single-source controls. This type of flexibility will allow EIPs to respond to environmental issues of greatest concern in their communities.

Some of the major regulatory issues that may limit or discourage EIP-type development fall into the following categories:

- definition of waste
- definition of a "source"
- liability
- single-medium permitting focus
- brownfield versus greenfield development
- U.S.–Mexico border environment issues

Permitting staff at the TNRCC indicated during interviews that federal solutions to these problems will be difficult and slow. However, states are empowered to structure their regulatory system with great flexibility as long as federal requirements are met. If EIPs can provide both environmental protection and economic benefit, state regulators can address many regulatory issues, which will, however, require a high level of commitment and interaction between state and local governments and EIP members.

Over the next ten years, over $1 billion have been devoted to industrial park development (Youngblood et al., 1995). To encourage these developments to incorporate EIP design options, we will have to immediately start looking at optimal regulatory solutions for industrial parks.

5.5.1 Clearly Define the Problem

It is imperative to the success of IE and EIP development that the main problems be identified and clearly defined. Many of these problems that discourage the incorporation of IE in industrial park development have been identified in Sections 5.1 and 5.2 of this chapter. Ongoing initiatives are needed to identify and define these and other issues limiting the application of IE concepts and environmental technology development. With clearly defined problems, efforts can proceed to modify existing programs or create new programs that provide well-informed solutions.

5.5.2 Allow Industry Maximum Flexibility Consistent With Solving Environmental Problems

As described in Sections 5.3 and 5.4, efforts are already underway to promote flexible regulatory alternatives that encourage the recycling and reuse of materials. Some of these approaches include the following:

- modify regulatory language (e.g., definition of waste and source)
- develop provisions allowing for the storage of “secondary material” being recycled off-site prior to processing (180 days is suggested to allow for accumulation of inventory needed for batch operations)
- streamline permitting processes
- consolidate regulatory reporting requirements
- promote facilitywide permitting
- promote multimedia permitting

Such efforts must continue to support industry and states in developing and implementing innovative environmental technologies.

5.5.3 Encourage Open Communication and Cooperation Among Key Stakeholders

A new standard of communication and cooperation between key stakeholders is critical to the realization of EIP development. As stated in the introduction to this chapter, these stakeholders include industries participating in EIPs; state, local, and federal government agencies; citizens of regions where EIPs are sited; and the environment as a whole. As evidenced by the current initiatives described in Section 5.4 and the various examples provided in Section 5.3, much progress has been made in supporting innovative approaches to environmental protection through better communication and cooperation between industry and federal, state, and local government agencies. Mechanisms for continuing such collaboration and for including more stakeholders are needed to develop economically efficient and environmentally sound technologies.

5.5.4 Encourage a Systems Approach to Regulation

A major obstacle to developing and implementing regulations for EIPs is the structure of government environmental regulatory systems (Weinberg et al., 1994). The current regulatory system is fragmented into separate program offices for air, water, and land pollution issues. In addition, taxes and research are all under the jurisdiction of separate committees. EPA is organized around regulatory responsibilities for protecting air, wastes, and land; it does not address industries or industrial sectors. The Department of Commerce, on the other hand, is concerned with the competitiveness of industrial sectors but has little environmental expertise. Recognizing opportunities for systems-oriented design requires that the economic performance and environmental performance of industries or sectors be viewed as complementary objectives. Individual companies have little incentive to promote an overall environmental vision of their industry. And, in general, this cannot be done in the context of a single federal agency. For example, a more environmentally benign oil refining industry may involve not only improved production efficiency and pollution control but also better management of oil-based products as used by consumers (e.g., better recycling practices).

Creating a separate institution within government to promote EIPs does not make sense, but greater coordination between agencies would certainly be beneficial. EIPs and IE concepts could be integrated into new interagency initiatives, such as the Manufacturing Technology Initiative and the Advanced Materials and Processing Program. However, policymakers currently lack critical information on how materials flow through the economy and about the relative dangers of different materials, products, and waste streams. A systems view is critical to identifying the major sources of environmental pollutants.

6 Technologies Supporting Eco-Industrial Parks

Although the environmentally indiscriminate use of technology has contributed to many of our environmental problems, technology has also been important to many environmental solutions. New technologies have been responsible for averting predicted environmental crises by developing substitutes for scarce resources, such as wood and metals; by designing alternatives to toxic and environmentally harmful materials, such as lead; and by developing remediation technologies that allow us to reverse much of the environmental damage caused by previous misuse of industrial technologies.

> The typically myopic cycle of environmental technology development must be replaced by a systematic approach to environmental solutions.

However, the cycle of environmental technology development has been somewhat myopic. Driven largely by market forces, and more recently by environmental regulation, technology development typically invents new products and processes only when scarcity and other environmental considerations threaten the sustainability of the status quo technology. As noted by Ausubel (1989), environmental problems might be more easily averted by stimulating systematic approaches to environmental problems that replace the piecemeal solutions of the past.

We view the EIP as part of a remedy for the myopia that has typically characterized the application of technology. The EIP can provide the incentive and the opportunity to think more systematically about technology and its best applications. Applying IE principles virtually redefines our notion of waste. Ideally, everything produced is a useful product. Taken to its logical conclusion, the EIP takes a life-cycle approach to waste. Not only does it prevent the generation of wastes in production but also in the consumption of the goods and services produced in the EIP.

The EIP encourages the application of technology consistent with a clear hierarchy in waste management (Science Advisory Board, 1988). The first priority in this hierarchy is to discover ways in which the EIP can mobilize the joint resources of its members to prevent waste generation. The second technological priority for the EIP is to find opportunities to apply the concepts of IE to recycling and reuse. By locating symbiotic partners close to each other, the EIP improves the economic viability of recycling and reuse and reduces the risk of exposure due to mishandling or accidents during the transportation of these products.

Treatment and destruction of waste products are final resorts for the EIP, because they result from the limitations of the technology applied upstream. Waste represents an inefficiency or an opportunity for the EIP that has not been captured. The purpose of the EIP is to seize these opportunities and turn them into environmental and economic gain. Inevitably, we will be unable to fully capture these opportunities; treatment and destruction technologies provide a final defense against the limitations of the EIP and its technology.

The appropriate technologies can improve the sustainability of the EIP:

- They can improve the economic efficiency of the EIP.
- Technological change can make symbiotic relationships technically and culturally feasible that previously were not.
- Appropriate technologies can reduce risk by improving the flexibility of the relationships between the members of the symbiosis.
- These technologies can reduce the environmental burden of the production and consumption of the goods and services provided in the EIP.
- These technologies can play a role in reducing the costs of complying with environmental regulations.

Each of these changes improves the sustainability of the EIP's industrial ecosystem.

This chapter provides a framework for identifying technologies that improve the sustainability and success of an EIP.

This chapter provides a framework for identifying technologies that improve the EIP's sustainability and success and discusses how specific technologies fit into this framework. Clearly, the technologies contributing to the success of each EIP are specific to the EIP's particular industrial activities, the characteristics of the industrial symbiosis, the geophysical characteristics of the location, the available resources, and many other factors. Therefore, we cannot identify specific technologies that are important to any EIP, but we can provide a framework for identifying them.

In Section 6.1, we identify the technological challenges that face EIP members and discuss ways of identifying technologies that might meet these challenges. In Section 6.2, we present several categories of technologies that are important for almost any EIP and explain how they contribute to meeting the technological challenges. Section 6.3 contains several examples of potential technologies for the EIP from our case study of Brownsville/Matamoros. Finally we conclude with a brief summary of the technological requirements of a sustainable EIP. Appendix D contains sources of information about EIP-supporting technologies.

6.1 TECHNOLOGICAL CHALLENGES FOR EIPS

Technology's role in the EIP is to help communities, EIP members, regulators, designers, and managers solve potential problems and meet challenges. Technologies can help an EIP meet challenges by

- improving the EIP's economic efficiency,
- improving the technical and cultural feasibility of symbiotic relationships,
- reducing risk and improving flexibility for the symbiosis,
- reducing the environmental burden of the production and consumption of EIP goods and services, and
- reducing the costs of regulatory compliance.

6.1.1 Improving Economic Efficiency

Technology can improve the economic efficiency of EIPs by helping members reduce transaction costs and take advantage of economies of scale and scope. Transaction costs are the costs of making a trade. We incur transaction costs for gathering information about products and services; for locating, transporting, and storing goods;

and for limiting the use of funds while the transaction is taking place. Transaction costs might be reduced within the EIP using

- technologies for disseminating information about available byproducts,
- technologies that improve transportation and storage of byproducts within the EIP, and
- information technologies that allow transaction to take place with better knowledge of the characteristics of a good and the specific needs of the customer.

Examples of transportation and information technologies and the role they play in the EIP are provided in Section 6.2.

The EIP provides a convenient mechanism for capitalizing on economies of scale, which occur when per-unit costs decline as production volume rises. The EIP can give the power of a larger company to a group of smaller companies. For some industrial processes, the per-unit cost of production or processing falls as the number of units rises. This may be the case for several ancillary processes of the EIP members, such as water treatment, solvent and oil recycling, landscaping, and other services. Technologies that allow the companies to join forces to harness this lower cost of production will improve the economic sustainability of the EIP. By conserving materials, they might also lead to a lower environmental burden than would be the case if each company engaged in the process by themselves.

Economies of scope occur between two production activities when one company producing both products can produce one or both more cheaply than two separate companies can. Economies of scope result from complementary components in the production process (e.g., when the same equipment can be used to produce two products, training for production of one type of product is also applicable to production of the other, or the production of one product leads to byproducts that are used as inputs to the production process of the other). In this case, a firm that produces both products can do so more cheaply by eliminating the costs associated with buying and selling inputs.

A technology taking advantage of economies of scope would improve the “fit” between the two production processes. For example, this technology might alter one process so that its output is compatible with the other process. Alternatively, it might allow a variety of products to be processed with the same equipment. Waste treatment technologies, such as solvent recycling processes, that can accept waste products from a variety of processes are one example.

6.1.2 Improving Technical and Cultural Feasibility

Technologies appropriate to a specific EIP must be technically and culturally feasible, given the specific conditions of the park. By technical feasibility, we mean the ability of the technology to fit existing production systems. By cultural feasibility, we mean the ability of existing workers and managers to work with, or be trained to work with, the new technology. This is not a trivial matter. For example, technologies that require round-the-clock monitoring may be difficult to implement in cultures that traditionally observe a day of rest for religious or cultural reasons.

6.1.3 Reducing Risk and Improving Flexibility

Technologies that will reduce customer/supplier risk and improve process flexibility will also improve the viability of the EIP. By customer/supplier risk, we mean the risk that a member of the industrial symbiosis cannot purchase or supply a material in the required quantities or of the required quality. Technologies that improve process flexibility will reduce this risk. For example, suppose the power plant in our case study wanted to change its process or its fuel to respond to market changes. Suppose that the changes would result in byproduct gypsum that was more alkaline than before the process change. If the technology for making gypsum wallboard depends on gypsum with a specific level of alkalinity, the symbiosis would be limited. However, if the wallboard technology is sufficiently flexible, the power plant can change its process without sacrificing the symbiosis.

6.1.4 Reducing Environmental Impact

Many, but not all, of the technologies that take advantage of economic efficiencies will also provide environmental benefits to the EIP. For example, a technology that decreases transaction costs may do so by decreasing the demand for transportation services. Since this demand is often met by burning fossil fuels, technologies that decrease transportation demand have secondary environmental benefits. Similarly, technologies that take advantage of economies of scale may be more fuel and water efficient by processing larger batches or using only one piece of equipment when two might have been used in the absence of this technology.

Technologies being considered for use in the EIP should be evaluated against environmental criteria, as well as economic-efficiency criteria. These criteria might be based on the environmental objectives of the EIP. Questions to be asked regarding the environmental appropriateness of a particular technology include the following:

- Does the technology decrease resource use, particularly resources that are scarce in that particular location?
- Does the technology reduce environmental emissions, particularly to media that are already overburdened?
- Does the technology improve the interaction between industrial activity and the natural ecosystem?

Although the economic and environmental criteria often identify the same technologies, sometimes they recommend different technology choices. In this case, EIP members must weigh their economic objectives against their environmental objectives. However, if two technologies provide similar gains in economic efficiency, the environmental criteria can be used as a secondary filter with which to choose the technology that will contribute most to the sustainability of the EIP.

6.1.5 Reducing Regulatory Costs

In a broad sense, any technology that reduces the cost of reducing air emissions, water discharges, hazardous wastes, and solid waste will reduce the cost of complying with the associated regulations. These include technologies that enable companies to remove the hazardous component of a product, closed-loop recycling systems, and any other technology that cost-effectively reduces the generation of regulated wastes for a given amount of production.

Other technologies are more specific to meeting the demands of the regulatory process. In Chapter 5, we discuss some regulatory innovations that will improve the viability of the EIP. Some of these regulatory options become much more feasible given the availability of technologies supporting the collection of information required to implement them. For example, one of these innovations involves joint permitting of all members of the EIP. This type of regulatory innovation requires that EIP management have sufficient information to manage the permit and to ensure that each EIP member is meeting its terms for the permit. Thus, environmental monitoring technologies become an important part of this regulatory strategy and contribute to the sustainability of the EIP.

6.2 TECHNOLOGIES MEETING EIP CHALLENGES

Because each EIP will have a unique set of companies and symbiotic relationships, identifying a list of technologies that might be important to its sustainability is difficult. However, certain categories of technologies help capture the efficiencies available to an EIP and meet the technical, cultural, and environmental criteria discussed above. Figure 6-1 illustrates several categories of such technologies that might contribute to the sustainability of an EIP. They include transportation technologies; recovery, recycling, reuse, and substitution technologies; environmental monitoring technologies; information technologies; energy and energy-efficiency technologies; and water treatment and cascading technologies. These categories overlap somewhat; for example, environmental monitoring can also be considered an information technology, and some energy technologies might also be considered recycling technologies.

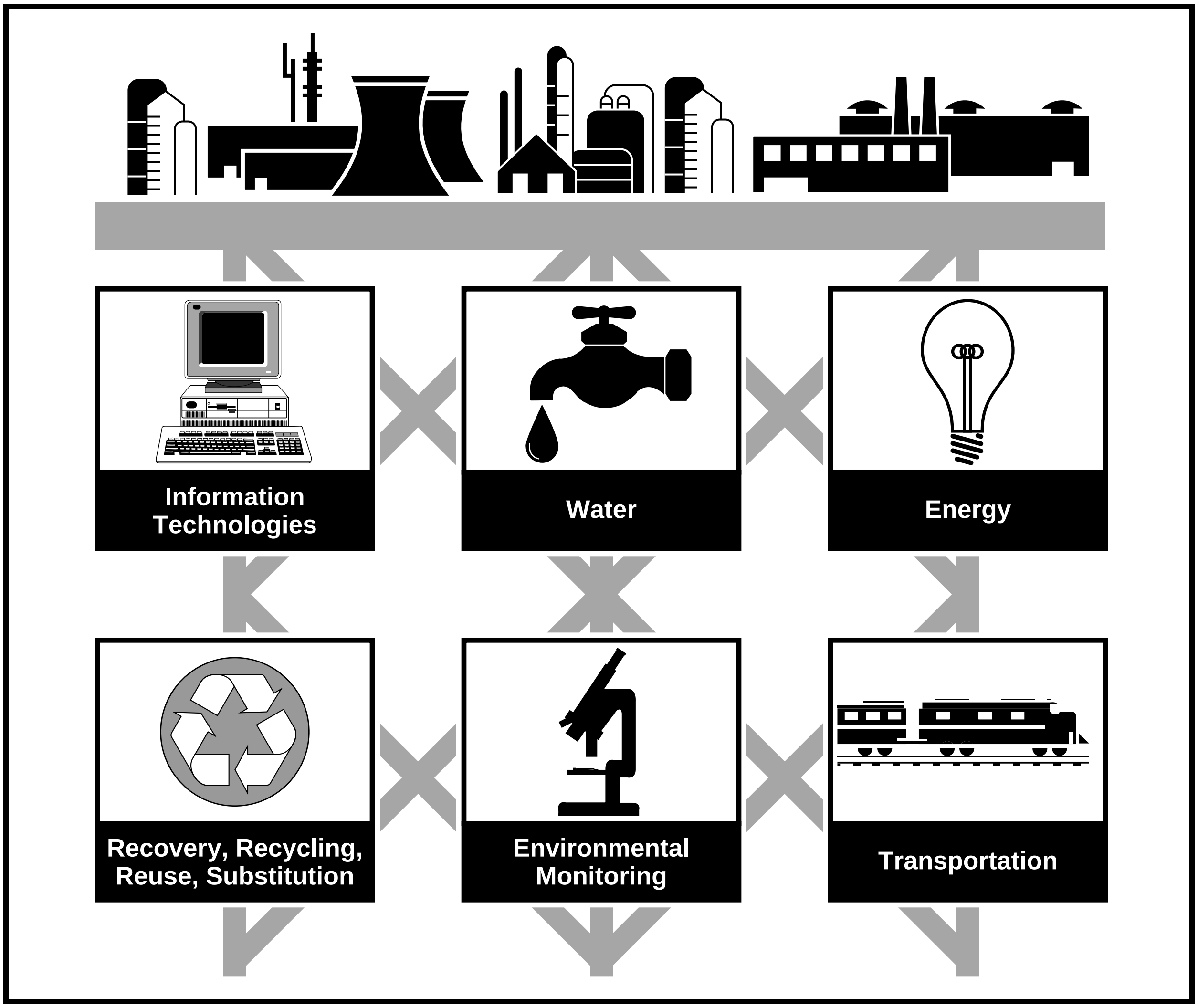
6.2.1 Transportation Technologies

Any industrial park or office must provide adequate facilities for moving materials and workers within the park and between the park and its suppliers and markets. Therefore, issues of transportation within an EIP and between the EIP and the community are not unique to an EIP.

Because members of an EIP conduct frequent exchanges of materials among each other, intra-park transportation infrastructure is critical to the economic success of the EIP.

However, within an EIP, transportation becomes more critical than in a typical industrial or office park. Many of the benefits of the EIP are derived from the short distance between suppliers and users of an intermediate product. Just as the efficient movement of materials, intermediate products, and workers within a plant is essential to its productivity, efficient movement of traded materials among the members of the EIP is essential to the EIP's

Figure 6-1. Technologies Supporting the EIP
A variety of technologies form the infrastructure of support for the EIP.



profitability. Appropriate transportation technologies enable EIP members to capture the efficiencies generated from this proximity.

Within the EIP, most methods for transporting people and materials are not considered cutting-edge technologies. Materials may be transported over the ground via truck, on conveyer belts, or beneath the ground in pipelines. Sophisticated materials handling equipment, such as automated storage and retrieval systems and automatic guided vehicle systems, are not very commonly used in U.S. plants (U.S. Bureau of the Census, 1993). However, established technologies, such as pipelines and conveyers, may be modified with sophisticated sensing, gauging, or separating equipment specific to the application needed by the EIP.[1]

Moving materials, products, and people in and out of the EIP is a consideration common to all industrial and office parks. Determining the amount of traffic generated by a park and providing for the appropriate transportation systems is key to sustaining the park. Software that forecasts the amount of traffic that an industrial or office park will generate supports these decisions. The Institute of Transportation Engineers (1987) reviews some of these models.

Environmental criteria may have an important impact on the choice of transportation technologies in the EIP. Because transportation is a nonpoint source of air emissions, it can be a major contributor to the environmental impact of the park, particularly if the park has a high density of employees. Alternative transportation systems for people, such as those discussed in the EIP *Fieldbook* (Lowe, Moran, and Holmes, 1996) should be considered in designing transportation systems for the EIP.

6.2.2 Recycling, Recovery, Reuse, and Substitution

Recycling, recovery, reuse, and substitution technologies play an important role in capturing the efficiencies of the industrial ecosystem and take advantage of the relatively captive market represented by EIP members.

Technologies that allow companies to use a byproduct that might otherwise be removed from the industrial ecosystem as waste are central to the technology infrastructure of the EIP. Just as the efficiency of an organism's metabolism can be improved so that less fuel is wasted, the metabolism of the industrial ecosystem can be improved through appropriate technologies. These include recovery technologies that extract valuable materials from waste streams, recycling technologies that prepare a byproduct for reuse, technologies that allow reuse, and process technologies that incorporate previously unused feedstocks.

Although none of these technologies are unique to the EIP, each has a special role in capturing the efficiencies of the industrial ecosystem. Recovery and recycling technologies might only be economically feasible when a relatively large volume of material is processed, taking advantage of economies of scale. This is evident,

[1] For example, see the conveyer system developed for separating fly ash cited in Makansi (1994).

for example, in solvent and oil recycling technologies.[2] Other technologies take advantage of the relatively captive market represented by the EIP members. For example, processes that improve the extraction of gypsum from FGD take advantage of the increasing transportation costs, the nonuniform distribution of natural gypsum, and the proximity of a customer such as a wallboard plant or cement plant.

6.2.3 Environmental Monitoring Technologies

Environmental monitoring can support the implementation of alternative regulatory approaches and provide feedback regarding the success of environmental management efforts.

Environmental monitoring is very important to the relationships developed among the members of the EIP and accomplishes several objectives:

- It supports the implementation of alternative regulatory approaches by providing the information needed to verify that the EIP is meeting the required environmental performance standards.
- Environmental monitoring relieves some of the liability concerns associated with the joint-permitting option. Members of the EIP must be confident that their participation in joint environmental management does not subject them to liability and cost exposure from other members of the EIP.
- Environmental monitoring technologies provide feedback to the members and management of the EIP regarding the success of their efforts to reduce waste.

For example, larger companies routinely use water quality monitoring to prove EPA compliance, to monitor for product loss, and to provide feedback for their pollution control efforts. Monitoring equipment ranges from inexpensive kits that use widely known samplers and reagents to systems that automatically monitor effluent streams 24 hours per day. These technologies are reviewed in Masi (1994).

6.2.4 Information Technologies

Information technologies provide part of an important support system for the EIP. They allow the EIP members to reduce their transaction costs by providing information about the needs and byproducts of other EIP members. They also can provide an important marketing and supply link between the EIP and external

[2] A detailed description of the economics of solvent and oil recycling technologies and their potential for the Brownsville/Matamoros case study is provided in Appendix B.

suppliers and markets. Finally, they can provide feedback for comparing economic and environmental performance of the EIP and its members over time or comparing performance to similar companies.

The information technology to support an EIP should include three components:

- data
- data storage and retrieval system
- data analysis system

> Information technologies can assist EIP members with intra-EIP byproduct exchange, can provide important marketing and supply links to external suppliers and markets, and can support economic and environmental benchmarking against other companies and EIPs.

Data should include anything that is important to managing the EIP and sustaining the symbiosis between members. Perhaps the most important data will be derived from member surveys that poll EIP members about their input needs and their available byproducts. Data might also be derived from secondary sources, such as economic and environmental databases published by EPA and the Department of Commerce. Members can use these databases to benchmark their operations against industry averages and to evaluate the relative economic and environmental performance of members of the EIP compared to non-EIP companies. Other potential data categories include P2 information, technology databases, and electronic marketing and supply bulletin boards.

A data storage, retrieval, and analysis system allows the EIP members to access and analyze these data. Software that assists members in searching through databases, locating sources of supply, and calculating performance indicators will ensure the data are used. Researchers at Dalhousie University have developed a prototype EIP decision support system for the Burnside Industrial Park in Dartmouth, Nova Scotia (Côté et al., 1994).

6.2.5 Energy Technologies

Energy technologies sometimes dominate the structure of EIPs. Because all industrial processes require energy, energy technologies can be an important vehicle for taking advantage of efficiencies of scale and partner proximity. This is especially true where cost reductions and environmental benefits can be realized from increased efficiency of primary energy use, use of the energy content of industrial waste, and/or reduced distance to move energy products (e.g., steam).

Three categories of energy technologies will probably be applicable to many EIP configurations:

- ➤ cogeneration and integrated energy systems
- ➤ energy recovery technologies
- ➤ process changes that allow the economical use of nontraditional energy sources, including renewable energy

> The EIP can benefit from cogeneration and integrated energy systems, energy recovery technologies, and process changes that allow the economical use of nontraditional energy sources, including renewable energy sources.

Integrated energy systems are broadly applicable to energy systems planning and design (Lee, 1989). The integrated energy system takes a step forward from cogeneration technologies, integrating energy flows, transformation processes, and materials flows. In integrated energy systems, loss of heat or useful components is minimized, as are operation and capital costs. However, these systems require an enterprise large enough to justify the needed investment in physical and human capital and to transcend the disciplinary or professional barriers (Lee, 1989). The EIP can provide this critical mass of organizations and activities.

Renewable energy can play a role not only in the industrial process design, but also in the design of EIP buildings and infrastructure. As described in the EIP *Fieldbook*, renewable energy, particularly solar power, may be feasible for some EIP locations.

One advantage of renewable energy sources is that most renewable energy equipment is small, and many are modular. As explained in the EIP *Fieldbook*, modular systems allow capacity to grow with the EIP's energy needs and reduce up-front investment and risk. The small size of renewable systems improves the speed at which equipment improvements can be made and may reduce the environmental burden of construction. Large energy facilities require extensive construction in the field, where labor is costly and productivity gains difficult to achieve. Most renewable energy equipment can be constructed in factories, where it is easier to apply modern manufacturing techniques that facilitate cost reduction. The small scale also makes the time from initial design to operation short so that needed improvements can be identified by field testing and quickly incorporated into modified designs (Johansson et al., 1993). Furthermore, since these units are not constructed on site, the environmental impact on the site is reduced.

6.2.6 Water Treatment and Cascading Technologies

Like energy, water is used by virtually all manufacturing and service industries. Technologies that maximize the efficiency of water use are joint wastewater processing and water cascading and reuse technologies.

> Water treatment and cascading technologies can help the EIP use water efficiently by prioritizing water and water treatment needs.

Joint processing and reuse of wastewater is one way that EIP members can take advantage of the economic benefits of location in the park. Because the EIP members may have a variety of water needs, the maximum benefit can be obtained from water treatment if it is designed with a hierarchy of water needs in mind. The principle of water cascading is applied in Singapore where industrial reuse of reclaimed water has been practiced since the 1960s. Treated wastewater is principally used for industrial cooling, floor cleaning, and toilet flushing. It is also increasingly being used as process water in paper, textile, plastic, chemical, rubber, and steel factories as well for the production of concrete.[3] In Singapore manufacturers pay 48 cents less per cubic meter for the reclaimed water than for virgin supplies.

Our Brownsville/Matamoros case study examines several possible methods of wastewater processing and reuse.

6.3 TECHNOLOGICAL CHALLENGES IN THE BROWNSVILLE/MATAMOROS CASE STUDY

Some technologies of interest to the Brownsville/ Matamoros EIP are

- *plastics separation*
- *solvent recycling and recovery*
- *recovery of byproducts*
- *cogeneration*
- *water treatment and cascading*

In this section, we discuss several technologies that we examined while investigating our case study. We discuss the technical challenge addressed by the technology, the ways in which the technology captures efficiency advantages of the EIP, and some of the environmental impacts of these technologies.

[3]See Chin and Ong (1992) and Tay and Chui (1991) for an overview of the Singaporean system.

6.3.1 Recovery, Recycling, Reuse, and Substitution

Our case study examined several applications of materials recovery, recycling, reuse, and substitution technologies. Specifically, the case study explored the feasibility of several types of plastics separation in Scenario 3, reuse of synthetic gypsum that is a byproduct of power plants and chemical manufacturers in Scenario 4, and solvent recycling and recovery in Scenario 5.

Plastics Separation

Several of the companies in our case study used industrial plastics and their waste included plastics from scrap and rejected parts, coverings, and containers. One of these companies used a grinder to grind their scrap plastics before sending them to the landfill. We wondered why the company was landfilling the plastics after going to the trouble to grind them. The company has several different types of plastics mixed in the waste stream and did not believe the volume was great enough to justify hiring someone to manage the separation and recycling of the plastics. Thus, if the company could find a cost-effective way to separate different types of plastics after they have been ground, it could sell the plastics for recycling, rather than landfilling them.

Most commercially available sources of plastics separation technology have limited capabilities for separating industrial plastics. There are two main plastics separation technologies: mechanical and optical. Mechanical separation techniques take advantage of the different densities of the plastics by using a float/sink method. The operator floats the ground plastic in a flotation tank that contains water and salt or solvents. The salt or solvents adjust the water's density so that only the plastic with a specific density will float. This method is most successful when plastics have very different densities; for example, PVC and PET can easily be separated by this method. One processor we spoke with said that he used a proprietary process that would separate flaked plastics with differences in specific gravity of as low as 5 percent (Moore, 1995).

While companies processing small quantities of plastics would probably not find mechanical or optical plastics separation technology cost-effective, a broker or recycler of plastics, such as an EIP-operated plastic recycler, could take advantage of economies of scale to provide this service to EIP companies economically.

Optical, an alternative to mechanical separation, is separation by color or opacity. This method is commonly used in the post-consumer plastics market. Light and color-sensitive equipment senses the color or opacity of the plastic and separates it based on this difference.

The equipment used to mechanically or optically separate plastics is expensive, so it would only be economically feasible if a large quantity of plastic is being separated. Thus, while individual companies processing small quantities of plastics would probably not find this technology cost-effective, a broker or recycler of plastics, such as the EIP plastic recycler, could take advantage of economies of scale to provide this service to the EIP companies economically.

Reuses of Byproducts from Power Plants

In Scenario 4 of our Brownsville case study, we simulated the addition of a power plant to the industrial ecosystem. The power plant provided the potential to capture and reuse some of its byproducts. We incorporated the reuse of byproduct gypsum into our scenario. However, fly ash is another byproduct that might be reused in some EIP situations.

Recently developed technologies can increase the value of symbiotic relationships by maximizing the market potential for the byproducts of power production.

The disposal of wastes from the combustion of fossil fuels is a technological challenge for the electric utility industry. Millions of tons of fly ash are collected from coal-fired power plants each year, and no more than a quarter of that amount is reused (Makansi, 1994). In addition, 35 to 45 million tons of waste sludge are produced each year by the FGD process (Griffin, 1995). Conventional waste control and disposal methods for this sludge are expensive and require access to large landfill areas (Griffin, 1995). Some recently developed technologies can help to maximize the market potential for the byproducts of power production, reducing the economic and environmental costs of the processes that produce them.

Fly Ash. The consistency of the carbon content of fly ash is very important to its resale value. Fly ash that consistently has less than 3 percent carbon content can be used in high-performance concrete and can be used in high-density polyethylene as a filler. Fly ash with carbon content greater than 40 percent can be burned to recover its thermal value. Thus, one important technological hurdle for fly ash reuse is separation of carbon from the ash to create a consistent formula. Just as separation technologies are important to the marketability of recycled plastics, they are also important to the potential of fly ash reuse.

A separation technology developed by Separation Technologies, Inc., (STI) in Needham, MA, is based on the principle of triboelectric charging (Makansi, 1994). The feed material, which has carbon content between 4.7 and 12 percent, is sent through a triboelectric charging unit. The unit separates the feed material into two separate wastestreams, one with a carbon content of less than 3 percent (90 percent of the reclaimed product) and the other with a carbon content greater than 40 percent.

Separation technologies can also be used to reclaim metals from the fly ash produced from burning fossil fuels. For example, the fly ash that is a byproduct of burning Orimulsion, the fuel used in the power plant in our case study, contains vanadium. A company in Sweden has been experimenting with a technology for separating out vanadium and other valuable metals from the ash (Makansi, 1994).

FGD Waste. Certain types of FGD processes produce gypsum as a byproduct. The potential of this gypsum as a marketable byproduct has only recently been recognized in the U.S., because there are a number of natural gypsum mines here and the supply of natural gypsum is virtually inexhaustible (O'Brien et al., 1984). Gypsum is used to manufacture wallboard and as a minor ingredient in Portland cement to retard the setting rate. It is also used as a soil amendment and conditioner for some types of crops and soils.

Over the last 10 years, the marketability of FGD gypsum for wallboard has improved considerably. Several factors have contributed to this increased marketability:

- the rising price of gypsum
- the recognition by wallboard producers of the valuable properties of FGD gypsum
- the advance in gypsum-producing FGD technology that has decreased the cost of producing byproduct gypsum. Forced-oxidation FGD processes that produce marketable gypsum are competitive with other FGD systems and are chosen by

some power plants with the intention of marketing the gypsum produced (O'Brien et al., 1984)

Power plants have begun to explicitly consider the sale of byproducts when choosing FGD systems.

A study by the Tennessee Valley Authority has verified the cost competitiveness of gypsum-producing FGD systems by comparing the costs of two sulfur dioxide emissions control options (O'Brien et al., 1984). The first was a generic limestone FGD process with in-loop forced oxidation, the type required to produce marketable gypsum. The second was a similar limestone process that did not use forced oxidation and used treatment and landfill disposal for the byproduct. Under specific technological conditions, the plants using the process that allowed them to market their gypsum had lower FGD costs than the plants using the process that required fixation and landfill waste disposal.

Researchers have recently developed new technologies that demonstrate further the potential for applying IE in power plants. A bioprocess that recovers sulfate and sulfite waste from FGD sludge has been successfully tested on an industrial sodium-based FGD system (Griffin, 1995). A new FGD system being tested by Engineered Systems International, Inc., recovers all flue gas scrubbing chemicals and produces sulfur for resale (Ciriacks, 1995). These technologies demonstrate the potential for new designs based on the IE concept. When engineers view process waste as the result of process inefficiency, process technology ideas emerge that work toward reducing that inefficiency and recovering valuable product.

Solvent Recycling and Recovery

A solvent is a substance (usually liquid) capable of dissolving or dispersing one or more other substances (EPA, 1989). Solvents have been used in a variety of applications in industry. Their usefulness is almost always based on their ability to function as transfer media by dissolving another material in a processing step, followed by the transfer and separation of the solvent.

Solvent recycling and recovery are important considerations for any company that uses solvents. Both economic and environmental factors contribute to the importance of recycling, reusing, and reclaiming solvents. Many solvents, including chlorinated and halogenated solvents, are ozone depleters. Many are very volatile; they evaporate readily and contribute to smoke formation. Furthermore, many are toxic or carcinogenic, and exposure can irritate mucous membranes. Many have low flashpoints, making them hazardous to work with because of the threat of fire and explosion.

The cost of solvents varies greatly. They can range from $1 to $3 for kerosene and mineral spirits, $7 to $12 for metal cleaning formulations, and up to $30 for some specialty and electronic cleaning formulations. Chlorinated solvents have become quite expensive since their ozone-depleting nature has led to efforts to reduce their use (EPA, 1994b).

Because solvents are so commonly used in industry, and because their use and recovery have important economic and environmental consequences, solvent recycling may be an important service provided by an EIP for its members. If each member uses only small quantities of solvents, a joint solvent recycling service may be the most economically efficient means of solvent recovery and reuse. In this section, we explore the economic, environmental, and technical conditions that determine the feasibility of such an arrangement.

Solvent Recycling Potential. Over 1,500 common types of solvents encompass a wide range of properties. These include solvency, volatility, polarity, viscosity, reactivity or stability, and toxicity.

These properties determine appropriate applications for a solvent, its value, and the method by which it is disposed of or recycled. Stability is an important property of solvents, because it permits reuse without degradation (Hulm, 1987). Table 6-1 provides a list of commonly recycled solvents.

Solvent mixtures that are valuable, lightly contaminated, or easy to separate are the best candidates for recycling or reuse. These can generally be recycled economically using distillation (or some other method) and can yield high-quality levels of recycled material. Solvents that are not very valuable or are difficult to separate are usually not economical to recover and reuse.

Solvent Recycling Technologies. Common methods for recycling liquid waste solvents include distillation and thin-film evaporation. Distillation is the act of purifying liquids through boiling so that the steam condenses to a pure liquid and the pollutants remain in a concentrated residue (EPA, 1989). Different forms of distillation can

Table 6-1. Commonly Recycled Solvents
The diverse composition and properties of solvents complicate solvent recycling and reuse.

Petroleum Distillates	Halogenated Solvents	Oxygenated Solvents
Aliphatics	Chlorinated Solvents	Alcohols
Mineral spirits	Methylene chloride	Isobutyl alcohol
Naphthas	Perchloroethylene	Isopropyl alcohol
Stoddard solvent	Trichloroethylene	n-butyl alcohol
Heptane	1,1,1, Trichloroethane	Methanol
Hexane		
Aromatics	Fluorinated Solvents	Ketones
Toluene	Fluorocarbons	Acetone
Xylene	1,1,2 Trichloro-trifluoroethane	Methyl isobutyl ketone
		Methyl ethyl ketone (MEK)
		Esters
		Ethyl acetate
		Butyl acetate

be used to recover single solvents or solvent mixtures. The simplest form is batch flash distillation where the used solvent is heated to drive off the volatile components, which are condensed and collected. Fractional distillation is the separation of two volatile streams in a rectifying column. The more volatile component (the low boiler) concentrates at the top, and the high boiler concentrates at the bottom. Mounting a rectifying column over a batch still is also possible. This method allows the sequential removal of each volatile component of the batch in the order of their boiling points.

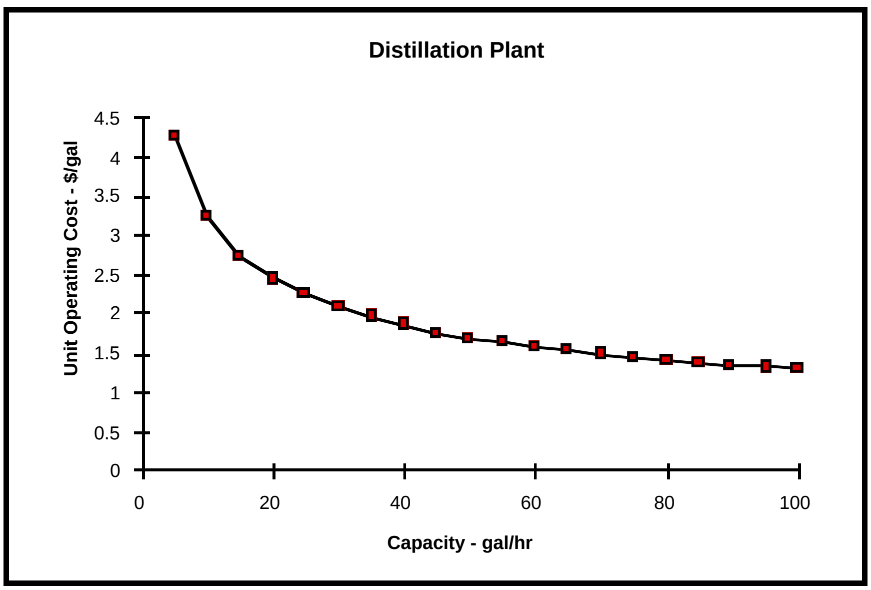
The ease or difficulty of separation is determined by the relative volatility of the mixture components (Hulm, 1987). For example, if their boiling points are very close, separating the solvents may be difficult. Another problem that can arise is the formation of azeotropes, where the mixtures boil at a lower temperature than either component, so they do not separate at the top of the column. Fractional distillation is not suitable for liquids with high viscosity at high temperature, liquids with high solids concentrations, polyurethanes, and inorganics (Glynn et al., 1987).

In a thin-film or wiped film evaporator, used solvent is fed into a heated cylinder and distributed around the walls by a rotating wiper assembly. The volatile components are vaporized, passed through a mist eliminator, and collected. The nonvolatiles run down the sides of the cylinders and are collected at the bottom (Hulm, 1987).

Some mechanical separation methods commonly used in oil reclamation technologies, such as filtering, can also be used to remove contaminants from in-process solvents or waste solvents, extending their life. Most fuel-blending programs use these techniques for cleaning solvent waste.

Economies of Scale in Solvent Recycling. Solvent recycling becomes less expensive and more cost-effective as the volume recycled rises. Figure 6-2 shows how capacity affects the per-gallon costs of operating a solvent distillation facility. This figure is based on an analysis of a permanently constructed distillation system designed to handle 50 gallons per hour with an annual operation and maintenance cost of approximately $610,000 or $1.70 per gallon (thus assuming a run time of approximately 7,176 hours in a year) in 1985 dollars. The capital construction cost for such a unit in 1985 dollars would be $200,000 (Glynn et al., 1987). The 0.6 factor rule, an order-of-magnitude estimating technique, is applied here to illustrate increasing returns to scale using the cost figures for this 50 gallons per hour plant. Order-of-magnitude estimates are usually accurate within -30 percent to +50 percent.

Figure 6-2. Economies of Scale in Solvent Recycling
Operation and maintenance costs for solvent distillation fall exponentially as the unit's capacity increases.



Eq. (6.1) expresses the relationship between the total cost of building and operating a plant of various capacities as

$$\frac{C_2}{C_1} = \left(\frac{Q_2}{Q_1}\right)^x \qquad (6.1)$$

where C_2 is the total cost of a plant of capacity Q_2, and C_1 is the cost of capacity Q_1. Analysts frequently set the value of x to 0.6 when historical costs are not available; consequently, this rule is often referred to as the six-tenths factor rule (Jelen and Black, 1983).

This relationship suggests that a joint recycling service for EIP tenants can have important economic effects for the EIP members under certain situations. If the solvent recycler can find the volume and technical conditions to operate a closed-loop system, where all solvents are returned to their generators for reuse, the liability risk to the EIP members of sending their solvents to an outside recycling service decreases. The economic and environmental benefits of such a system are discussed more fully in Chapter 2.

Joint recycling for EIP members will be easier and less expensive if members can agree on a small number of solvents.

Methods for Increasing the Recyclability of Spent Solvents/Oils. Generators can take many measures to increase recyclability of their spent solvents. These include segregating solvents, preventing contamination, and recording composition of wastes. Separating a solvent from its impurities is much easier than separating two solvents. P2 engineers recommend always segregating chlorinated from nonchlorinated wastes, aliphatic from aromatic solvent wastes, freon from methylene chloride, and waste from flammables. Labeling and sheltering containers can prevent contamination that complicates recycling. Chemical identification labels should be used to record waste composition and method of generation (North Carolina Office of Waste Reduction, 1993). In addition, reducing the number of different solvents that are used at a plant can make recycling easier. For the EIP, joint recycling will be easier and less expensive if the members can agree on a small number of solvents to be used throughout the park.

Recovery of Solvents from Vapor (Schlomer and Volker, 1994). Recent advances in exhaust gas purification technology have enhanced the recovery of solvents from exhaust air. One technology, called the Cryosolv® process, avoids environmental pollution and permits the reuse of vaporized solvents. The process, developed by Messer Griesheim of Germany, uses liquid nitrogen as a coolant. Thus, a company that uses liquid nitrogen (e.g., as an inert gas) can use the refrigeration potential usually dissipated into the atmosphere for the Cryosolv® process. Alternatively, the nitrogen from one company could be fed into a Cryosolv® process in a nearby plant; the nitrogen can be returned to the original company after it is used in the Cryosolv® process.

The Cryosolv® technology takes advantage of the unique vapor pressure curve of each substance, which is only slightly affected by the presence of air or an inert gas for a low pressure system at or near 1 atmosphere. Organic solvents are low boiling substances with correspondingly high vapor pressure. Very low temperatures are required to condense these substances; the Cryosolv® process uses liquid nitrogen as the cooling agent. The process has been designed for exhaust gas with high concentrations of solvents. It is a closed process; nitrogen is recycled and the solvent is recovered. The absence of oxygen in the closed system prevents the threat of explosion. The Cryosolv® process can separate gas streams containing many kinds of solvents based on their condensation temperatures.

Applications of this technology include purifying exhaust gas from chemical reactors, metal greasing facilities, and paper making and printing. It is especially appropriate in the chemical industry, where nitrogen is usually required for inerting purposes.

6.3.2 Energy Technologies—Cogeneration

> The economics of steam distribution dictate that partners in a cogeneration relationship must be relatively proximate. If other factors are favorable, cogeneration is a natural choice for an EIP.

Scenario 4 of our EIP case study included a simulation of a cogeneration relationship between a power plant and other members of the EIP. Cogeneration is a classic example of an opportunity for a partnership between two or more companies with the aim of improving economic and environmental performance. It takes advantage of economies of scope in the production of two or more energy products (e.g., steam and electric power, hot water, and electric power), which is often one of the most expensive inputs to manufacturing processes. In so doing, it decreases the environmental burden of energy conversion by producing an equivalent amount of energy with less fossil fuel input than conventional electricity generation systems.

Cogeneration in its broadest sense denotes any form of the simultaneous production of electrical or mechanical energy and useful thermal energy in the form of hot liquids or gases. The fundamental difference between a conventional energy system and a cogeneration system is that the conventional system produces either electricity or thermal energy and the cogeneration system produces both. By recapturing some of the thermal energy that is normally discharged from an engine, a cogeneration system can reduce system fuel requirements by 10 to 30 percent (U.S. DOE, 1978).

Cogeneration is a natural choice of energy systems for an EIP. The economics of steam distribution dictate that the partners in a cogeneration relationship must be relatively proximate. Furthermore, the existing relationships between EIP partners may lessen the uncertainty that normally discourages cogeneration relationships between industrial partners. In this case, the cogeneration relationship is only one of many such supplier-customer and partnership relationships.

Indicators of cogeneration profitability:

- ➤ ratio of purchased power cost to fuel cost
- ➤ plant operation at average load conditions
- ➤ kilowatt load
- ➤ process steam load

Cogeneration will not be profitable in all cases. Several indicators can determine whether cogeneration might be an appropriate and profitable energy alternative for an industrial plant or group of plants. The first indicator is the ratio of purchased power cost ($ per kWh) to fuel cost ($ per Btu). The higher this ratio, the greater the potential profitability of a cogeneration relationship. The second indicator is the plant's capacity utilization at average load conditions. A plant's potential for benefiting from cogeneration is greatest if it operates continuously. Kilowatt load is the third indicator; as load increases, so does the potential benefit of cogeneration. A plant or group of plants with a load of less than 5 megawatts is probably a poor candidate for cogeneration. Finally, the higher the process steam load, the greater the potential for economical cogeneration. A load of less than 100,000 pounds per hour indicates a poor candidate for cogeneration (Franklin, 1979).

Aside from the quantitative indicators mentioned above, a number of other factors add to the appropriateness and profitability of cogeneration. These include

- ➤ the utility's ability to meet the plant's kilowatt load,
- ➤ the availability of waste or refuse fuels,

- the timing of replacement of old boilers,
- the availability of surplus of low-pressure steam in process, and
- the pressure reduction of 150,000 pounds of steam per hour (Franklin, 1979).

Cogeneration is not a new or emerging technology but a proven and widely applied technique. It has been in use, particularly in the industrial sector, since the late 19th century. While not particularly common in the utility sector in the U.S., cogeneration has been used to provide district heating in Europe since World War II. The energy crisis of the 1970s stimulated a great deal of additional interest in cogeneration in the U.S. Today, cogeneration accounts for a small percentage of the electricity generated in the U.S.; cogeneration by U.S. public utilities is very rare.

Recently research on cogeneration systems has focused on three major areas:

- developing alternative fuel capability
- developing more efficient heat recovery components
- integrating engine and heat recovery systems into advanced cogeneration systems

As discussed by Lee (1989), the most promising recent developments involve the natural gas systems and the integration of other industrial process, such as industrial gas separation, into the energy system. These developments may find their proving ground within the unique institutional relationships developed and fostered by an EIP.

6.3.3 Water Treatment and Cascading

> The feasibility of water treatment and reuse in the Brownsville/Matamoros EIP relies on the advantages of collocation.

Scenario 5 of the EIP case study included a discussion of an exchange of brownwater between the seafood processing plant, which produced it as a byproduct of seafood processing, and the textile company, which could use it to cools its roof. This was one example of water cascading.

Water cascading is the sequential reuse of water. The water is used first in processes with strict purity requirements and is cascaded to processes that can use the wastewater of the previous process without further treatment.

Typically, water cascading is found in areas such as Singapore where the supply of freshwater is limited. Other large-scale schemes are found in Israel and California—both semi-arid parts of the world where the price of water is relatively high. However, water cascading has also been practiced for several decades in Chicago, which has an abundant supply of freshwater. In Chicago the re-treated sewage is used by Commonwealth Edison, the Alsip Paper Associates, L.P., and Uno-Ven Company. The water is also used within the Metropolitan Water Reclamation District's plants as process water as well as in local parks and golf courses for irrigation. Knight and Sokol (1991) note that the main motivation for reuse is not a limited water supply but rather its cost-effectiveness. They estimate that the cost of reuse within district plants is $255,366 or 22 times less the $4,978,583 purchase cost of securing potable water.

We investigated the feasibility of applying several types of water treatment and cascading schemes in the prototype EIP in Brownsville/Matamoros. In the Rio Grande Valley water is relatively plentiful compared to the rest of Texas. The economic feasibility of the water treatment and reuse scheme described below does not depend on the inflated water prices but instead on the locational advantages of manufacturing within the park. In the next section we describe the types of wastewater generated by potential industries in the park. Then we describe the quality requirements and the treatment technologies needed to treat the water for industrial reuse. Finally, we look at the economic feasibility and benefits of location in the park as they relate to wastewater.

Characterization of Wastewater

The type of wastewater generated by the prototype EIP falls into three broadly defined categories: oily water, water with heavy metals, and water with organic compounds. Table 6-2 lists the specific content of effluent streams in the park. Oily water is generated by the oil refinery, the oil recycling plant, the textile plant, and the discrete parts plant. Water with heavy metals content is generated by the discrete parts plant, the automobile parts manufacturer, the power plant, and the oil refinery. Only the seafood processing plant releases water with organic compounds such as nitrogen and phosphorous.

Table 6-2. Sources of Wastewater in the Park
The types of wastewater include oily water, water with heavy metals, and water with organic compounds.

Industry	Operation	Wastewater Content
Discrete parts	Aqueous cleaning system	Wash water—probably some metals; oily water
	Mop water	Heavy metals
Textiles (assembly)	Compressor operation	Oily water
Automobile parts	Metal plating and cleaning	Wash water with heavy metals
Power plant	Cooling system	Heavy metals
	Flue gas desulphurization	Heavy metals, gypsum, fly ash
Seafood processing plant	Cleaning	Solid particles, nitrogen and phosphorous
Oil refinery	Cooling system	Heavy metals
	Spent soda streams	Phenols, oil, and gases
	Main commingled effluent	Oily water
Chemical plant	Cooling system	Heavy metals

Typically the companies would treat these wastewater streams separately and reuse them internally or send them into the municipal sewage works for further treatment and disposal. Some industrial parks have found pooling their wastewater for treatment in a single plant beneficial. One example is the Limassol Industrial Estate in Cyprus. In Limassol the wastewaters of industries ranging from food processing to pharmaceuticals are pooled together for joint treatment. Hadjivassilis, Tebai, and Nicolaou (1994) note that "mixing together all the effluents from different industries (at Limassol) was proved to be very advantageous and cost effective" (p. 100). However, joint treatment is not the best option when reuse is an objective because the various uses of reclaimed water require varying degrees of quality. Also the wastewater streams require different levels of treatment, and the cost-effectiveness of treatment and recovery depends on the concentration of material in the water.

Companies in the EIP can take advantage of a variety of treatment methods to avoid costly over-dilution of wastewater. Also, as explained below, the water quality requirements for cascading vary by reuse option. Thus the companies can treat the wastewater to the degree that the reuse option requires and avoid using cleaner (more expensive) water than is necessary.

Quality Requirements for Reusing Wastewater

Approximately 70 percent of all industrial water is used for cooling (Williams, 1982). In the EIP, the power plant, the oil refinery, and the chemical plant need cooling water. The quality requirements are somewhat less stringent for cooling water than other industrial water needs. The only water quality considerations are the removal of residual organics, ammonia, phosphorus, suspended solids, calcium, magnesium, iron, and silica (Crook, 1991). Phosphorus and metals may be present in discharged cooling water, and phosphorus may be present in the wastewater from the seafood processing plant. When these components are present in cooling water, they cause scale formation problems. Ammonia can cause corrosion in copper-based alloys and stimulate microbial growth while interfering with disinfection. In addition, small concentrations of ammonia may be present in the process and wash water from the discrete parts plant. Finally, residual organics can cause bacterial regrowth, slime/scale formation, and foaming. However Goldstein and Casana (1982) note that foaming is no longer a problem because of the widespread use of biodegradable soaps.

The industries in the EIP can also use wastewater as process water, boiler water, and wash water. These applications require removing heavy metals, softening the water, and adhering to guidelines to ensure worker health and safety. The treatment approach differs by the source of the water.

Landscaping is another potential option for reusing wastewater. Water used in this application must meet few requirements. The presence of nitrogen and phosphorus even in high concentrations is acceptable and even desirable for this use. In particular the wastewater from the seafood processing plant would be ideal for this application.

A roof cooling system could also use the filtered seafood processing water or water with heavy metals without being treated. There is no runoff with this system because the rate of evaporation is electronically monitored and the flow rate is automatically adjusted accordingly. Users of this system have reported over a 20 percent reduction in temperature in a nonair-conditioned building on warm days (Markovsky, 1995).

Potential EIP Wastewater Technologies

Table 6-3 lists reuse options of wastewater and treatment byproducts. Five wastewater treatment technologies could be used jointly by the participants in EIPs:

- oil–water separator
- flocculation/DAF separator
- an aerated pond
- ultra-high lime treatment
- ion exchange

A wastestream may require treatment by all or some of these technologies depending on the source and destination of the water.

The oil refinery and the other companies listed in Table 6-2 as having an oily water waste stream use the oil–water separator.[4] The separator produces an oily sludge and treated water. The oily sludge byproduct is separated, and the resulting oil is recycled back to the plants. The leftover water is finally piped into the flocculation/DAF system.[5]

The flocculation/DAF system is included in the process because it substantially increases the quality of the effluent by removing suspended solids and oil (Galil and Rebhun, 1992). As the second stage of the treatment of oily water, it releases oil sludge as a byproduct that can be combined with the sludge released by the separator. The resulting water is then piped into the aerated pond.

> A byproduct of the ultra-high lime treatment is lime sludge, which can be filtered and recycled to the asphalt plant.

Aerated ponds are used for biological treatment of the wastewater. The quality of the water after aeration is sufficient for landscape irrigation and roof sprayers and as mixing water for the cement

[4]The oil–water separator technology is specific to oil type. Thus, its use in the EIP may require that the companies agree on the types of industrial oils used in their plants.

[5]This method has been implemented at the oil refineries, Haifa Ltd., Israel. See Galil and Rebhun (1992) for an in-depth description of this system as it applies to an integrated oil refinery.

Table 6-3. Potential Reuse of Wastewater and Treatment Byproducts

The degree of treatment of wastewater depends on the source of the effluent and the reuse option. The requirements for cooling water are much less stringent than those for boiler/process water.

Reuse Option	Source	Technological Requirements	Byproduct Reuse Option
Cooling	Ore emulsion plant	Ultra-high lime treatment	Lime for cement
Cooling	Oil refinery cooling waters	Ultra-high lime treatment	Lime for cement
Cooling	Brownsville municipal sewage	1) Primary treatment plus filtration (various methods available)	
		2) Aeration	
		3) Ultra-high lime treatment	Lime for cement
Cooling	Oily waters (various sources)	1a) Oil–water separator (refinery)	Oil back to refinery or other uses in the park
		1b) Oil–water separator (machines)	Oil recycled back to source
		2) Flocculation/DAF	Oil recycled back to source
		3) Aerated ponds	
		4) Ultra-high lime treatment	Lime for cement
Boiler water/process water	All sources	Above methods plus ion exchange	
Metal plating and washing	Automobile parts	Ion exchange	Depends on whether streams are comingled
Metal plating and washing	Discrete parts	Ion exchange	Depends on whether streams are comingled
Cement mixing	All sources	Quality after aeration or greater	
Roof sprayers	Seafood plant	Filtration to remove solids	
Landscaping	Seafood plant	Filtration to remove solids	
Landscaping	All	Quality after aeration or greater	

plant.[6] This water is also of sufficient quality for once-through cooling. The pre-treatment requirements include screening and pre-chlorination, chemical clarification, and rapid gravity filtration.[7] See Middlebrooks (1982) or Crook (1991) for alternative treatment methods that can be used to prepare domestic sewage.

The next step in preparing wastewater for reuse is ultra-high lime treatment. Batchelor et al. (1991) found this process to be economically and technically superior to lime softening/clarification. This stage removes the heavy metals that can cause scale formation in cooling towers and boilers. All of the major scalents—silica, magnesium, phosphate, calcium, and sulfate—are removed. One byproduct of this process is lime sludge, which can be filtered and recycled to the asphalt factory (Galil and Rebhun, 1992). Cooling water can be recirculated through the ultra-high lime treatment process for reuse. If the final destination of the water is as boiler or process water, further treatment by ion exchange is necessary.

The ion-exchange process can take water directly from the automobile parts and metal fabrication company and process it for reuse in their washing and plating operations (see EPA [1990], pp. 30-31). Also if reuse in boilers or as process water is an objective, the water from the ultra-high lime process can be used (Williams, 1982). The water leaving the plant at this stage is the cleanest in the entire system, and potable quality can be achieved with little additional treatment.

Economic Feasibility and Benefits

Joint treatment of segregated waste streams allows companies to achieve economies of scale not possible if they operated independent wastewater treatment plants. The capital investment will be much lower for each individual firm when they jointly build a plant. More importantly, Batchelor et al. (1991) note that operation and maintenance costs are lower when the degree of recycling is increased (see Batchelor et al., [1991], pp. 990). Approximately 75 percent of the wastewater treatment cost is

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[6] Tay and Chui (1991) found that the compressive strength of cement with reclaimed wastewater was superior to potable water. However, the setting time is slightly longer.

[7] These are part of the treatment requirements at the Jurong Industrial Water Works. See Chin and Ong (1992).

related to the lime process. Lime not reused in the ultra-high lime treatment might be recycled to the cement manufacturer in the park. By locating within the park, the cement manufacturer secures a reliable source of lime with minimal transportation costs. This, in turn, lowers costs further for each user of the process.

Furthermore, the firms can jointly achieve economies of scope. The pooling of wastewater allows firms to treat a larger variety of wastes within the park than would be feasible if they acted independently. Wastewater containing heavy metals is often classified as Class I hazardous material and disposal is expensive. Purchasing an ion-exchange process is not worthwhile when the wastestreams are small. However, when the wastes are pooled, on-site treatment and reuse become feasible for firms who would not ordinarily consider this option.

Another benefit is firms can take advantage of the variety of treatment options in the EIP. In doing so they avoid costly overtreatment of wastewater. They can also lower input costs by conserving expensive potable water for potable uses. In the EIP, both consumers and producers of wastewater are located in the same area, greatly lowering the transportation cost.

One of the greatest benefits of the EIP is location. Asano (1991) notes, in regard to reclamation of municipal sewage, that "the conveyance and distribution systems for reclaimed water represent the principal cost of most proposed water reuse projects" (p. 5). He goes on to say that reclaimed wastewater represents a low-cost alternative only when reclamation facilities are located near large industrial centers and when little treatment is necessary.

6.4 SUMMARY AND CONCLUSIONS

Ultimately, the technologies that will be developed and applied to support the sustainability of the EIP will be those that make economic sense. Lee (1989) has noted that government support for energy and other technology development has not been successful in the past without market incentives to industry to apply them to the appropriate markets.

Both "demand pull" and "technology push" will lead to applying new technologies to IE. The EIP in many cases will provide the institutional setting that creates demand for supporting technologies. By providing a systems view of industrial processes, the EIP reveals opportunities to apply technologies that increase production efficiency and decrease environmental burden by capturing the efficiencies available from this unique form of industry organization. However, developers will certainly create technologies not specifically intended to support IE initiatives but nevertheless influential in the structure of EIPs.

Each EIP will be faced with the challenge of finding the technologies that will maximize its specific opportunities or finding the opportunities that make best use of available technologies. These opportunities can be assessed by examining the extent to which they take advantage of the grouping of industries that characterizes the EIP. As companies begin to work together to improve the environmental and economic performance of the EIP, the technological needs will become apparent.

7 Summary and Conclusions

Our simulation of an EIP for Brownsville/Matamoros showed that, under our assumptions, the EIP can generate economic and environmental benefits. Our Scenario 5 analysis showed the following results for the EIP as a group:

- total annual economic benefit of over $8 million
- fifty-nine percent ROI
- payback period of less than 2 years
- over 240 million pounds annual reduction in landfill waste
- reduction in fossil fuel use of over 110,000 bbls per year
- an increase in the use of water by over 15 million gallons per year

The purpose of this report was to address four research questions. The first question was, "How do we determine the potential economic and environmental benefits that may be realized by applying the concepts of IE to current and planned U.S. and Mexican commercial and industrial developments, and what might these benefits be for a prototype EIP in Brownsville/Matamoros?" We addressed this question by developing and analyzing a prototype EIP case study.

We took a five-step approach to our EIP case study. First, we developed a methodology for identifying and quantifying the potential environmental and economic impacts of the EIP. Then, we designed a prototype EIP for Brownsville, TX/Matamoros, Mexico, and developed five EIP scenarios that allowed us to examine the impact of incrementally changing the relationships among the EIP members. We collected data from existing companies in the Brownsville/Matamoros area and from pertinent technical literature to apply our methodology for quantifying the EIP's economic and environmental impacts. Finally, we used the data to simulate for the EIP as a whole changes in profit, return on investment, and annual changes in solid waste and resource use. The simulation showed that, given the right conditions, an EIP can generate environmental and economic benefits for the community.

The second research question was, "What is the range of government's appropriate role (federal, state, and local) in facilitating the development and management of EIPs, and how might this role vary in alternative EIP venues?" We addressed this question in the context of the case study in Chapter 5 by examining the baseline regulatory status of EIP members and ways each EIP scenario might affect their regulatory status, assuming no changes in current environmental regulations. Then we suggested regulatory innovations that might reduce the regulatory burden for EIP members while maintaining environmental compliance. Some current regulatory initiatives are already moving in this direction.

> Technologies that support the EIP include transportation technologies; recovery, recycling, reuse, and substitution technologies; information technologies; energy technologies; and water technologies.

The third research question was, "How do we identify the environmental technologies needed to fully apply IE principles and concepts, and which specific technologies will be needed for the prototype EIP in Brownsville/Matamoros?" We answered this question in Chapter 6. We described the role technologies can play in supporting EIPs, described the types of technologies that are most important to EIPs, and provided some specific examples of technology's role from the Brownsville/Matamoros case study.

The final research question is, "How applicable are the results of the Brownsville/Matamoros case study to other venues, particularly other border area industrial parks?" In this chapter, we address this question in two ways. First, we note the assumptions and conditions that were specific to our case study and scenarios and explain how our results may be more or less applicable in other circumstances. Second, we summarize the challenges to EIP development that we identified while building the EIP prototype, developing the simulations, calculating the case study results, exploring regulatory roles, and investigating the potential impact of technology.

The transportability of the results of the case study depends on whether communities; EIP members; regulators; EIP developers, designers, and engineers; and EIP managers can meet these challenges. The EIP *Fieldbook* (Lowe, Moran, and Holmes, 1996) further investigates these challenges, provides potential solutions, and gives examples of cases in which the solutions have been successful.

7.1 TRANSFERRING RESULTS TO OTHER EIPs

Our case study and the analysis of regulatory and technological changes needed to support an EIP were driven to a certain extent by the specific conditions we found in Brownsville/Matamoros. Not all potential EIPs will have these same elements.

Our scenarios were motivated largely by a cogeneration situation. In Brownsville, we found a situation in which the community's power needs suggested a new power plant with cogeneration. However, cogeneration is not profitable in all cases and therefore may not be appropriate for all EIPs.

However, usually an anchor tenant provides rich opportunities for converting byproducts into useful intermediate goods. In Brownsville/Matamoros, the anchor tenants are an oil refinery and a power plant. In other cases, it could be a chemical plant, a large food processor, or some other company that produces byproducts that have a low ratio of value to weight. This low ratio implies that, to be valuable, these byproducts must be processed nearby to decrease transportation costs.

Other issues that are likely to affect the success of an EIP are the following:

- Resource scarcity: The EIP should aim to conserve resources that are scarce and use those that are plentiful. In Brownsville, potable water is scarce, and water quality is an important concern. Thus, we looked for ways to conserve potable water through water cascading technology. In other areas, the public utility system may be overburdened, suggesting the use of energy cascading or alternative energy sources.
- Community industrial structure: The EIP must build on the existing industrial base, and the first step toward industrial symbiosis should be developing lines of communication between existing companies.
- Industry dynamics: Industries and companies interested in moving to the area represent an opportunity to create connections between new and existing companies and to create symbiosis. Companies that are planning to relocate will have an easier time deciding to locate at the EIP than companies that have already invested in a specific location in the area. An area that is experiencing very little in-migration of new companies will have to rely more heavily on involving existing business in an EIP and on developing new companies by exploiting entrepreneurial niches created by the EIP. The EIP *Fieldbook* discusses this issue in Chapter 6.
- Environmental considerations: EIP planners should aim to address the most troublesome environmental problems in the area and contribute to their solution. In the case of

Brownsville/Matamoros, atmospheric emissions, water quality, and landfill waste were of great concern. In other areas, the important issues might be preserving wetlands, effectively using scarce land, or providing employment that does not risk the health and safety of the community's residents.

Our simulation of the potential economic and environmental effects of an EIP has demonstrated that success is possible under the right conditions. Ultimately, the success of an EIP depends on the specific local context for EIP development. However, to assess their chances for success, communities can apply an analysis framework similar to the one we have developed in this report. Communities also must consider whether they can meet the considerable challenges to EIP development.

7.2 EIP CHALLENGES

Developing a successful EIP presents challenges to each of the EIP stakeholders. Our study addressed in detail the risks and benefits of an EIP resource exchange and also addressed shared EIP services and infrastructure. However, as explained in the EIP *Fieldbook*, an EIP can include a number of other design options, including integration of the EIP into natural systems, energy systems, EIP management and support services, and sustainable design and construction. Some of the challenges we identify below refer to these design options as well as the EIP resource exchange, shared infrastructure, and shared EIP services.

7.2.1 Challenges to Communities

Community organizations and local government may be very important to the EIP's success. These organizations may play an important part in the following EIP activities:

- building local support
- setting EIP performance objectives
- sharing ownership, development, and costs
- developing EIP financing strategies
- recruiting industry
- reducing administrative red tape

Each of these activities is important to the EIP's success. In Brownsville, the local community organizations were responsible for organizing community meetings, discussing the objectives of the EIP, and participating in funding initiatives. They continue to participate in EIP planning as the project moves forward.

7.2.2 Challenges to Potential EIP Members

Companies considering EIP membership must realize the extent to which the EIP can affect their operations. They must determine which of the EIP design options will be appropriate for their company. In particular, potential EIP members face the following challenges:

- estimating EIP benefits and costs
- determining the right mix of partners
- finding appropriate technologies
- reducing regulatory uncertainty and liability
- marketing EIP membership to customers

Potential EIP members must determine which of the EIP design options will be most appropriate for their company.

Meeting the first challenge is a necessary first step for potential EIP members. They must determine which of the EIP design options will be most appropriate for their company. The second challenge, determining the right mix of partners, refers primarily to the byproduct exchange of an EIP, but it also refers to EIP partners in shared services, management, and infrastructure. The third challenge, finding appropriate technology, applies to resource exchange and the design of buildings, infrastructure, and EIP industrial processes. The EIP byproduct exchange introduces some important regulatory issues that are discussed in Chapter 5. However, the other elements of the EIP, including the outsourcing of environmental management functions, also present regulatory and liability issues. Finally, EIP members may be able to capitalize on their EIP membership to gain customers that are interested in purchasing from environmentally conscious companies. An EIP member may pursue this marketing strategy regardless of which of the EIP design options they adopt.

7.2.3 Challenges to the Regulatory Community

Local, state, and federal regulatory agencies will play an important role in shaping emerging EIPs. During our investigation of the Brownsville EIP, we observed local, state, and federal agencies working together and contributing to the EIP plan. Local regulatory agencies may control EIP siting, require specific infrastructure, or set performance standards for noise, smoke, dust, odor, vibration, and lighting (Urban Land Institute, 1988). In Brownsville, local leaders played an important role in developing local support, which should make the public approval process easier.

State agencies interpret and enforce federal environmental regulations. They may also provide technical assistance and training through community colleges, universities, and other state technical assistance organizations. In the Brownsville/Matamoros project, the TNRCC participated in finding EIP funding and has provided technical assistance, through the Office of Pollution Prevention and Recycling.

The federal government will influence the formation of EIPs by adapting federal environmental regulations, by funding technology development and transfer programs, and by encouraging the exchange of information among EIPs (Bell and Farrell, 1996). EPA participated in the Brownsville/Matamoros project by funding the EIP case study; participating in the design of the study; and participating in the President's Council on Sustainable Development, which has highlighted EIPs as a tool of sustainable development and organized meetings among communities considering EIP projects.

To support the success of EIPs, federal, state, and local regulatory agencies are challenged to

- streamline zoning, permitting, and other development regulations;
- add flexibility to environmental regulations;
- develop appropriate technology, promote technology transfer, and provide technical training; and
- encourage the exchange of information among EIPs.

7.2.4 Challenges to Developers, Designers, and Builders

The economic and environmental performance of an EIP depends not only on the performance of an EIP byproduct exchange, but also on the design and operations of all buildings and facilities in the EIP. Those who develop, design, and build EIPs are challenged to improve the success of the EIP by

- choosing a site that will maximize the economic and environmental benefits of an EIP,

- designing park infrastructure that incorporates the needs of the EIP members for specialized services,
- designing industrial facilities that build in the flexibility that allows the EIP to grow and evolve,
- designing buildings that maximize the efficiency of energy and materials, and
- using construction practices that are consistent with the EIP vision.

In our EIP case study, some of our results depended on assumptions we made about the EIP design details.[1] For example, the size of the EIP property and the distance between members affect the cost of the infrastructure needed for resource exchange and shared services. These details are not trivial and must be considered before determining whether the EIP is economically and environmentally viable.

7.2.5 Challenges to EIP Managers

Although the Brownsville/Matamoros EIP case study did not address the role of EIP management, an EIP's success and long-term viability depend on competent management. An EIP manager must fulfill not only the usual functions of an industrial park manager, but also the additional requirements of maintaining the EIP community. EIP managers face the following challenges:

- managing the design and development process
- maintaining relationships between companies
- managing EIP property and shared support services
- ensuring the future viability of the EIP

Without these management functions, the EIP operations discussed in the Brownsville/Matamoros case study would not be possible. For example, someone must finance and manage the shared infrastructure and support services and the exchange of information that supports the byproduct exchange.

[1]Some options are explicitly stated in Chapter 4; others are explained in Appendix B.

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Appendix A:

Literature Review and Annotated Bibliography

At the start of this project, we examined the literature to explore the extent to which the EIP concept had been studied. This review was especially difficult because of the interdisciplinary nature of the EIP concept and its application. The annotated bibliography contains citations for literature in many areas, including industrial ecology, design for environment (DFE), industrial parks, economics, sustainable development, ecology, systems science, environmental accounting, environmental auditing, and pollution production. It provides annotations for key pieces. In the literature review below, we explain how this body of literature addresses this project's research questions.

A.1 LITERATURE REVIEW

A broad and deep body of knowledge contributes to our understanding of the planning, development, and economic and environmental impacts of the eco-industrial park (EIP). The EIP applies industrial ecology, a relatively new framework for organizing industrial activity, to industrial parks, an established form of organization for industrial activity. Thus, the lessons of both the new and established organizational forms are important to our understanding of EIPs.

The EIP applies industrial ecology, a relatively new framework for organizing industrial activity, to industrial parks, an established form of organization for industrial activity. Thus, the lessons of both the new and established organizational forms are important to our understanding of EIPs.

The body of previous research that contributes most to the research questions of this study (identified below) lies in the intersection between established disciplines, such as ecology, design, engineering, economics, accounting, and new ways of integrating and applying those disciplines, such as industrial ecology.

Research Questions

This literature review assisted us in identifying gaps in the literature and refining the research questions for the study. We posed four primary research questions:

1. How do we determine the potential economic and environmental benefits that may be realized by applying the concepts of industrial ecology to current and planned U.S. and Mexican commercial and industrial developments, and what might these benefits be for a prototype EIP in Brownsville/Matamoros?
2. What is the range of government's appropriate role (federal, state, and local) in facilitating the development and management of EIPs, and how might this role vary in alternative EIP venues?
3. How do we identify the environmental technologies needed to fully apply industrial ecology principles and concepts, and which specific technologies will be needed for the prototype EIP in Brownsville/Matamoros?
4. How applicable are the results of the Brownsville/Matamoros case study to other venues, particularly other border area industrial parks?

The purpose of this literature review was to identify gaps in the body of knowledge about EIPs. Identifying unavailable information helped us articulate our research questions and build on the work of earlier researchers who have examined these issues. This review describes the current frontier in the application of some of these interrelated disciplines to the organization of industry. More specifically, we assess how completely each of the research questions identified above has been addressed in the literature. Given this assessment, we provide recommendations for expanding the application of these disciplines to these research questions. Our project was designed to meet this challenge.

Sections A.1.1 and A.1.2 review the research on industrial parks and EIPs in particular. In Section A.1.3, we trace the progress of research in industrial ecology and the application of a variety of disciplines to industrial ecology. Finally, in Section A.1.4, we discuss the literature that relates to each research question identified above.

A.1.1 Industrial Park Literature

Most information about industrial parks aims either to provide guidance for building and managing successful industrial parks or to explain the success or failure of industrial parks. Several industrial park handbooks provide general references for designing and managing industrial parks. The Urban Land Institute (ULI) and the National Association of Industrial and Office Properties (NAIOP) have both published a great deal of information on land use planning, urban and regional planning, and residential and commercial development.

Among the industrial park literature, the most relevant to EIPs includes the *Business and Industrial Park Development Handbook* by ULI. This book includes the history of industrial and business parks, market and financial analysis, planning, engineering and design, marketing and management, as well as 17 case studies. Another comprehensive, though more dated, handbook on industrial parks is *Planning and Designing an Industrial Park* by the NAIOP.

Other handbooks that are of interest include *The Project Infrastructure Development Handbook* by ULI. This book describes the water, sewer, and energy infrastructure needed for developing an industrial park. The *Mixed Use Development Handbook*, also published by ULI, could be useful for planning and designing an industrial ecosystem in an urban setting. The NAIOP Educational Foundation also publishes *Office Park Development*. This book examines the elements of office park development including history, planning, and site selection.

> EIPs can be seen as a variation on the growing trend towards industrial parks based on specialized business clusters such as high technology/research, business incubators, and transportation parks.

Many of the case studies discussed in the *Business and Industrial Park Handbook* mentioned above are about specialized business clusters. Much of the industrial park literature has recently focused on specialized industrial park concepts, such as research parks, business incubator parks, and transportation parks. EIPs might be viewed as a variation on this trend of specialization in industrial parks. Recently, a small but growing body of literature has focused on the conceptualization, organization, management, and economic and environmental success of EIPs. This literature is addressed separately in the next section.

A.1.2 Eco-Industrial Park Literature

A recent report addresses the EIP as a viable form of industrial development. *Designing and Operating Industrial Parks as Ecosystems*, by Ray Côté and his research team (1994), outlines the concepts of industrial ecology and industrial ecosystem and illustrates their application in an existing industrial park. The authors used the Burnside Industrial Park in Dartmouth, Nova Scotia, as a test case for developing and applying the principles and guidelines they developed for designing and operating EIPs.

The most cited example of the application of industrial ecology principles to industrial organization is the industrial site at Kalundborg, Denmark. While the Kalundborg symbiosis does not take place within the fence of an industrial park, it shows the potential benefits of applying industrial ecology principles. The relevance of the Kalundborg experience to developing EIPs in the U.S. may be limited by its evolution as a series of bilateral relationships and by the differences between the environmental regulatory frameworks in the U.S. and Denmark. Peter Knight provides a rich source of information about the details of the Kalundborg symbiosis in his article "Closing the Loop" (1992). Nickolas Gertler (1995) also provides an excellent overview of the Kalundborg industrial symbiosis.

> With few exceptions, the literature on industrial parks has not specifically addressed why industrial ecology is an appropriate framework for organizing a group of companies.

Many other examples of EIPs are emerging (see Lowe, Moran, and Holmes, 1995). However, at the time this review was written, most other relevant information referred to industrial parks that have in some way specialized in minimizing environmental impact. Although some of these parks might not fit our definition of an EIP (see introduction), they demonstrate the industrial developer's recent awareness of the importance of environmental issues in industrial decisions, and they provide background for the emergence of the EIP concept.

For example, The Savannah Economic Development Authority's industrial park was built with the twin goals of environmental performance and economic success. Two authors, Neuhauser

(1992) and Knowlton (1992), have written about the process through which the park was conceived and developed. They provide advice about building consensus among stakeholders during the planning stages of the park. The articles describing this park also discuss the difficult issues surrounding changes in wetlands regulations.

Another industrial park in which the relationship between environment and industry is described is Therse Weters's article, "The Old World Has a New Idea: An Industrial Park in Denmark." The article overviews an industrial park that includes wastewater processing and landscaping as part of its environmental program.

These contributions to the literature on EIPs provide some examples of the application of industrial ecology. However, with the exception of the report by Côté and his colleagues, this literature has not specifically addressed why industrial ecology is an appropriate framework for organizing a group of industrial processes. For this discussion, we turn to the recently emerging literature on industrial ecology.

A.1.3 Industrial Ecology

Broadly defined, industrial ecology is a framework for environmental management that seeks to model industrial systems on ecological principles.

Broadly defined, industrial ecology is a framework for environmental management that seeks to model industrial systems on ecological principles. The concept of industrial ecology was first explored in a seminal article in 1989 by Robert Frosch and Nicholas Gallopoulos. Industrial ecology was described in this article as a system whereby the consumption of energy and materials is optimized, and the effluents of one process serve as the raw material for another process.

Hardin Tibbs in his article, "Industrial Ecology: An Environmental Agenda for Industry" (1992) further defined industrial ecology by describing the six dimensions of industrial ecology:

- creating industrial ecosystems through closed-loop recycling,
- balancing industrial input and output to natural ecosystem capacity,
- dematerializing industrial output,
- improving the metabolic pathways of industrial processes and materials use,

- incorporating systemic patterns of energy use, and
- aligning policy with a long-term perspective of industrial system evolution.

Tibbs' description implies that industrial ecology requires applying many disciplines, including ecology, engineering, economics, and public policy.

A recent, comprehensive overview of industrial ecology, *The Greening of Industrial Ecosystems* (Allenby and Richards, 1994), indicates a broadening of interest in industrial ecology. The book is a compilation of presentations given at a National Academy of Engineering conference held in 1992. Other good overviews of the concept of industrial ecology can be found in Ernest Lowe's articles, "Industrial Ecology: Implications for Corporate Strategy" (1994) and "Applying Industrial Ecology" (1993).

Environmental Development and Design Frameworks

A number of analysis frameworks have emerged in the environmental literature that are related to industrial ecology because they examine the interactions between artificial and natural systems. These include industrial metabolism, design for the environment, and sustainable development

Industrial Metabolism. Industrial metabolism research is the precursor to both product life-cycle analysis and industrial ecology. Industrial metabolism is a way of seeing materials and energy flow from the biosphere, through the industrial system, and back to the biosphere. The analytic methods developed by Robert Ayres (1989; 1992; Ayres and Simonis, 1993) are used to analyze the fate of materials that dissipate in industrial processes. In his work, Ayres describes the differences in the metabolism of natural systems and of industrial systems. In natural systems nearly all material is recycled, while in industrial systems materials are dissipative.

Design for the Environment (DFE) incorporates environmental concerns into the design of products and industrial processes. This design process can include products, package design, process engineering, and facility design.

Design for Environment. DFE incorporates environmental concerns into the design of products and industrial processes. This design process can include products, package design, process engineering, and facility design. The field grew out of the engineering concept of Design for (X), where X is the desired characteristic to be optimized. Braden Allenby (1991; 1992) writes extensively on this topic. His article, "Design for

Environment: A Tool Whose Time Has Come" (1991), summarizes the field and includes substantive suggestions on how to apply DFE concepts in a firm. The Environmental Protection Agency also has started a Design for Environment Program, and documents can be acquired from the Pollution Prevention Clearinghouse at the EPA (EPA, 1992).

The European counterpart of DFE is the Product-Life Extension field that extends product life by including design strategies for durability. Literature by Walter Stahel (1986) discusses this concept in detail.

Sustainable Development. The Brundtland Commission's book, *Our Common Future* (World Commission on Environment and Development, 1987) coined the term "sustainable development." For those unfamiliar with the concept, some other good references are *Earth in the Balance* (1992) by Albert Gore, and Barry Commoner's *Making Peace with the Planet* (1990).

Paul Hawkin discusses the role of businesses in promoting sustainable development in his book *The Ecology of Commerce* (1993). This book discusses how the current economic and business system can improve its sustainability. Another book discussing sustainable development is Stephan Schmidheiny's *Changing Course*. This book, written for the United Nations Conference on Environment and Development, includes the Declaration of the Business Council for Sustainable Development.

Applications of Traditional Disciplines to Industrial Ecology

Several traditional disciplines have a great deal to contribute to our understanding of industrial ecology and its application to the concept of EIPs. Some traditional disciplines that have been applied in this way include ecology, systems science, and economics.

Ecology, systems science, and economics have been applied to the EIP concept.

Ecology and Biogeochemistry. Industrial ecology models industrial systems on ecological systems. Concepts borrowed from ecology such as interconnection, ecosystem evolution, adaptation, and self-regulation are borrowed by industrial ecology and applied to industry. A background in ecology, therefore, is helpful for understanding industrial ecology. The work of ecologists C.S. Holling and Howard Odum describes the subtleties of ecosystems and other ecological concepts. These authors build on concepts from systems science and cybernetics in their work.

Biochemistry contributes to our understanding of industrial ecology. William Schessinger's book, *Biogeochemistry: An Analysis of Global Change* (1991) provides a good overview of the global ecosystem and contributes a full understanding of industrial ecology. The book describes global processes and reaction and cycles such as the carbon cycle, the water cycle, and nitrogen and phosphorus cycle. Schessinger discusses the human perturbations of the global cycles.

Systems Science. Ecology is one type of system described and analyzed by systems scientists. They also study complex systems, critical systems, and information systems, all of which contribute to an industrial ecosystem. *Systems Science: Addressing Global Issues* provides a recent review of this topic. The book contains the proceedings of the United Kingdom Systems Society Conference on Systems Science held in 1993.

In 1974, A. M. Andrew discussed how the concept of ecofeedback, which is usually applied to the human nervous system, could also be applied to economic and social systems. Within an EIP, environmental monitoring technologies and information technologies are essential to providing the ecofeedback required to maintain relationships between the EIP members and between the EIP and the government. This concept is discussed more fully in Chapter 5.

Systems scientists also study *cybernetics* and *ecofeedback*. Cybernetics is a the study of models of communication and control systems as they relate to complex machines and the functions of organisms. The ideas of cybernetics have also been used to analyze the socio-economic system and company management systems. Many of the theories of cybernetics parallel and pre-date the theories in industrial ecology. One recent book in this area is *Cybernetics and Applied Systems*, edited by Constantin Negoita (1992).

Ecofeedback requires using information systems as feedback loops for self-regulation in environmental management. The idea was originally introduced by Erwin Lazlo. Jan Hanhart (1989) successfully used the concept in environmental information projects in the Netherlands. The ecofeedback concept shows that, with the use of information, a system could self-regulate. One article that explains the field well is "Ecofeedback and Significance Feedback in Neural Nets in Society," written by A.M. Andrew and published in the *Journal of Cybernetics* (1974).

Structural Economics/Input-Output Modeling. Faye Duchin has built on Robert Ayres' work in industrial ecology by applying sophisticated models from structural economics to create input-output models to analyze the structure of industrial ecology systems. The input-output models have traditionally been used to analyze the economic impact of a significant change in the economic structure of a community. Duchin has used these tools to analyze the transportation sector, the auto industry, and bio-waste recycling. She has also analyzed the recommendations of the Brundtland Report using input-output models.

A.1.4 Research Questions

In the introduction to this report, we state four research questions for this project. Each of these questions has been addressed to a greater or lesser degree by the work that has preceded this project. In this section, we examine how far previous work has gone in addressing these questions and therefore provide a foundation for this project.

Research Question 1: Determining Economic and Environmental Impact

The EIP concept is based on the idea that companies can benefit from working together in an EIP by producing more cost-competitive products and services and that this partnership can also reduce the environmental burden of producing these goods and services. Economic benefits result from increased materials and energy efficiency, waste recycling, and avoidance of regulatory penalties. Park members can also achieve greater economic efficiency than nonpark members by sharing the costs of infrastructure and research and development. The potential environmental benefits of EIPs are derived from a reduction in pollution and a decreased demand for natural resources. Establishing EIPs demonstrates the principles of sustainable development and can spur innovation in technologies for pollution prevention and sustainable development.

Some existing tools from accounting, structural economics, welfare economics, and environmental accounting and auditing are quite appropriate for measuring the environmental and economic impact of the EIP.

Some existing measurement tools can analyze the magnitude of these economic and environmental benefits. Some of these tools have been designed specifically to analyze the benefits of pollution prevention, but they can be applied in many cases to an industrial symbiosis between members of an EIP as well. These tools come from a wide range of disciplines, including accounting, structural economics, welfare economics, and environmental accounting and auditing.

Input-Output Modeling/Industrial Metabolism. Within the industrial ecology literature both Faye Duchin in her work with input-output modeling, and Ayres, with his work in industrial metabolism, have presented tools for measuring the economic and environmental benefits of the application of industrial ecology. As mentioned previously, input-output models are an analytic tool to determine the potential outcomes from changes in economic structure. Input-output models have been used to analyze the economic impacts of the Brundtland report recommendations and to test ways of combating deforestation in Indonesia.

Applications of input-output modeling to an EIP would require a complete description of the technology for producing each product and byproduct and residuals. The model allows us to simulate changes in production technology in a closed economic system.

Methods from the field of industrial metabolism are used to analyze the total pattern of energy and materials from initial extraction of resources to final disposal of wastes in an industrial system. Ayres has developed and used industrial metabolism tools to determine the fate of heavy metals in the Rhine basin and to study the industrial metabolism of the aluminum industry. The literature describes some measures of sustainability: the ratio of virgin to recycled material, the ratio of actual to potential recycled material, and materials productivity (economic output per unit material input).

Environmental Economics. Economic efficiency is often used as a measure of the impact of changes in the economy. Traditional welfare economics can be applied to examine how changes in the operations of companies that may come about through participation in an EIP affect economic efficiency. However, these changes in efficiency may be difficult to value because they involve environmental amenities such as clean air, clean water, and natural scenery, which often are not traded in markets.

Most environmental economics texts address the problems of valuing environmental assets and achieving economic efficiency. One example of such a text is Thomas Tietenberg's *Environmental and Natural Resource Economics* (1992). This text outlines the economics of the environment and discusses limitations of traditional economic theory for addressing environmental issues. Problems such as the lack of property rights, lack of information, and uncertainty are outlined. The economics of population, renewable resources, depletable energy resources, economics of pollution control, and the economics of sustainable development are also discussed. A book that specifically tackles the problem of nonmarket valuation is a book edited by Rudiger Pethig, *Valuing the Environment: Methodological and Measurement Issues* (1994).

Environmental Accounting. To correctly measure benefits from EIPs, an accounting system must identify the environmental costs and liabilities associated with particular products and processes. The field of green/environmental accounting has developed tools to address this issue. The green accounting literature includes documents on adjusting the national income accounts to more accurately describe the environmental and economic standing of countries. More applicable to the case of EIPs, however, is the literature relating to full-cost accounting. This term is often used interchangeably with life-cycle costing and full-cost pricing. In these types of analyses, environmental costs are allocated to the correct product, process, service, or activity throughout the life of the product.

An overview of environmental accounting and its applications to management was recently written for the EPA by ICF Inc. (1995). This document updates a previous EPA document, "Accounting and Capital Budgeting for Pollution Prevention" by Martin Spitzer and his coauthors (1993). A more extensive guide is the *Pollution Prevention Benefits Manual* (1989) by EPA, which includes worksheets on costs (including hidden regulatory and liability costs) to help companies assess the true costs accruing to products and processes. *Total Cost Assessment* (1992) is another EPA report that overviews the field. *The Facility Pollution Prevention Guide* (1992) also discusses the acquisition of data and methods of analyzing the data and includes worksheets for companies. In the particular context of industrial ecology, a good reference is Rebecca Todd's article in *The Greening of Industrial Ecosystems* (1994).

Environmental auditing can be useful to EIP developers for several purposes.

- First, an environmental audit can help identify waste exchange opportunities between companies.
- Second, an environmental audit can help estimate the potential economic and environmental benefits of different types of EIP relationships.
- Finally, once an EIP is operating, environmental audits can be used to assess whether the predicted benefits have been realized.

A number of sources of information on conducting environmental audits are listed in the bibliography.

Environmental Auditing. Environmental auditing could be a useful tool for comparing the status quo environmental and economic costs of production to the costs within an EIP framework. The literature on environmental audits is diverse, ranging from papers discussing regulatory compliance audits to information about waste audits and comprehensive environmental management audits.

One source for information on environmental audits is the *Industrial Waste Audit and Reduction Manual* by Canviro Consultants. The Department of Energy (DOE) (1992) also publishes an *Environmental Audit Manual* and has documented several environmental compliance audits on DOE facilities. Many of the pollution prevention references also include waste auditing as a core tool for implementing pollution prevention programs. An entire section in the book *Environmental TQM* (Willig, 1994) is dedicated to measurement techniques, and many of these papers state that audits are integral for measuring environmental and economic benefits from total quality management (TQM) projects.

Case Studies. A number of case studies describe the economic and environmental benefits that result from pollution prevention projects within specific companies. Compendiums of success stories include the Institute for Local Self-Reliance's *Proven Profits from Pollution Prevention* and the EPA's *Pollution Prevention Case Studies Compendium*. The World Resources Institute also published a book, *Beyond Compliance: A New Industry View of the Environment*, that describes specific company initiatives.

A case study of the Kalundbourg Industrial Symbiosis also provides a model for measuring the economic and environmental benefits of EIPs. The paper by Peter Knight cited earlier and Nickolas Gertler's paper provide case studies.

Despite the variety of tools that have been used to measure the economic and environmental impact of various kinds of environmental projects, very little has been written on the magnitude of benefits to expect from participation in an EIP, and a systematic framework for measuring these benefits does not exist.

Traditional economic models can be applied to the EIP setting to examine the potential effects of government regulation companies' motivation to participate in an EIP. Where government regulations interfere with a company's choices with respect to production, revision of these regulations may promote EIP participation. For more information regarding the impact of regulation of economic efficiency, see Chapter 3.

Despite the variety of tools that have been used to measure the economic and environmental impact of various kinds of environmental projects, very little has been written on the magnitude of benefits to expect from participating in an EIP, and a systematic framework for measuring these benefits does not exist. Our work integrates much of the previously existing work into a model that combines engineering estimates of changes in materials required under an EIP with cost data to simulate economic and environmental impacts of joining an EIP.

Research Question 2: The Government's Role in EIP Development

With a few exceptions, very little research addresses the appropriate role for government in an EIP. Some of the research on Kalundborg discusses how government unknowingly encouraged the formation of the symbiosis through various regulations. Côté and his colleagues (1994) explain how the government can contribute to the EIP by supporting educational programs on industrial ecology.

However, a great deal of literature discusses how government regulation affects environmental and economic performance. Some of the environmental economics literature mentioned earlier addresses the welfare effects of alternative types of environmental regulation, and these models can be applied to the EIP setting to examine how government can design regulations that promote EIPs.

For an overview of the role that governments, particularly local governments, have played in developing industrial parks, the section on "Development Incentives" in the *Business and Industrial Park Development Handbook* is a good reference. The book outlines types of public-private partnerships that have been used to encourage economic development in local areas.

Research Question 3: Environmental Technologies to Support EIPs

This question is perhaps the most interdisciplinary of the four research questions. Technologies to support the EIP are derived from all of the sciences and are developed by all of the engineering disciplines. Chapter 5 of this report discusses a number of types of technologies and an approach to identifying the technologies required to support an EIP. While no papers have previously been written specifically about this subject, we can draw on a number of disciplines when formulating this framework and identifying these technologies.

Environmental Audits. The identification of technologies for supporting the EIP can start with an environmental audit of pre-existing facilities. Thus, the literature on environmental auditing mentioned earlier contributes to answering this question by suggesting methods of environmental auditing. An environmental audit can highlight situations within the EIP in which a specific technology is needed to solve a problem or to promote an exchange of waste. Furthermore, the specific technologies needed for any particular EIP can only be identified by taking a close look at the EIP partners and their interactions with the environment prior to joining the EIP. No two EIPs will need the same technological solutions, just as no two companies will achieve the same results from an environmental audit.

Green Architecture and Design for the Environment. EIP-appropriate technology has also been addressed (somewhat tangentially) by the literature on green architecture and DFE. The tools of green architecture can be used to design the buildings and infrastructure. The American Institute of Architects (AIA) publishes an Environmental Resource Guide quarterly that is a useful guide to publications and information about sustainable development and building design. The AIA also publishes *The Sourcebook for Sustainable Design: A Guide to Environmentally Responsible Building Materials and Processes*.

A book recently published by the Rocky Mountain Institute (1995) integrates much of the previous 10 years' thinking on green architecture in *A Primer on Sustainable Building*. This book is aimed at architects and developers who are interested in applying sustainability in buildings and small residential and commercial developments.

Energy-efficient building design can also suggest technologies to support the EIP. The Rocky Mountain Institute also has expertise in energy-efficient building design. The Institute also has a Green Development Service program. The program works with architects, builders, developers, and property managers to encourage cost-effective, state-off-the-art construction that saves energy, materials, and water; reduces traffic; preserves habitats; and produces comfortable and healthful interior spaces. They have a forthcoming book, *A Primer on Sustainable Building*, written for architects and developers on sustainability and green development as applied to individual buildings and small residential and commercial development.

Allenby's work in DFE describes how DFE can be used to promote technologies with low environmental impact. DFE methods have been used by AT&T and the automobile industry as described in *The Greening of Industrial Ecosystems*. The Office of Technology Assessment also has a book called *Green Products by Design: Choices for a Cleaner Environment* that summarizes environmental aspects of material use, product design, and the environment as well as strategies of green design and an international comparison of policies affecting green design.

Industry-Specific Technologies. The pollution prevention literature contains information about many production-specific technologies. One comprehensive source is the *Pollution Prevention Technologies Handbook*, edited by Robert Noyes. This book presents technical information on current and potential pollution prevention and waste minimization techniques in 36 industries. For each industry a description of the manufacturing processes is followed by the types of waste generated and specific pollution prevention and waste minimization opportunities. The industries described include the automotive and aircraft services, coal-fired power plants, iron and steel, metal fabrication, petroleum refining, and pharmaceuticals.

The EPA also publishes industry-specific pollution prevention guidance manuals. These manuals supplement the EPA's generic waste reduction manual titled *the Facility Pollution Prevention Guide*. Industry-specific manuals cover automotive refinishing, auto repair, commercial printing, fabricated metal, and mechanical equipment repair industries.

Sources of other technical information can be found through the Pollution Prevention Information Clearinghouse. The Clearinghouse is a distribution center for EPA documents and fact sheets dealing with source reduction and pollution prevention. It also provides a reference and referral service for pollution prevention questions. The EPA's Center for Environmental Research Information (CERI) and the National Technical Information Service (NTIS) are also good sources for industry-specific, as well as general, information on pollution prevention and related topics.

Materials exchange services can be used to locate buyers and sellers of byproducts. These services present opportunities to use technology to add value to otherwise wasted resources.

Materials Exchange and Recycling Information. Materials exchange networks are another good reference for identifying technologies appropriate for EIPs. Many material exchange services are bulletin boards where wastes that could be a potential input for another process are posted. Numerous materials exchange networks are located throughout North America. Many of these networks can be found by contacting the Industrial Material Exchange Service. This same type of waste bulletin board could be used in a more local area within an EIP to provide information on potential material to be exchanged. These services present opportunities to use technology to add value to otherwise wasted resources.

For information on business recycling, particularly information on recycling office paper, aluminum, and other traditionally recycled materials, *The McGraw-Hill Recycling Handbook*, edited by Herbert Lund (1993), is a very comprehensive reference source. Business recycling information can also be found in *The Business Recycling Manual* by the Westchester County Association Inc. This manual also includes useful worksheets for a waste audit and recycling market survey guide. The Institute for Local Self Reliance also published "Salvaging the Future: Waste-Based Production" (Rennie and MacLean, 1989), which focuses on a hypothetical city of one million that maximizes the value of its waste materials. Despite these numerous sources of information about environmental technologies, no framework exists for identifying which of these technologies might best support an EIP.

Research Question 4: Applying Results to Other Venues

Ray Côté and his colleagues (1994) have developed guidelines and principles for the Burnside Industrial Park that can be extended to other EIPs. Thus, it seems that many of the general lessons to be learned about EIPs can be transferred to other venues. However, the technical differences in the infrastructure and processes will limit the transportability of specific findings about economic and environmental benefits. No literature has specifically addressed a method for determining the transportability of the results from one venue to another. Furthermore, differences in corporate culture among nations and even among regions within the U.S. will limit the transportability of methods used to develop the EIP.

Some lessons on the transportability of the EIP concept may be taken from studies of successful and unsuccessful research parks. Studies have shown that cultural differences around industrial parks will affect the factors that contribute to their success. Herberg and Golden (1993) in their paper, "How to Keep the Innovative Spirit Alive: An Examination of Evolving Hot Spots," describe the necessary ingredients for successful industrial/research parks like Silicon Gulch in Austin, Texas, and the Research Triangle in North Carolina. The paper also examines the decline of Route 128 in Massachusetts and Silicon Valley in California.

Another paper that analyzes two of the same industrial parks in detail is "Silicon Valley Versus Route 128" by Anna Lee Saxenian. This paper discusses the successful adaptation of Silicon Valley to international competition while Route 128 is losing its competitive edge. The paper finds that the two areas reveal variations in the local conditions that play a role in determining how well a company will adapt to changes in the industry. The same author wrote a book, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, that expands on this idea.

A.1.5 Summary

The literature contributing to the development and study of EIPs comes from a variety of disciplines. Literature on industrial ecology, industrial parks, ecology, systems science, and sustainable development can be useful in designing and implementing an EIP.

Literature in all of these fields can be used when discussing this project's specific research questions. Tools for measuring environmental and economic benefits from an EIP can be found in the literature from environmental economics, environmental accounting, and environmental auditing. Methods for identifying the specific technologies needed to implement an EIP can be found in the environmental auditing, green architecture, and DFE literature. Material on environmental regulations and the appropriate role for governments as well as the applicability of the results of this project to other industrial parks can be found in the environmental and public economics and industrial park literature.

Although the body of research that is related to developing and analyzing EIPs is rich and diverse, there is little synthesis of the many disciplines that apply to EIPs. In particular, we find that this project's research questions are not sufficiently addressed by any of the previous literature. This project employs the research and the tools mentioned above to address the research questions discussed above.

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Industrial ecology is described as an emerging field that views manufacturing as part of the larger ecosystem. The article is specifically written for electronics and telecommunications engineers. It mentions that information management and telecommunications are tools to implement sustainable development.

Allenby, Braden, R., and Deanna J. Richards eds. 1994. *The Greening of Industrial Ecosystems*. Washington, DC: National Academy Press.

Based on a workshop held at Woods Hole, Massachusetts, in July 1992, the book is a product of the National Academy of Engineering program on Technology and Environment. It examines the greening of industrial systems through the lens of industrial ecology and examines environmentally conscious design and manufacturing. Good comprehensive overview. Some of the papers in the book are mentioned individually in this bibliography.

Allenby, Braden R., and William E. Cooper. 1994. "Understanding Industrial Ecology From a Biological Systems Perspective." *Total Quality Environmental Management* pp. 343-353.

The authors explain that economic activity since the industrial revolution resembles patterns in a rapidly evolving biological community. Sustainable economies will resemble mature biological communities. The paper is unusual in that it details the relationship between the industrial ecology and biological systems.

Ausubel, Jesse H., and Sladovich, Hedy E. 1989. *Technology and Environment.* Washington, DC: National Academy Press.

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The report is an overview of the streams on development in the field of industrial ecology and emphasizes how industrial ecology can be applied to business organizations. The streams of development considered are modeling industrial systems on ecosystems, industrial metabolism, structural economics, dynamic input/output modeling, design for environment, management of the interface between industry and natural systems, and feedback for self regulation.

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Updated overview of industrial ecology. Industrial ecology is described as a potential organizing framework for the future of industrial operations. Outlines the industrial ecosystem in Kalundborg, Denmark. Outlines ways to incorporate industrial ecology within a company. Specific tools used in industrial ecology such as design for environment, industrial metabolism, and dynamic input-output models are described.

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A.2.2 Industrial Ecology—Industrial Metabolism

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A.2.3 Design for Environment

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"Design for Environment" (DFE) describes a way to ensure that all relevant environmental constraints are considered in product and process design. It is a subset of the Design for X (X is the desired product characteristics). Article discusses how DFE can be implemented in the electronics industry but could apply to other sectors. Good summary with some substantive suggestions on how to apply DFE.

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Outlines current practices in automobile recycling. Author notes that industrial ecology, life-cycle waste management, and pollution prevention are similar and are based on practices already in place in the automobile industry. Mentions that these approaches must be combined with total quality management to be effective. One of barriers to the success of these types of approaches is the inflexible environmental regulatory system now in place.

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A.2.4 Industrial Parks—Selected References

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Appendix B:

Background for Case Study Analysis

This appendix provides background for the case study analysis and presents some of the analysis details that were not included in the main text. The first section provides some background on the Brownsville/Matamoros area. The second section provides some details for the Scenario 3 analysis of plastics recycling. Also in this appendix we provide some background on cogeneration and the details of estimation of the economic impacts of heat cascading in Scenarios 4 and 5. In the final section of this appendix, we provide some details regarding the recycling of solvents and oils.

B.1 THE SETTING FOR INDUSTRIAL ACTIVITY IN BROWNSVILLE/MATAMOROS

The potential economic and environmental benefits of closer interaction among a group of industries will vary from region to region and depend on a variety of characteristics that may be quite different for different potential sites for an EIP within a given region. Here we present some background information on the industrial make-up of the Brownsville/Matamoros region, its transportation infrastructure, and its energy usage and delivery system.

B.1.1 Industrial Parks

According to the Brownsville Economic Development Council's *Economic Overview of Brownsville/Matamoros* (August 1994), Brownsville currently boasts ten established industrial parks. Two industrial parks of particular interest are the Airport Industrial Park and the Port of Brownsville. The Port of Brownsville, situated about 5 miles east of Brownsville, is Brownsville's largest industrial park. It covers more than 44,000 acres of land around the ship channel and turning basin. Currently only about 5,000 acres are developed. The Airport Industrial Park is located just north of Brownsville, near the Brownsville/South Padre Island International Airport. Both the Port and the Airport industrial parks are designated as Enterprise Zones. This means that tax abatements are available to new businesses in selected industries if they locate in an Enterprise Zone and comply with certain new construction, job creation, and other criteria and hiring practice conditions.

The Port and the Airport industrial parks also offer industrial tenants an advantage not available in the other industrial parks in Brownsville: a Foreign Trade Zone (FTZ). The Brownsville Navigation District, which runs the Port, is Grantee and Operator of FTZ No. 62—the largest FTZ in the United States at 2,300 acres. FTZs are "enclosed and secured areas physically located in the United States but deemed to be outside the U.S. for duty and revenue purposes."

Manufacturers that use imported materials and market their goods internationally have numerous cost-saving advantages to locating within an FTZ. FTZ No. 62 is divided between the Port of Brownsville and the Airport Industrial Park. The 300 acres of FTZ area within the Airport park permit duty free "plane-to-plant" access to park tenants. The Port can allocate its 2,000 acres of FTZ rights on a spot basis to any collection of parcels within its developable area. The Port owns a total land mass of over 40,000. This area includes over 5,000 acres that are already developed with existing infrastructure and production facilities as well as over 18,000 acres of available land that is developable for industrial purposes and Port facilities. It can currently offer duty-free access to Port tenants for ships and barges entering the Port from the Gulf of Mexico. If existing plans for a new international bridge are realized, the Port will also soon be able to offer its tenants duty-free access to goods brought to the Port from Mexico by truck or rail. Over $1.3 billion of business flows through the Brownsville FTZ each year.

Matamoros has five existing industrial parks and plans to construct another. The existing parks house about 90 maquiladora facilities, at least 18 of which are owned by Fortune 500 companies. Besides the maquiladora facilities, these parks serve as hosts to Mexican facilities that cater to U.S. companies following other strategies than the twin plant, or maquiladora, approach to transboundary production sharing. Such companies subcontract labor-intensive intermediate manufacture and assembly stages of production to established Mexican companies without ever creating a corporate link between the two companies. The subcontracting firm takes care of all shipping from and to the border, all customs procedures, management production stages conducted in Mexico, product testing and inspections to the specifications of the U.S. corporation. The industrial parks in Matamoros also house a great number of shelter operations that operate in much the same way as the subcontracting firms but for an hourly rate that is tied to the number of employees needed for the manufacturing efforts. Shelter operations do not generally perform any of the quality control exercises undertaken by subcontractors.

B.1.2 Transportation

The Brownsville-Matamoros area has more transportation options for passengers and cargo than any other community along the Texas-Mexico border. Five modes of transportation are available to industries residing in Brownsville-Matamoros. The Port of Brownsville offers access by sea to the rest of the world via a 16-mile long channel to the Gulf of Mexico. It is the western terminus of the U.S. Intracoastal Waterway and thus offers one of the least expensive modes of transportation of goods to cities along both the Ohio and Mississippi Rivers. A tow boat leaving the Port of Brownsville on the intracoastal waterway can access 60 percent of U.S. markets. A single tow boat can haul up to 40 barges, each capable of carrying as much freight as 60 trucks or 15 rail cars (Port of Brownsville, 1995). International road and rail networks link Brownsville and Matamoros to U.S. and Mexican suppliers and markets. Three airports within 25 miles of Brownsville, two on the U.S. side of the border and another in Mexico, that offer international travel and shipping opportunities to area visitors and residents.

The Brownsville-Matamoros area also plans to improve and expand several infrastructures to facilitate freight transportation in the region. A 2-year federally funded dredging project to deepen the port channel will be completed by May 1995. Deepening the channel will enable the Port to accommodate ships and barges weighing up to 60,000 tons, whereas it could previously only accommodate vessels of about 30,000 tons. Furthermore, a major railroad relocation project is in its second stage of completion to allow Port-related highway and rail traffic to reach the Port without entering downtown Brownsville. The first stage involved constructing a mile-long, $5 million highway overpass that will carry traffic between Brownsville and points north uninterrupted over rail and vehicle traffic headed for the Port of Brownsville. Phase II of the railroad relocation effort is a $21 million dollar project currently underway to connect rail lines from the Port with Union Pacific and Southern Pacific rail lines north of Brownsville. At present all rail traffic to the Port must first go into downtown Brownsville.

Another change to the regional transportation network is a plan to construct a new international bridge for vehicle and rail traffic across the Rio Grande. This bridge will connect a 3-mile long Port-owned transportation corridor from the Port of Brownsville to the Rio Grande with a proposed new industrial area on the Mexican side. This international bridge and the proposed connecting highway and railroad links in Mexico will offer much cheaper freight of goods between the port and existing and planned industrial sites in Mexico. Currently all rail and vehicle traffic from the Port of Brownsville to Mexican destinations has to pass through the congested traffic and densely populated areas of both Brownsville and Matamoros.

B.1.3 Energy

As the Brownsville area has grown in population and industrial activity, its consumption and demand for electricity has also grown. The Brownsville Public Utilities Board (PUB) makes decisions regarding meeting Brownsville's electricity requirements. According to PUB's Electrical Engineering Manager, Richard Smith, peak demand for electricity in Brownsville is currently about 170 MW, and peak load times can run as long as 7 to 8 hours per day during the summer months.

Current Sources

At peak load times the electricity used in Brownsville comes from four different sources. According to Mr. Smith, the primary source of electricity used in Brownsville is a coal-fired power plant located in a town called Oakley Union, situated approximately 600 miles to the north of Brownsville. The PUB owns about one third of the stock in this power plant, and it supplies approximately 70 MW of Brownsville's peak demand. The next most important source of supply is a gas turbine power plant in Brownsville. The peak load that this plant can supply is only 50 Megawatts. According to Mr. Smith, when these two sources cannot provide enough electricity to cover Brownsville's demand, PUB can obtain up to 50 MW from other Lower Rio Grande Valley utilities north of Kingsville, about 80 to 90 miles away. PUB can purchase 25 MW at fixed, but expensive, rates from Central Power and Light (CP&L) and up to 25 MW at variable, but generally higher rates, from Central Southwest (CSW) on the spot market.

Current Cost

According to PUB's quarterly status report (September/October 1994) Brownsville's PUB customers pay less for their electricity than all other electricity users in the Lower Rio Grand Valley. With an average rate[1] of $0.057 per kWh for industrial users, prices charged for electricity in Brownsville compare very favorably with prices charged throughout the state of Texas (Brownsville Economic Development Council, 1994). It is striking that Brownsville's electricity costs are lower than those of most other cities in Texas given the fact that the power plant supplying the largest share of Brownsville's electricity is near the Oklahoma border, over 600 miles away.

According to Mr. Smith and Andrew Samaripa of the PUB, the cost of the coal burned to generate the 70 MW load supplied by the Oakley Union plant is close to the combined costs of paying for energy lost in transmission and the wheeling fees paid to other utilities for use of their transmission lines to deliver the electricity from Oakley Union to Brownsville. Mr. Samaripa claims that it costs about $0.016 to pay for the coal required to generate one kWh

[1]Per-kilowatt-hour cost based on 120,000 kWh monthly use and 300 kW demand during September 1993 to August 1994.

of electricity at the Oakley Union plant and about $0.018 to pay for O&M costs, wheeling fees, and transmission losses associated with delivering one kWh from Oakley union to Brownsville. This compares with costs of $0.03 per kWh for gas and $0.0015 per kWh for O&M at the Brownsville power plant.

Future Needs

According to a February 21, 1995, article in the *Brownsville Herald*, the city of Brownsville will need additional power generating capacity by the year 2001. The PUB already has the right of first refusal on a large parcel of land at the Port of Brownsville as the site for a new power station. The idea of opening a power plant at the Port has been on the table for about two years. It appears to have great economic as well as some environmental merit and is gaining popularity in some circles in Brownsville. Legislation is currently pending that would permit PUB and Magic Valley Electric Cooperative (MVEC) to become partners in building a new power plant. MVEC has indicated an interest in teaming with PUB in building a new plant if existing laws prohibiting cooperatives from agency membership and sales of electricity to public utilities are changed.

B.2 PLASTICS RECYCLING

Several details of the plastics recycling scenario were not developed in the text. They include the choice of options for the discrete parts manufacturer and the sales of plastic pellets by the plastics recycler to the discrete parts manufacturer. These details are provided below.

B.2.1 Marketing Unsorted Ground Plastic

In Scenario 3, three options were available to the ballast manufacturer for marketing his mixed ground plastics:

1. Sell unsorted plastic flakes to the plastic recycler, who will separate it;
2. Purchase the machinery required to separate the plastics and sell mixed, ground plastics to the recycler;
3. Separate the plastics prior to grinding, and sell mixed, ground plastics to the recycler.

In the case study, we analyzed only the first scenario. However, we did perform a simple analysis of the other two options and found that the first would probably be most economically feasible. Here, we explain how we came to this conclusion.

The first option would be the simplest since it would require no change in operations, no purchase of machinery, and no additional labor. The manufacturer would simply sell the ground plastics to the recycler rather than landfilling them. The plastics have limited resale value because they are mixed together. Although it is possible to separate many types of ground plastics (see Chapter 4 for a discussion of plastics separation technology), the additional processing required decreases the price that will be paid for the mixed ground plastic. Making no changes to their operation other than selling the ground plastic would provide revenues of approximately 3 cents per pound and eliminate the landfill fee.

The second option, purchasing the machinery required to separate the plastics, is probably not feasible given the relatively low volume of plastics they are generating. One commercially available optical and mechanical plastics separator costs approximately $170,000 for a machine with a capacity of 3,000 pounds per hour (Lancaster, 1995). Other machines for mechanical sorting have similarly large capacities, and could be an option for a joint-EIP recycling facility. We do not analyze this strategy further.

The third option is to implement a sorting operation prior to grinding. In this case, the recycler would pay higher prices for the plastics, with the exact prices depending upon the type of plastic. Given what we know about the composition of the plastics from the manufacturer, we assume that the composition of the plastics is equally distributed between low value plastics and high valued plastics. High valued plastics are bought by the recycler for 15 cents per pound, and, after being processed, are sold for 25 cents per pound. They include PBT, Nylon 6/6, polycarbonate, and PET. The low valued plastics are purchased for five cents per pound and sold, after processing, for 15 cents per pound. These are PVC, polyethylene, polypropylene, and polyacetal.[2]

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[2]There is also medium valued plastic, which the recycler purchases for 10 cents a pound and sells, after processing, for 20 cents per pound. Our assumption of only two types of plastic simplifies the model but has no impact on the results.

The third strategy would require some labor to manage the pre-grinding sorting operation. However, it is difficult the estimate how much labor would be required. The plant managers feel that this would require more labor time than it would generate in revenue. This may very well be the case. Suppose the management of the sorting operation required 1 hour per day of an employee that makes approximately $18,000 per year. Adding 40 percent for benefits, the cost to the company for this person's labor is $25,200 per year. If one eighth (or one hour per day) of this person's time is used to manage this sorting operation, the annual cost is approximately $3,150 per year. Even under the most generous revenue forecast (i.e. assuming that the flaked plastic is worth a full $0.25 per pound for the ground, sorted plastic), and accounting for the avoidance of landfill cost ($0.0125 per pound), the net revenue would be $2,948.40, and could not cover this labor cost. Thus, we assume the manufacturer will choose the first option, selling unsorted plastic.

B.2.2 Exchange of Plastic Pellets

The discrete parts manufacturer uses plastic pellets of various types. The local recycler has recently purchased a 2″ screw extruder and will begin making plastic pellets very soon. We were not able to determine from the available data whether the discrete parts company would be able to use these pellets in their process. However, assuming that the plastics they recycle are the same as what they use in pellet form, and assuming that they implement the sorting system so that the plastic is pure enough to recycle, it is conceivable that this company could take plastic that they were previously landfilling, send it to the recycler, and repurchase the plastic in the form of pellets, rather than purchasing virgin plastic pellets. This scenario is not included in the quantitative analysis.

B.3 REUSE OF BYPRODUCT GYPSUM

In Scenario 4, we assume that a power plant and a remotely located gypsum wallboard facility become part of the EIP. This enables the power plant to sell the byproduct gypsum from its FGD process to the wallboard facility. We also considered the exchange of byproduct gypsum between the chemical plant and the wallboard company. However, this was not economically feasible until

Scenario 5, in which the gypsum wallboard facility becomes collocated with the other companies. Below, we describe some of the details of the analysis of this exchange.

B.3.1 Power Plant FGD Gypsum

For our analysis of changes in the power plant's management of its byproduct gypsum flows we assume that, at baseline, the gypsum byproduct that is captured in the power plant's wet-limestone FGD system is only dried to about 35 percent moisture content and that it is subsequently landfilled. In Scenario 4, we assume that an additional $6,000,000 is spent to upgrade the FGD system so that is capable of lowering the moisture content of the gypsum to about 5 percent. We assume that it costs an additional $20 per kW of electricity that the power plant is capable of producing each hour (Kellerman, 1995). For a 300 MW plant this would equate to a $6 million investment (300,000 * $20 = $6,000,000). The annualized cost of this expenditure comes to $566,358 following the approach described in Section 2.3.3. Such a FGD system is assumed to require about 3 percent of the power plant's electricity production as opposed to the 2.5 percent of electricity production required for the FGD system that produces gypsum with a 35 percent moisture content.

A New Wallboard Producing Facility

We obtained much of the information presented in this section from discussions with a representative of a major gypsum and gypsum wallboard producer who is familiar with the value and uses of synthetic gypsum (Gaynor, 1995). Most often wallboard manufacturers locate their facilities adjacent to captive gypsum mines to minimize the cost of transporting such heavy, bulky material. The effective delivered price of virgin gypsum mined from captive mines averages about $1 per ton. This is the approximate delivered price that synthetic gypsum producers would have to meet or beat to become a competitive supplier of gypsum to most wallboard producers. Several wallboard producers along the eastern seaboard operate without a captive gypsum mine, but most of these are located near large metropolitan areas in the northeast. They are willing to pay a higher price for the gypsum they use, because they save money in transporting their finished product to market. Most of these facilities use virgin gypsum mined in Nova Scotia.

Only one wallboard producer in Texas does not have a captive gypsum mine. This facility, a wallboard manufacturer near Houston, relies exclusively on synthetic gypsum as feedstock to its production process. The plant typically pays a delivered price of $10 to $12 per ton for synthetic gypsum. Prices vary with the moisture content of the synthetic gypsum. The moisture content of the synthetic gypsum should be as low as possible when delivered to a wallboard plant, because wallboard manufacturers incur a cost of about $1 per ton per 5 percent reduction in moisture content, and very dry gypsum is required for wallboard production.

In Scenario 4, presented in the text, we assume that the new power plant will choose to transport its gypsum byproduct to the wallboard company near Houston. Location of the EIP at the Port of Brownsville has a significant influence on the power plant's ability to do so at a cost that can offer it some economic benefit over nearby disposal in a landfill. This is because the Port is on the inner coastal waterways and there is no cheaper way to transport heavy, bulky materials than by barge. Assuming that the power plant would be able to stockpile small amounts of gypsum close enough to the Port so that a stevedore could load the byproduct gypsum onto a barge using its own onboard equipment, the cost of transporting the 5 percent moisture content synthetic gypsum to Houston would be about $11 per ton. These large volume dependent costs include a barge rate of $8 per ton and $2 per ton in loading charges to be paid to the stevedore and an assumed $1 per ton in wharfing fees that would have to be remitted to the Brownsville Navigation District (Hoskins, 1995). Adding the $1 per ton cost of final drying at the wallboard plant, the effective sales price of the byproduct gypsum is exactly zero. This is far better from the power plant's point of view than the effective price of -$25 per ton that the power plant would receive if it were "selling" its byproduct to a nearby disposal site. If the power company operates at 80 percent capacity and ships all of its byproduct gypsum (233 tons per day at 5 percent moisture content) to the remote wallboard plant, it would avoid the daily cost of disposing of 333 tons (at 35 percent moisture content) of waste in its local landfill. This amounts to a yearly savings of almost $3,040,000.

Under Scenario 5, we assume that a wallboard producer such as the model plant near Houston has chosen to locate at the Port. A "typical" older wallboard facility consumes about 300,000 tons of gypsum per year (822 tons per day) in its production process, while some newer plants might use twice that amount. We assume that two EIP members, the power plant and the chemical company, generate about 830 tons of dry synthetic gypsum (adjusted downward to account for the initially higher moisture content). Thus, it is conceivable that a wallboard plant might choose to locate at the Port to take advantage of the available supply of synthetic gypsum.

Issues that are likely to influence a wallboard producer's decision to move its plant near a source of synthetic gypsum include:

- the size and extent of the local market for its finished products (i.e. would the local market include Matamoros),
- the level of saturation of the local market for gypsum products,
- the dependability of supply sources for the synthetic gypsum,
- access to other sources of gypsum should their primary source close down,
- the relative cost of supplying the local market with finished wallboard from mined gypsum produced elsewhere vs. the cost of supplying it with locally produced wallboard made from more expensive feedstock, and
- the relative cost of transporting its finished product to markets other than the local market.

The economic impact to EIP members of the gypsum recovery relationships that are possible under Scenario 5 is simulated by estimating the changes in net annual revenues that the two EIP members would incur if they were paid $11 per ton for their synthetic gypsum (dried to a 5 percent moisture content) as an alternative to their without EIP disposal options. The chemical company currently gives its waste gypsum to the Mexican transportation department and incurs no costs in managing its byproduct gypsum. In the absence of an EIP the power plant could either landfill its gypsum waste on-site or ship it to the Brownsville landfill for disposal at a tipping cost of about $25 per ton. We do not consider the on-site disposal option due to a lack of data regarding land costs and operating and maintenance expenses.

There may be some resistance in the community to allowing the power plant to develop a landfill at the port. We assume the $25 per ton landfill fee is a good proxy for the cost of acceptable nearby disposal and do not include the cost of transporting the waste to the landfill in the estimated "price" received at baseline for the gypsum byproduct in our simulation. The economic impacts of the gypsum recycling relationships made possible by a wallboard company located at the Port are presented in the text.

Other Gypsum Marketing Options

We offer analysis of other approaches that the power plant might take to avoid the cost of landfilling their waste without collocation of a wallboard facility at the Port. These include selling the gypsum to the stone company at the port and making the byproduct available to local farmers for use as a soil amendment.

The stone company currently sells limestone as a road-base material to road developers, but the sub-base material that underlies the limestone is made from local clay with about 5 percent added lime. The lime serves to harden the clay and make it more resistant to water erosion. The clay is generally taken directly from the ground at each job site, but the lime is brought all the way from San Antonio to Brownsville and it sells on the local market for about $90 per ton. A representative of the stone company suggested that, while he would have to conduct some research to come up with a maximum offer price that his company would be willing to make, he is confident that the gypsum is worth at least $1 per ton to the stone company at the 35 percent moisture content level. He claims that the stone company could buy and resell up to 300,000 to 500,000 tons of the byproduct gypsum at a reasonable profit if it were available for them to pick up at the Port (Linck, 1995).

Such a relationship might be economically superior to EIP members than the gypsum recovery symbiosis simulated for the power plant and the remote wallboard facility under Scenario 4. Because the stone company would prefer a damp gypsum byproduct, this relationship would eliminate the need for a superior FGD system and increased electricity consumption needed to dry the gypsum for reuse by the wallboard company, and it would still save the power company the expense of landfilling the byproduct gypsum. With annual gypsum production levels for the power plant of approximately 120,000 tons and the cost of transporting the gypsum to the Houston area identical to the assumed delivered price of the gypsum at the wallboard company, the power plant could conceivably increase its annual revenues by at least another $120,000 per year over avoided landfill costs if the gypsum were sold to the stone company instead. It should be noted, however, that some type of storage and containment area would be needed to prevent the gypsum that would accumulate between road construction jobs from becoming a nuisance or an environmental concern at the Port. We do not have an estimate of what such a containment area might cost, but it is unlikely that it would cost as much as the combined cost of upgrading the FGD system, additional electricity consumption and developing or using a nearby landfill.

Another option open to the power plant for gypsum disposal is to sell or give the byproduct to local farmers. Gypsum is quite commonly spread on fields and lawns in the Brownsville area as a soil amendment to counteract the high salinity of local soil. Bulk gypsum currently sells for about $150 per ton as a soil amendment. It is not clear how much gypsum local farmers would be likely to use if the power plant were to offer it to them for free, but even if only a small portion was used for local agricultural production this might be an effective way to add value to the local community and improve public relations at the same time (PUB, 1995).

B.4 COGENERATION AT THE BROWNSVILLE/MATAMOROS EIP

Cogeneration, or simultaneously producing electric or mechanical energy and useful thermal energy, has been widely researched and its technical merits have been repeatedly demonstrated since the late 1880s. Analysis of cogeneration includes three basic components:

- the energy added to the cycle (in our case this would be the Btu/lb added by burning Orimulsion™),
- the energy extracted for use, be it in the form of mechanical work (the amount of energy converted to electricity) or in the form of heat (where heat is imparted from the steam to another cooler material), and

- the energy rejected, where the thermodynamic availability of the steam is insufficient to perform work or impart heat to its surroundings[3] (U.S. DOE, 1978).

Energy use efficiency is measured by the ratio of the energy extracted, whether in the form of work or process energy, to the energy added. The advantage of cogeneration is that by cascading heat within a closed loop energy cycle from one system designed to generate electricity (work) to another system designed to extract heat (process energy), *or vice versa*, the total amount of energy rejected can be reduced for a given amount of energy added. Cogeneration takes advantage of economies of scope, since it takes less added energy to produce both products (for example, steam and electricity) simultaneously than it would to produce them separately (U.S. DOE, 1978).

To estimate the economic impact of the energy cascading relationship modeled in Scenario 4, we needed to estimate the additional amount of Orimulsion™ required to produce both the baseline level of electricity and the steam needed by the refinery. This type of estimate depends upon the efficiency of the real world configuration of the energy cycle and the temperature and pressure at which the process steam is extracted. This calculation is difficult without evaluating a specific power plant and process design. By making a number of assumptions and consulting with a number of energy engineers, we were able to develop ballpark estimates to use in the simulation.

The refinery has to heat its crude oil to 1,200° F to achieve vaporization. The crude is then condensed into the four products (naphtha, diesel oil, light residual oil and heavy residual oil) that it recovers in the fractionation tower. In our simulation, heat, in the form of 800° F steam, is extracted from the boiler at the power plant and used by the refinery to preheat their crude prior to vaporization. As noted by representatives of PUB, 800° F steam is not what most people would call "waste heat." Steam of that temperature still contains a significant amount of thermodynamic energy. Fortunately, consultants of PUB were able to offer us ballpark estimates of the remaining work potential of that steam.

[3]In reality, there is also a fourth component that should be added to the equation: the amount of energy that is lost to thermal, mechanical and energy inefficiencies of the actual cycle.

We assume that the power plant will operate at 80 percent of capacity and that 3.5 percent (about 163,142 barrels per year) more Orimulsion™ (Rosdorfer, 1995) must be burned by the power plant to generate the same amount of electricity that it otherwise would, while at the same time offering enough heat (262,000,000 Btus/hour) in the form of 800° F steam to the refinery to preheat its crude oil (Hurd, 1995). We also assume that at 80 percent capacity the power plant must extract and pretreat about 43,200 gallons of boiler feed water per day to be able to offer the steam to the refinery without reducing its electricity production.

The price of city water at the Port is $1.64 per 1,000 gallons (PUB, 1995) and the cost of pretreatment is assumed to be $2.50 per 1,000 gallons (Hurd, 1995). There is a linear relationship between the amount of Orimulsion™ burned at the power plant and both the amount of limestone required for the FGD system and the amount of synthetic gypsum that can be recovered from the FGD system (Rosdorfer, 1995). Thus, as a result of the heat cascading relationship between the power plant and the refinery, the amount of limestone to be delivered from the stone company and the amount of gypsum that the power plant can sell to the wallboard company are also projected to increase by 3.5 percent.

At baseline, the refinery produces 3,041,667 bbl per year of residual oil. Of this, 456,250 is burned at baseline to heat its crude to 1200° F. The cogeneration relationship reduces the amount of residual oil the refinery must burn by about 60 percent, or 750 barrels per day (Linck, 1995).

To estimate the incremental annualized fixed costs of heat cascading we assume the cost of laying the steam distribution system and the condensate recovery system to be $1.50 per linear foot of piping (Hurd, 1995) and the cost of a waste heat recovery boiler capable of reheating “waste” steam to temperatures usable by the refinery to be $7.5 million (Kellerman, 1995). These one time costs of $8.4 million were annualized over 20 years at a 7 percent interest rate to arrive at the incremental annualized fixed cost estimate of $792,000 that were assigned to the power plant. The difference in lump-sum capital costs needed to outfit the refinery with a combination of a heat exchanger and a burner that are appropriately sized for the simulation vs. what would be used without the availability of “waste” steam from the power plant is assumed to be $2 million (Linck, 1995), or $188,786 per year when annualized as described in Section 2.3.3. Our simulation assumes these costs are incurred by the refinery.

We assume that the price paid for the steam by the refinery covers any additional costs that the utility would incur as a result of the heat cascading symbiosis. These costs include annualized incremental capital costs as well as all variable costs associated with producing the extra steam. To arrive at an appropriate unit cost we divided the total annual costs by the amount of heat (Btus) we assumed would be provided to the refinery each year. Specifically, we assumed the price charged per Btu of steam delivered to the refinery should equal the incremental annualized fixed costs of installing the steam distribution system and purchasing the waste heat recovery boiler needed at the power plant, plus the annual cost of purchasing the additional Orimulsion™, water, and pretreatment chemicals needed to produce the extra steam divided by the 262,000,000 Btus of heat in the form of steam that refinery is assumed to receive from the power plant.

The price established between the refinery and the power plant has no bearing on the results of the study. We calculated the collective change in revenue brought about by increases in energy efficiency. If the refinery paid a higher price or lower price for the steam, this would decrease or increase its net revenues from the symbiosis, but it would not affect the collective change in revenue.

B.5 JOINT SOLVENT AND OIL RECYCLING

In Scenario 5, we explored the possibility of the EIP operating a solvent and/or oil recycling facility. The analysis in the text focused on solvent recycling, and was based on a number of assumptions that were somewhat unrealistic. In this section, we provide some information about solvent and oil recycling and explain why it was so difficult to develop estimates of the cost-effectiveness of developing an EIP solvent or oil recycling facility.

B.5.1 Options for the EIP Solvent/Oil Recycling Facility

There are several possibilities for the EIP to assist its member companies with handling waste oils and solvents. First, it can operate a closed loop solvent and/or oil recycling center. By closed loop, we mean that no solvents would be accepted from outside the EIP and no solvents would be sent outside the EIP for recycling. Some disposal (for example, of still bottoms), is unavoidable.

The benefits of the closed loop system include: minimization of the environmental impact of the EIP on the community (i.e. what leaves the EIP) is minimized;and limitation of the liability of companies when compared to liability concerns when using outside recyclers. That is, when companies are using outside recycling services, they can be held liable for environmental damage caused by improper management of the solvents or acceptance of non-qualifying materials. Within the EIP, the EIP management has more control over the mix of products that are being recycled, since it is aware of the production activities of its members.

Closed loop recycling also encourages companies to take steps to reduce the costs of solvent and oil recycling and reuse, since the cost savings translate directly into lower cost of recycling for them.

The second way the EIP can provide these services is to operate a solvent and/or oil recycling facility in the park that accepts solvents for recycling from outside the EIP. This is not a closed loop system, so liability would be a more important issue than under the closed loop system. However, for EIPs that have a small number of companies and/or a small volume of solvents, this could be the only economically feasible way to operate an on-site facility.

The third option is for the EIP to operate as a broker, rather than operating a recycler on-site. This takes advantage of the market power of handling all the solvents and oils of all the members of the EIP.

The simulation in the text provided an example of how one might analyze the feasibility of a closed-loop system. We based the analysis on information obtained from several companies visited in the Brownsville/Matamoros area and on a number of assumptions that abstract from the conditions that actually exist in those firms. The simplifying assumptions were necessary to conduct the simulation. Below, we explain why these assumptions were necessary.

B.5.2 Solvent Varieties and Recycling

In our analysis of solvent recycling we assumed that the facilities in the EIP were using only two types of solvents. This is an unrealistic assumption given the fact that there are over 1,500 different types of solvents that encompass a wide range of properties. The companies we originally talked with were using about five different types of solvents. The number and types of solvents that must be separated and recycled by a facility influences the cost-effectiveness of recycling. For example, if only one solvent is used, a simple still can be used to separate the pollutants from the solvent. However, if many solvents are mixed, a more expensive distillation process is required to separate them. Furthermore, as the number of solvents in the mixture increases, the separation process becomes more difficult, and limits the solvents' reuse potential.

The ease or difficulty of separation is determined by the relative volatilities of the mixture components. For example, if the boiling point of the solvents in the mixture are very close, it may be difficult to separate them. Simple distillation of solvent blends often yield products that differ in composition from the original blends (Hulm, 1987). Companies may consider selling the recycled product to another user, although this is not a common course of action.

If companies in an EIP consider their equipment and process specifications and discuss the possibilities of reducing the different types of oils and solvents used, the potential for cost-efficient solvent and oil recycling increases. This would be relatively easy to accomplish in the planning stages of new equipment purchase. It would be relatively difficult to retroactively limit the number of solvents used in a park with diverse industries.

B.5.3 Solvent Recycling Equipment

We assumed that the solvents used by the companies could be separated with a distillation unit. Actually, several methods are available for recycling solvents, and a number of factors influence the separability of the solvents, including the relative volatilities of the two solvents (Hulm, 1987), the susceptibility of the mixture to exothermic reactions, the viscosity of the liquids, and the solid content of the solvents. Fractional distillation is not suitable for polyurethanes or inorganics (Glynn, et al., 1987).

Chapter 4 contains more information about solvent recycling technologies.

B.5.4 Solvent Disposal

We assumed that at baseline, the companies have two choices for disposing of their solvents: incineration, for which they paid $1.50 per gallon, or they can send the solvents to a fuel blending program at a cost of $1.00 per gallon. Actually, there are two primary alternatives to recycling for used solvents: land disposal and incineration.

Land disposal is no longer feasible in many cases due to changes in regulations. In particular, the disposal of hazardous solvent wastes in landfills have been banned in most cases. Depending on their constituents, solvent wastes can be considered RCRA wastes F002 (halogenated solvents), F003 (non-halogenated solvents such as acetone and xylene), F004 (non-halogenated solvents such as cresols, cresylic acid, nitrobenzene, and solvent blends), or F005 (non-halogenated solvents such as toluene, methyl ethyl ketone, and benzene). These wastes are currently banned from land disposal (EPA, 1990).

Incineration is sometimes an option to land disposal. Solvent and oil wastes can often be burnt for energy recovery. In California, Senate Bill 86 prohibits the incineration of used oil, or burning as a fuel, unless authorized by other provisions of the law (EPA, 1988). The EPA does not list used oil as a hazardous waste, unless it meets one of the EPA's characteristics of hazardous waste. The EPA regulates characteristically hazardous used oil that either is destined for disposal or for burning in incinerators that do not qualify as boilers or industrial furnaces. State and federal regulations also limit the types of devices that can be used for destruction (EPA, 1988).

Appendix C:

U.S.–Mexico Border Agreements

The border region between the U.S. and Mexico has become a focal point for international partnership, particularly in issues relating to transboundary environmental health. In 1983, the La Paz Agreement on Environmental Cooperation was signed by both countries to better protect, conserve, and improve the environment. In 1992, the *Integrated Border Environment Plan, First Stage* (IBEP) was established to strengthen existing laws and reduce border area pollution. Most recently, the North American Free Trade Agreement (NAFTA) has created two very important tasks towards stimulating solutions for transboundary environmental problems. First, the debate on NAFTA has dramatically focused attention on issues related to the U.S.-Mexico border region, especially environmental issues. Second, environmental agreements to the treaty, especially the bilateral agreement between the U.S. and Mexico, provide environmental infrastructure in the border region. The North American Commission on Environmental Cooperation (CEC) was established by the U.S., Mexican, and Canadian governments to ensure border area environmental concerns would be addressed and to improve national enforcement of each country's laws relating to environmental protection and to uphold the provisions included under NAFTA.

These initiatives are described briefly in this appendix. Additional initiatives include the U.S. and Mexico established the Border Environmental Cooperation Commission (BECC) and the North American Development Bank (NADBank). These two bilateral institutions work with local communities to arrange financing for environmental projects.

To continue support of the border region, the Clinton Administration has expanded the scope of EPA's activities along the border area to include initiatives aimed at

- stricter environmental enforcement,
- improving environmental quality,
- promoting environmental justice,
- financing border area environmental infrastructure, and
- empowering border communities to improve their environmental through increased public participation (EPA, 1994a).

C.1 LA PAZ AGREEMENT

In 1983, a comprehensive U.S.-Mexico Border Environmental Agreement, known as the "La Paz Agreement," was signed (see Department of State, 1983). Entered into force on February 16, 1984, this agreement defined the border area as a 100-kilometer wide zone on either side of the political boundary and established a general framework to prevent and/or reduce environmental pollution in the border area. Under the general framework six workgroups were formed: enforcement, water, hazardous waste, air, emergency response and planning, and pollution prevention.

Article XI of the General Obligations, which addresses hazardous waste generated from raw materials admitted in-bond, is especially interesting. Article XI states that "hazardous waste generated in the processes of economic production, manufacturing, processing or repair, for which raw materials were utilized and temporarily admitted, shall continue to be readmitted by the country of origin of the raw materials in accordance with applicable national policies, laws and regulations." Unfortunately, no further detail than this is provided.

The La Paz agreement regulates the flow and treatment of waste materials from Mexican (maquiladora) facilities that use input materials from other countries, including the U.S. The La Paz Agreement states that if a company in Mexico uses an input from the U.S. (or originating country), the wastestream associated with activities that use the input must be shipped back to the U.S. (or originating country). Under the La Paz Agreement, the manufacturer of the input material is ultimately responsible for treatment/disposal of subsequent waste associated with using that input material in Mexican production operations.

Under the La Paz Agreement, hazardous waste cannot remain in storage (or transfer) for more than 10 days. Because it is not always clear which input materials are responsible for the waste materials that are generated, mass balances of Mexican production operations are performed. Companies use the mass balance information to determine if more than 50 percent of the wastestream originates from inputs materials imported from the U.S. (Mexico); if it does, the entire wastestream must be transported back to the U.S. (stays in Mexico) for treatment and disposal.

Within the next 10 years, ownership and definition (tax definition) will soon be removed and maquiladoras can be incorporated within Mexico rather than existing as a separate subsidiary of an American-based firm. This will result in removing some of the economic benefit for the American parent company locating in Mexico in the first place. The overall effect of the change in ownership is that pollution will increase within the new Maquiladora firms because they will no longer be required to ship waste back to the U.S. It is expected that Mexico will implement more stringent environmental regulations.

C.2 INTEGRATED BORDER ENVIRONMENT PLAN

Building on the La Paz Agreement, the U.S. EPA and Mexico's SEDUE (now SEDESOL) released the *Integrated Border Environment Plan, First Stage* (IBEP) in 1992 (EPA, 1992 and 1994a). The goal of IBEP was to improve cooperation between the U.S. and Mexico in improving the border area environment. The main objectives of the first stage were to strengthen enforcement of existing laws; reduce pollution through new initiatives; increase cooperative planning, training, and education; and improve the understanding of the border environment (EPA, 1994a).

At present, efforts are underway to review ongoing environmental initiatives and to establish new 1995-2000 initiatives in cooperation with the Mexican Government. These new initiatives will build upon achievements from the 1992 IBEP.

C.3 NAFTA

The border region between the U.S. and Mexico has become a focal point for international partnership, particularly in issues relating to transboundary environmental health (Reed, 1995). In 1983, the La Paz Agreement on Environmental Cooperation was signed by both countries in an unprecedented effort to better protect, conserve, and improve the environment. However, more was needed to fully address transboundary environmental issues.

Two environmental side-agreements to NAFTA, one a trilateral agreement including Canada and the other a bilateral agreement between the U.S. and Mexico are worth noting here. The trilateral agreement created the North American Commission on Environmental Cooperation (CEC), whose primary charter is to dispute resolution of environmental problems. The bilateral agreement devised a mechanism to tackle inadequate border environmental infrastructure by creating the Border Environment Cooperation Commission (BECC) and the North American Development Bank (NAD Bank). These two new entities are expected to begin operation early in 1995. The BECC will certify environmental infrastructure projects along the U.S.-Mexico border for financing by the NAD Bank. Priority will be given to projects in the areas of drinking water, wastewater treatment, and municipal solid waste. To bankroll the NAD Bank, the U.S. and Mexico have committed through the agreement to provide $430 million, which can increase to $3 billion. In addition, it is expected that other moneys can be leveraged through private capital markets, increasing available capital to as much as $8 billion.

The BEC and NAD Bank represent an innovative avenue through which both countries can work together to address transboundary environmental issues. NAFTA has also provided the impetus for other efforts directed to U.S.-Mexico border environmental issues. Every major federal agency with an environmental purview, fro the Department of Interior to EPA, is focusing attention on the border, often collaborating on projects with Mexican agencies. As indicated, Texas state agencies are doing the same. In 1994, the TNRCC met with the directors of ecology of four Mexican states that border Texas, as well as with federal environmental officials. The climate of cooperation NAFTA has encouraged is greatly responsible for such partnership-building.

By focusing on border regions, NAFTA has generated a ripple effect. During the last session, for example, the U.S. Congress appropriated $100 million in grants for the construction of wastewater facilities for colonias located in Texas along the border (Reed, 1995). In addition, many Texas state agencies are devoting tremendous resources to addressing environmental problems along the border. The Texas Natural Resource Conservation Commission (TNRCC) has more than 52 programs devoted specifically to the border region. Two of these programs are especially noteworthy: The Rio Grande Toxic Substances Study and the Lower Rio Grande Valley Environmental Monitoring Study (Reed, 1995). Texas and Mexican environmental agencies worked side-by-side in these studies to investigate the potential for human exposure to environmental pollutants in the Lower Rio Grande Valley region.

These studies are just two that highlight the increased attention that has been placed on determining the presence and effects of toxic chemicals in the U.S.-Mexico border region. Additional studies are underway to better quantify such potential environmental problems. A common complaint from many border residents, however, is that more studies are needed; they believe that the problems have been identified and that money is simply needed to begin bringing solutions (Reed, 1995). NAFTA is a prime vehicle that will help to answer such demands.

Appendix D:

List of Databases

This appendix provides a list of databases that we accessed while looking for technologies related to our case study. This is not intended to be an exhaustive list of technology databases.

I. Technology Databases on the Internet

A. EPA's Online System, telnet://epaibm.rtpnc.epa.gov

National Catalog: Contains citations and summaries on environmentally related topics encompassing biology, chemistry, ecology, and other basic sciences and EPA reports distributed through the National Technical Information Service. Includes citations on recycling technologies and methods. Publications are available from EPA by interlibrary loans or purchase from the National Technical Information Service.

B. DOE Environmental Inventions and Innovations, http://www.nttc.edu

Lists industrial and environmental technologies sponsored by the Departments of Energy and Commerce. The citations include a description of the technology, a contact person, and its stage of development.

C. COMPENDEX, telnet://192.204.252.2 {Note: not sure if this works after Friday (the free period)

Contains abstracts and indexing to some 425 international journals and key conference proceedings from 1987 to the present. Its broad subject coverage includes chemical engineering, civil engineering, metals and mining, manufacturing engineering, and more.

D. DOE Efficiency and Renewable Energy Network (EREN), http://www.eren.doe.gov

Contains information on a large variety of energy-related recycling and conservation technologies. Also includes published searches on the COMPENDEX and patent database, which can be purchased from NTIS.

E. CADDET, http://www.ornl.gov/CADDET

A database of demonstration projects on energy-efficient and renewable energy technologies.

F. EPA Gopher, gopher://gopher.epa.gov/

Includes a science, research and technology section. Currently this link is often unavailable.

II. Other Sources

A. Water Science and Technology

Journal that reports the results of major symposiums on wastewater issues. An excellent source for current information on wastewater technologies.

B. Center for Environmental Research Information

26 W Martin Luther King Dr.

Cincinnati, OH 45268

(513) 569-7562

Electronic Bulletin Board,

C. National Technical Information Service

5285 Port Royal Rd.

Springfield VA 22161

(703) 487-4650

U.S. Department of Energy, Office of Scientific and Technical Information. September 1994. "The Office of Technology Development Technical Reports. A Bibliography." Report to the assistant secretary, environmental management.

This bibliography contains information on scientific and technical reports sponsored by the Office of Environmental Management from its inception in 1989 through June 1994. Future issues contain reports from Technology Development activities and will be published biannually. This bibliography can be accessed through Dialog and ITIS. Questions pertaining to the technical contents of the bibliography should be addressed to Lana Nickols (301) 903-8493, who coordinated the publication of the bibliography.

Flue Gas Desulfurization Information System (FGDIS). Computerized database U.S. EPA, Industrial Environmental Research Laboratory, Research Triangle Park, NC. Access to FGDIS can be obtained through Walter Finch, NTIs, 5285 Port Royal Road, Springfield, VA 22161.

This is a database of information collected about utility Flue Gas Desulfurization (FGD) Systems. The data collection began in 1974. It includes information on boiler, stack, fans, pumps, tanks, materials of construction, coal composition, removal efficiency, particular matter control systems, waste disposal, byproduct utilization, performance data, including dependability, problems and solutions, and pollutant removal. Real system capital cost and annual revenue requirements.

Fly Ash: Reutilization and Applications in the Concrete and Cement Industry. June 1993. NTIS report PB-93-874147/XAB.

This bibliography is a compilation of latest citations from the Compendex database. It contains citations concerning the use of fly ash in the concrete and cement industry. Mechanical, physical, and chemical properties of fly ash-containing concretes, aggregates, mortars, and grouts are considered. Applications of these materials to highways, construction, soil stabilization, and building repair are included. The bibliography contains 250 citations and includes a subject term index and file list.

Appendix E:

Site Visit Protocol Used in the Case Study

Our project team used this form in initial screening of plants for the Brownsville case study. It may suggest useful questions to begin exploring the potential for creating a network of byproduct exchanges. A next step would require a more detailed level of inquiry, including questions about energy efficiency, pollution prevention, and management of environmental performance.

E.1 INFORMATION TO ASSESS POTENTIAL FOR WASTE, WATER AND ENERGY EXCHANGE

E.1.1 Introduction

The residents of Brownsville, TX, and Matamoros, Mexico are currently engaged in an important experiment in the application of a new strategy for organizing business relationships. This new strategy, based on the principles of industrial ecology, can be profitable for the businesses involved because it develops markets for byproducts. By turning a waste into a source of revenue, the application of industrial ecology can improve the environmental performance of businesses while also improving their bottom line. Similarly, by taking advantage of the opportunity to add value to the manufacturing in the Brownsville/Matamoros area, the application of industrial ecology can stimulate entrepreneurial business development. These new businesses would serve as brokers and technical linkages, enabling the existing business to take full advantage of the potential benefits of industrial ecology.

There are three major types of inputs and outputs that must be analyzed to determine what applications of industrial ecology might be viable in a specific instance: water, energy, and other materials. Companies may be able to use wastewater from other companies when the requirements for purity and temperature “match up” between the potential supplier and the potential user. Similarly, energy cascading might be possible when waste heat from one company is created at a temperature similar to what is needed by a proximate company. Materials exchange is often possible when the byproducts of one company are of sufficient quantity and quality to be substituted for a virgin material currently being used by another company. These three waste streams in any company—water, energy, and materials—could represent potential profit that is not being exploited. The accompanying document provides concrete examples of how some companies in Kalundborg, Denmark, are applying “industrial symbiosis” to take advantage of that profit potential.

The purpose of this interview is to conduct a preliminary assessment of the potential for incorporating your firm in a prototype application of industrial ecology in the Brownsville/Matamoros area. Your cooperation will help us to determine how your plant’s production process might benefit through cooperation with other companies in the area. Once we determine, through analysis of preliminary information on a number of plants, that your plant might fit in such a plan, we will, with your permission, work with one of your plant engineers or plant managers to work out the technical details.

E.1.2 Preliminary Information

1. What products are produced at this plant, in approximate order of value?

Rank	Product Description	SIC Code (if known)
1.		
2.		
3.		
4.		
5.		
6.		

2. What are the top 10 materials (by value) used by your company in producing these products? Note: Be as descriptive as possible. Note any technical requirements (i.e. water temperature or purity, form of material, etc.) offered by the interviewee.

Rank	Material Description
1.	
2.	
3.	
4.	
5.	
6.	
7.	
10.	

3. Is your production process particularly water-intensive or energy intensive?

4. What is your source of water?

5. What is your source of energy?

6. What byproducts are produced as a result of the manufacturing process?

Note: include byproducts that are disposed of as solid waste, are emitted into the air or water, or are recycled, either on premises or off-premises. If offered, pay special attention to describing the form the byproduct is in, i.e. purity of wastewater, form of solid waste.

Rank	Byproduct Description
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

7. How important is controlling the cost of environmental management and compliance to the competitiveness of your product?
(Note: These costs include tipping fees for solid wastes; air, water, underground storage tank permits; hazardous waste transportation and storage permits, etc. and the time to do paperwork)

Below are some suggested choices to give the interviewees:

1. Very important—Cost containment in this area is essential to our competitiveness
2. Important—We aggressively seek ways to control these cost
3. Not particularly important—We would like to control these costs, but other components of cost have a much higher priority

4. Not important at all—Our environmental costs are so small we give them little consideration

8. Would you be interested in participating in a project that might help you find ways to purchase inputs more cheaply, generate revenues from your byproducts, or reduce your environmental management and compliance costs?

9. If so, is there an engineer or plant manager who would be helpful in working out the more technical aspects of such an arrangement, including estimation of cost implications?